GHG EMISSIONS FOR CONSTRUCTION INDUSTRY IN MALAYSIA

CIDB TECHNICAL REPORT PUBLICATION NO 207

GHG Emissions for Construction Industry in Malaysia

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FOREWORD

Today, climate change is one of the most vital challenges faced by our generation. It urgently calls upon everyone, including Malaysia, to play their role to combat climate change and adapting climate change impacts.

Malaysia has committed to a voluntary reduction of our nation's greenhouse gas emissions intensity of gross domestic product (GDP) by 40% by 2020 at the 15th Conference of the Parties. Subsequently, Malaysia submitted its Nationally Determined Contribution to the United Nations Framework Convention on Climate Change with a target reduction of greenhouse gas emissions intensity by 45% by 2030 with the condition.

Specifically, for the construction industry, a national collaborative effort through a programme called Construction Industry Transformation Programme or CITP 2016 – 2020 is implemented to transform the construction industry through four strategic thrusts: Quality, Safety and Professionalism, Environmental Sustainability, Productivity and Internationalisation. Under this programme, the study on *Greenhouse Gas Emissions for Construction Industry in Malaysia* has been conducted by CIDB Malaysia and it is my hope this publication will give a better overview on the current greenhouse gas emissions, the major emissions sources and the way forward to achieve the key performance indicators under the Environmental Sustainability Strategic Thrust (ST02) of the CITP 2016 – 2020.

This report aims to determine the level of greenhouse gas emissions emitted by the construction industry value chain from the manufacturing of the material, transportation, and construction activities, and subsequently identify the potential GHG reductions from these activities as well as recommendations on the implementation of incentive and disincentive schemes of this industry.

We would like to thanks all contributing organisations for their professionalism and good work. This report could not have been written without the support of various organisations that involved in this effort.

Construction Industry Development Board (CIDB) Malaysia

PREAMBLE

In support of the national commitment, the Construction Industry Transformation Programme (CITP) was launched by the Ministry of Works (KKR) and Construction Industry Development Board (CIDB) Malaysia in 2015. One of the strategic thrusts under CITP is environmental sustainability where the objective is to emphasis the sustainable construction in the value chain, which will contribute towards Malaysia's commitment to the Paris Agreement.

Therefore, to establish a basis for the policymakers to formulate appropriate policies towards reducing the industry-wide GHG emissions, an assessment was carried out to understand and quantify the various sources of GHG emissions within the construction sector.

This report will outline the GHG emissions in the construction industry value chain from the manufacturing of material, transportation and construction activities, and subsequently, identify the potential GHG reductions from these activities as well as recommendations on the implementation of incentive and disincentive mechanisms in the construction industry in Malaysia.

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Miniwiz Singapore; and
All the developers/ contractors that participated in the survey.

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List of Abbreviations

AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
AR	Assessment Report
ASEAN	Association of Southeast Asian Nations
BAU	Business As Usual
BCA	Building and Construction Authority
BCISM	Building Cost Information Services Malaysia
BCRM	Billing and Customer Relationship Management
BUR2	Second Biennial Update Report
C&D	Construction and demolition
CDM	Clean Development Mechanism
CFP	Carbon Footprint of Product
CH_4	Methane
CIDB	Construction Industry Development Board
CITP	Construction Industry Transformation Programme
CLCD	Chinese Reference Life Cycle Database
CLT	Cross-Laminated Timber
CO_2	Carbon Dioxide
COP	Conference of the Parties
COVID-19	Coronavirus Disease 2019
CRC	Crumbed Rubber Concrete
CREAM	Construction Research Institute of Malaysia
DASH	Damansara – Shah Alam Elevated Expressway
DGS	Department of General Service California
DOE	Department of Environment
DOSM	Department of Statistics Malaysia
EC	Embodied Carbon
ECO	Eco-Ideal Consulting Sdn. Bhd.
ECO-CM	Embodied Carbon of Construction Material
EDMA	Emissions Data Monitoring and Analysis
EF	Emission Factor
ELCD	European reference Life Cycle Database

EPU	Economic Planning Unit
EU	European Union
EU-ETS	EU Emissions Trading System
FGD	Focus Group Discussion
FSP	Friction Stir Processing
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GM-GFA	Green Mark Gross Floor Area Incentive Scheme
GMIS	Green Mark Incentive Scheme
GMIS-DP	Green Mark Incentive Scheme – Design Prototype
GMIS-EB	Green Mark Incentive Scheme for Existing Buildings
GMIS-NB	Green Mark Incentive Scheme for New Buildings
GMS	General Market Specification
GSO	Grid System Operator
GT	Green Technology
$GtCO_2eq$	Giga tonnes of Carbon Dioxide Equivalent
GWh	Gigawatt hours
HKPC	Hong Kong Productivity Council
IBS	Industrialised Building System
ICE	Inventory of Carbon and Energy
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IPPU	Industrial Processes and Product Use
ISO	International Organisation for Standardisation
ITA	Investment Tax Allowance
ITE	Income Tax Exemption
KASA	Ministry of Environment and Water
KKR	Ministry of Works
kWh	Kilowatt hour
LPG	Liquefied Petroleum Gases

LRT3	Light Rail Transit 3
LULUCF	Land Use, Land Use Change and Forestry
LVT	Luxury Vinyl Tiles
MEA	Ministry of Economic Affairs
MEIH	Malaysia Energy Information Hub
MESTECC	Ministry of Energy, Science, Technology, Environment and Climate Change
MGTCCC	Malaysian Green Technology and Climate Change Centre
MRT2	Mass Rapid Transit 2
MS	Malaysian Standards
MyCREST	Malaysian Carbon Reduction and Environmental Sustainability Tool
MY-LCID	Malaysia Life Cycle Inventory Database
myN3C	National Construction Cost Centre
N_2O	Nitrous Oxide
NC1	First National Communication
NC3	Third National Communication
NEB	National Energy Balance
ODS	Ozone Depleting Substances
PROJEXIS	Projection of Construction and Material Demand for Projects Awarded
QA/QC	Quality Assurance and Control
R&D	Research and Development
RCA	Recycled Concrete Aggregates
RDF	Refuse Derive Fuel
SAR	Second Assessment Report
SC Fund	Sustainable Construction Capability Development Fund
SCMs	Supplementary Cementitious Materials
SCP	Sustainable Consumption and Production
SEB	Sarawak Energy Berhad
SESB	Sabah Electricity Sdn. Bhd.
SIRIM	Standard and Industrial Research Institute of Malaysia
SUKE	Sungai Besi-Ulu Kelang Elevated Expressway
SWCorp	Solid Waste and Public Cleansing Management Corporation
$tCO_2eq.$	Tonnes of Carbon Dioxide Equivalent
TCT	Total Coated Thickness

TJ	Terajoule
TNB	Tenaga Nasional Berhad
TNBR	TNB Research Sdn. Bhd.
UI	User-Interface
UK	United Kingdom
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WRI	World Resources Institute

EXECUTIVE SUMMARY

Introduction

Greenhouse gas (GHG) emissions, often referred to as carbon emissions, are one of the key factors that contribute to climate change and bringing negative impacts to the environment. To reduce GHG emissions, the international treaty has been signed and ratified to combat climate change as a common goal. National and sub-national governments are adopting and implementing a variety of climate change mitigation actions. Complete, consistent, transparent and accurate GHG emissions assessments are necessary to make sure these mitigation actions are achieving intended results and meeting domestic and international objectives.

Based on the third National Communication (NC) to the United Nations Framework Convention for Climate Change (UNFCCC) by Malaysia, the assessment of GHG emissions for the construction industry is not reported as a sector. The emissions related to construction are reported separately under multiple sources. These sources range from energy use in the construction industry, and industrial processes of construction materials. To provide a better understanding of the best possible combination of mitigation options based on available policies, plans and programs to achieve Malaysia's mitigation targets to the Paris Agreement[1], a sectoral GHG emissions assessment for the construction industry value chain in Malaysia needs to be conducted. The inventory will lend support to the assessment of potential mitigation measures within the construction sector.

In support of the national commitment, the Construction Industry Transformation Programme (CITP) was launched by the Ministry of Works (KKR) and Construction Industry Development Board (CIDB) Malaysia in 2015. The CITP outlines four (4) Key Strategic Thrusts to guide the transformation and development of the construction industry. One of the strategic thrusts is environmental sustainability environmental sustainability where the objective is to emphasis the sustainable construction in the value chain. This will contribute towards Malaysia's commitment to the Paris Agreement.

Therefore, in order to establish a basis for the policymakers to formulate appropriate policies towards reducing the industry-wide GHG emissions, it is important to understand and quantify the various sources of GHG emissions within the construction sector. By identifying the key sources of GHG emissions (including the construction value chain), targeted and effective GHG reduction strategies can be formulated and implemented targeted for the Malaysian construction industry.

The outcome will promote a better understanding of the relationship between the construction industry's emissions and economic development which can complement in developing more effective policies for each stakeholder engaged in the construction industry. Furthermore, consistency and clarity in calculating emissions are significant

[1] Refers to the climate change agreement reached in Paris in 2016 within the United Nations Framework Convention for Climate Change.

to compare emissions within and across sectors, and for the policymakers to plan and assess progress along the way.

Objectives

The objectives of the study are:

- To determine GHG emissions in construction industry value chain from the manufacturing of material, transportation and construction activities
- To identify the potential GHG reductions from these activities as well as recommendations on the implementation of incentive and disincentive schemes in the construction industry in Malaysia.

Project Scope and Coverage

The assessment of the construction value chain is the main scope of this study and encompasses material extraction, material manufacturing, transportation of the material and construction activities on site. The boundary condition of this value chain is commonly referred to as "Cradle-to-Site" (Figure a). "Cradle-to-Site" is an extension of "Cradle-to-Gate" which further includes transportation from the factory gate to the construction site as well as including activities at construction sites during the construction stage.

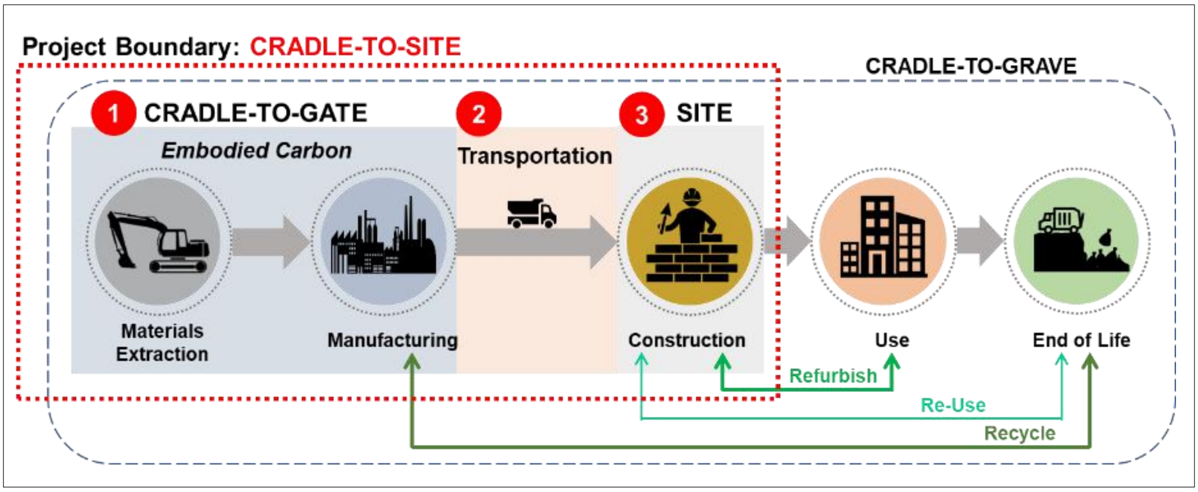


Figure a: Study scope and boundary (red dotted line)

The cradle-to-site GHG emissions can be categorised into three (3) groups as tabulated in Table a.

Table a: GHG emissions contribution from construction industry

GHG Emission Aspects	Main Sources of GHG Emissions
Embodied Carbon in Material 1) Demand for construction materials such as cement, concrete, steel reinforcement, etc.	This material consumes energy and produces GHG during the extraction and manufacturing process which is commonly referred to as **Embodied Carbon**[2] (cradle-to-gate).
Transportation of Material 2) Distribution of construction material to the construction site	The transportation of construction material to the site consumes **fossil fuel** such as diesel. GHG emissions from transportation of material included GHG emissions from the production, processing and delivery of fuel (Well to Tank[3]) and fuel combustion.
Emissions at Construction Site 3) Use of equipment and machinery during construction, maintenance and renovation as well as waste generated from the construction site	Construction stage utilises various machinery and equipment which consume **fossil fuel and/or electricity**. GHG is also emitted from the degradable **waste** disposed. The GHG emissions from utilisation of fossil fuel from machinery and equipment included the GHG emissions from production, processing, and delivery of fuel and fuel combustion.

Construction Material Consumption

For this study, fourteen (14) construction materials were selected and prioritised for the cradle-to-site analysis. Nine (9) major and (5) non-major construction materials included are tabulated below:

Table b: Selected major and non-major construction materials

Major Construction Materials	Non-Major Construction Materials
1) Steel Reinforcement 2) Ready Mixed Concrete 3) Plywood 4) Bricks 5) Paint 6) Sand (finishes) 7) Glass 8) Cement (finishes) 9) Ceramic Tiles	1) Aggregate 2) Roofing Tiles/ Sheet 3) Steel and Metal 4) Timber 5) Sanitary Ware

The summary of construction material demand (consumption) in Malaysia compiled is presented below and the trends over the past four (4) years illustrated in figure b:

[2] Embodied carbon is defined as the sum impact of all the GHG emissions attributed to the materials throughout their life cycle (extracting from the ground, manufacturing, construction, maintenance and end of life/disposal). Embodied carbon is usually expressed in kilograms of CO_2eq. per kilogram of product or material. Please refer to Section 3.4 for more information.

[3] A Well-to-Tank emissions factor, known as upstream or indirect emissions, is an average of all the GHG emissions released into the atmosphere from the production, processing and delivery of a fuel or energy vector (https://www.lowcvp.org.uk/Hubs/leb/TestingandAccreditation/WTTFactors.htm).

Table c: Summary of construction materials quantity in million tonnes

No.	Construction Material	Materials Quantity (million tonnes)			
		2016	2017	2018	2019
1	Steel Reinforcement	5.70	8.90	8.80	7.10
2	Ready Mixed Concrete	93.89	162.00	166.56	142.32
3	Plywood	1.14	1.36	1.54	1.44
4	Bricks	15.36	17.11	20.59	28.35
5	Paint	0.03	0.04	0.08	0.12
6	Sand (finishes)	10.40	14.00	22.90	38.40
7	Glass	0.12	0.11	0.18	0.31
8	Cement (finishes)	1.50	2.40	4.60	6.50
9	Ceramic Tiles	0.34	0.55	0.51	0.47
10	Aggregate	7.1	27.8	33.3	43.9
11	Roofing Tiles/Sheet	0.30	0.28	0.34	0.27
12	Steel and Metal	2.58	2.46	2.10	1.73
13	Timber	1.43	1.34	2.77	2.17
14	Sanitary Ware	0.12	0.11	0.03	0.02
Total (million tonne)		**140.02**	**238.58**	**264.11**	**273.11**

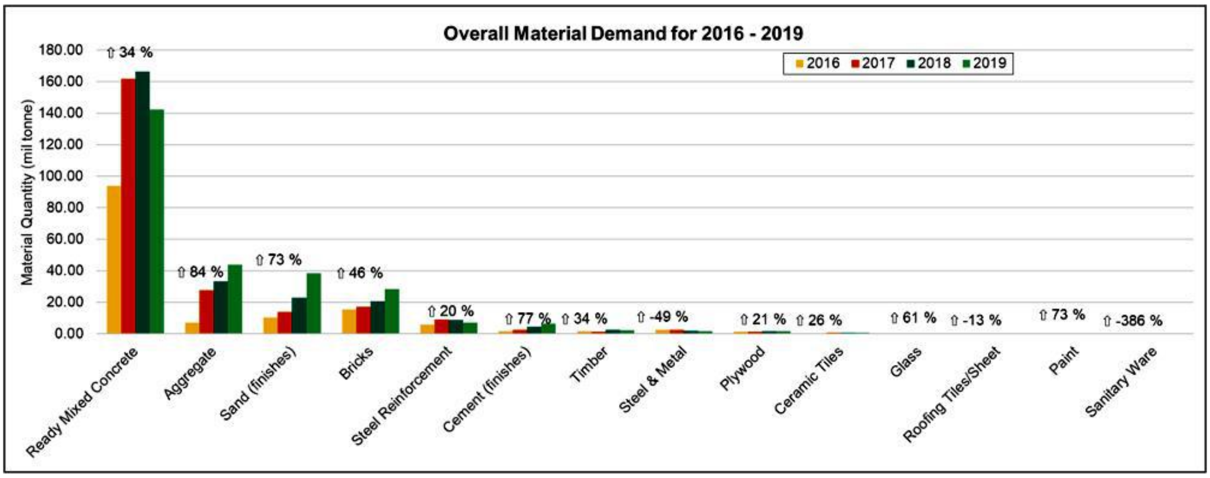


Figure b: Summary of material demand for year 2016 to 2019[4]

As shown in Table c, the quantity of construction material in 2016 was very low compared to 2017 – 2019, therefore, the average of the data obtained from the year 2017 – 2019 was used for the analysis, comparison and reporting purposes.

As shown in Figure c below, the highest average quantity of construction material consumed from 2017 – 2019 is ready mixed concrete (61%) followed by aggregate (14%), sand (10%), bricks (9%), steel reinforcement (3%), cement (2%) and others (3%) respectively.

[4] Converted from material demand data from CIDB

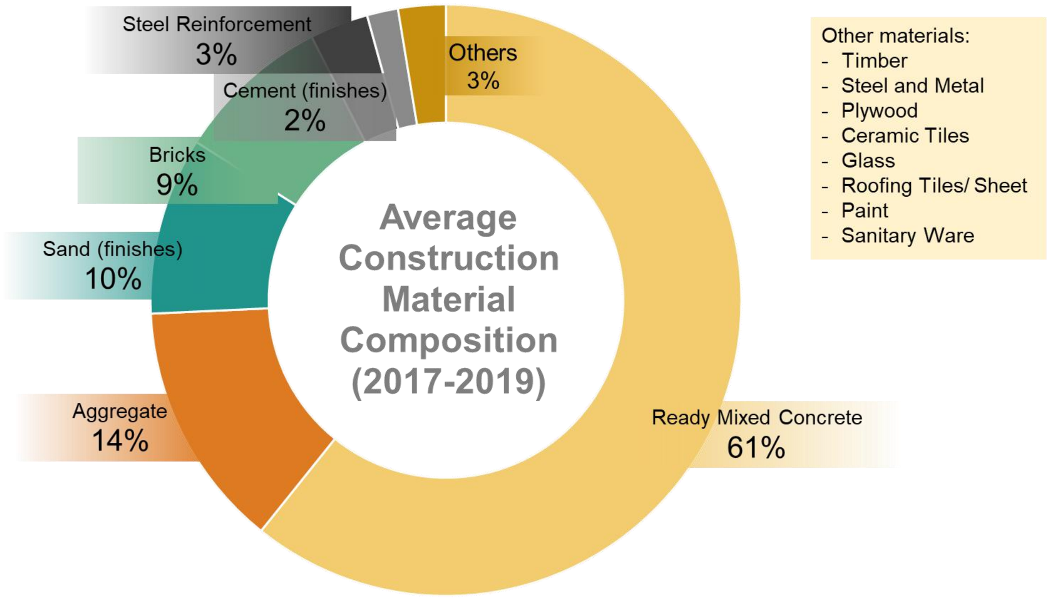


Figure c: Average composition of construction material consumption for year 2017 to 2019[5]

Under this study, a survey on actual completed construction projects was carried out to further verify and support the input values and assumptions used in the GHG assessment. In terms of composition for major material consumed by the construction sector, the results from the survey of actual projects are comparable to the data compiled from CIDB and other sources (refer to Table d for comparison).

Table d: Comparison of the average material demand composition with survey results under this study

No.	Construction Material	Composition (%)		
		CIDB	Survey (this study)	Difference
1	Steel Reinforcement	3%	2%	1%
2	Ready Mixed Concrete	61%	55%	6%
3	Cement (finishes)	2%	2%	0%
4	Bricks	9%	7%	2%

Approaches and Methodologies

For the purpose of GHG emission accounting and quantification, this study adopted the calculation-based approach, which is the most commonly adopted method of accounting for GHG emissions.

In accordance with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines and Good Practices,* the most common simple methodological approach is to combine information on the extent to which human activity takes place (called

[5] Data source: CIDB, 2019

activity data or *AD*) with coefficients which quantify the emissions or removals per unit activity (called *emission factors or EF)*. The basic equation is thus:

Emissions = Activity Data • Emission Factors

Based on the emissions sources identified, AD was collected from relevant data suppliers and respective emissions factors were applied accordingly to calculate GHG emissions. As mentioned earlier, a survey on actual construction projects completed in Malaysia was also carried out to provide further verification and support to the activity data and assumptions used.

GHG Emissions for Construction Industry Value Chain

This study focused on the GHGs which are converted into carbon dioxide equivalent ($tCO_2eq.$) as covered by the Kyoto Protocol. GHGs covered in this study include the following three (3) types of gases, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which have been found to have a direct impact on global warming (United Nations, 1997).

Total GHG Emissions (Cradle-to-Site)

The average total GHG emissions from cradle-to-site for the year 2017 – 2019 was calculated to be **76 million $tCO_2eq.$** This amount is approximately **24% of the total national GHG emissions** in the year 2014 (latest available report) as reported in NC3/BUR2 to the UNFCCC (Table e), which shows the significant contribution of GHG emissions from construction sector (cradle-to-site).

Table e: Total GHG emissions from cradle-to-site (year 2016 to 2019)

Year	GHG Emission (million $tCO_2eq.$)				% compared to National GHG Emissions 2014 (NC3/BUR2)
	Construction Material	Transportation	Construction Site	Total	
2016	45.6	1.2	4.9	51.8	16%
2017	67.9	2.1	5.2	75.3	24%
2018	71.8	2.3	5.5	79.6	25%
2019	66.8	2.3	5.6	74.6	23%
Average (2017 – 2019)	68.8	2.2	5.5	76.5	24%
Average Distribution (2017 – 2019)	**90%**	**3%**	**7%**		

As shown in Figure d below, **90% of the GHG emissions** were contributed from **embodied carbon in material consumption** (cradle-to-gate), **7% from construction site** emissions and remaining **2% from transportation** of construction material.

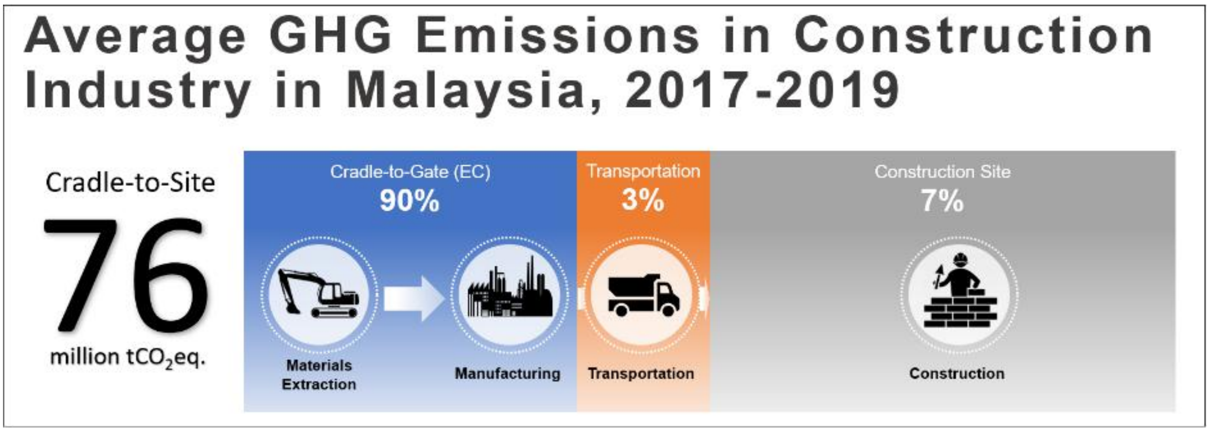


Figure d: Average of GHG emissions (million tCO_2eq.) from construction industry for year 2017 to 2019

As shown in Figure e below, out of the 7% from average total GHG emissions for the year 2017 – 2019 was contributed from the construction site where, **90%** were contributed from **fuel consumption**, **6% from electricity consumption** remaining **4% from waste treatment and transportation**. For fuel consumption, bitumen was identified as the main contributor (42%), followed by diesel (35%), lubricant (12%) and liquefied petroleum gases (LPG) (11%).

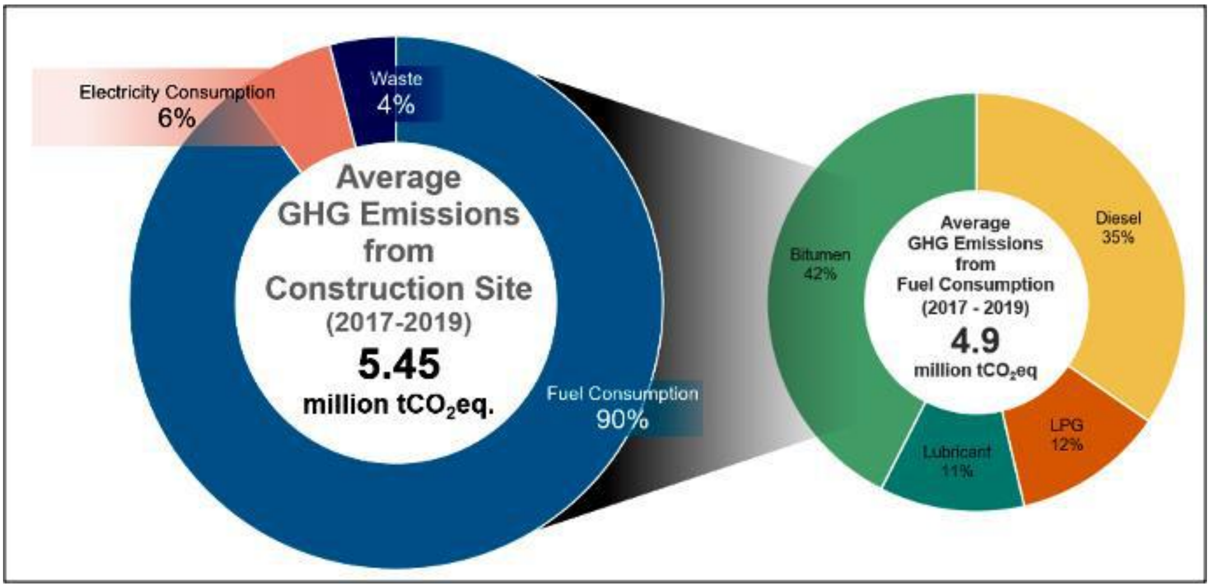


Figure e: Average GHG emissions (million tCO_2eq.) from construction site for year 2017 to 2019

Projection of Baseline GHG Emissions (2020 to 2050)

The GHG emissions projection from the year 2020 to the year 2050 contributed by the construction industry (cradle-to-site) in Malaysia was carried out under this study. The material consumptions, fuel consumptions, electricity consumptions, and waste projections up to 2050 were estimated using the econometric approach. The economic indicators used in a projection such as gross domestic product (GDP) were taken from the Department of Statistic Malaysia (DOSM), Economic Planning Unit (EPU) and World Bank. The historical correlation between consumption of construction materials and energy demand as well as macroeconomic and activity indicators were derived by regression analysis. It was projected that the total GHG emissions of **147 million**

tCO_2eq. (**92% increase** as compared to 2020) will be emitted from the construction industry (cradle-to-site only) by the **year 2050** (Figure f) if no mitigation efforts are implemented.

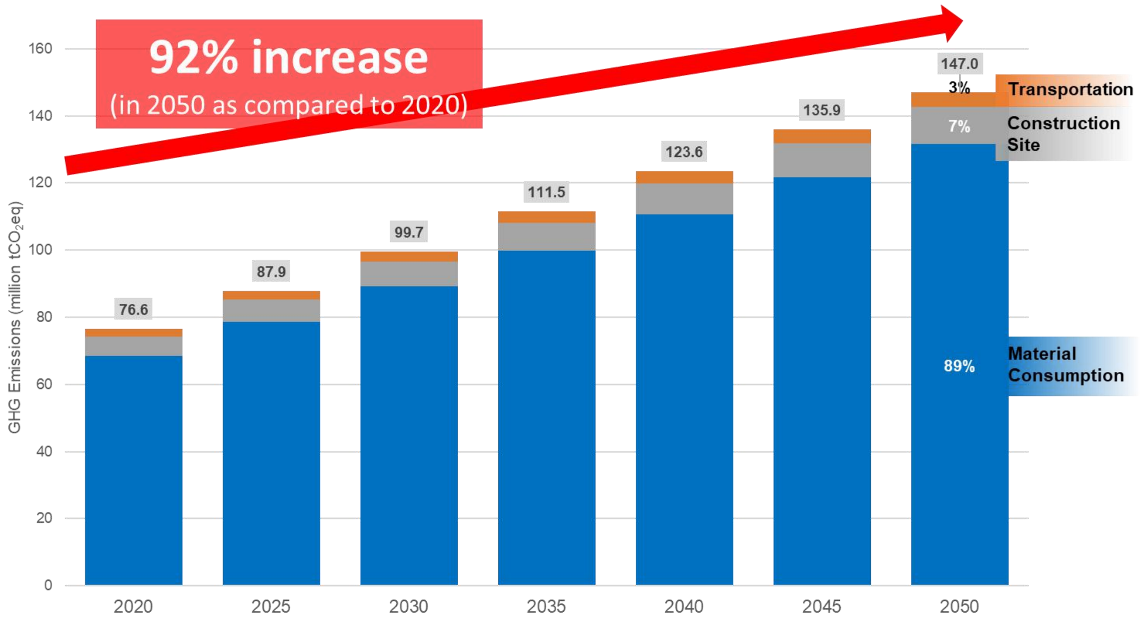


Figure f: Projected GHG emissions for construction industry in Malaysia for year 2020 to 2050

GHG Reduction Target Assessment

In order to mitigate climate change and reduce GHG emissions in Malaysia, one of the outcomes of the strategic thrust of CITP 2016 – 2020 is to support the nation's goal by reducing the industry's GHG emissions by **4 million tCO_2eq.**

As shown in Figure d above, the **embodied carbon** in construction material contributes to **90%** of the **total GHG emissions** (cradle-to-site). Thus, considering the impact of proposed mitigation strategies, it is suggested that the government to focus on GHG mitigation efforts related to developing and adopting low carbon construction material.

If low carbon construction materials are introduced in the initial building design of the construction projects, the total GHG emissions of the whole constructed facility can be efficiently controlled and reduced. A practical mechanism for GHG emissions reduction is through the adoption of low carbon construction material labelling, which involves the measurement of the embodied carbon from the extraction, production and final product (cradle-to-gate).

Based on the average GHG emissions calculation from the year 2017 - 2019, the five (5) construction material listed below are the major GHG emitters, contributed approximate **92% of the total embodied carbon emissions**:

- Ready mixed concrete;
- Steel reinforcement;
- Bricks;
- Cement; and
- Steel and metal.

Different scenarios for the target reduction were analysed and it was found that the reduction target under the CITP of 4 million tCO_2eq. could be achieved by reducing at least **6.4% of the total GHG emissions** from the five (5) construction materials listed above (Figure g and Figure h).

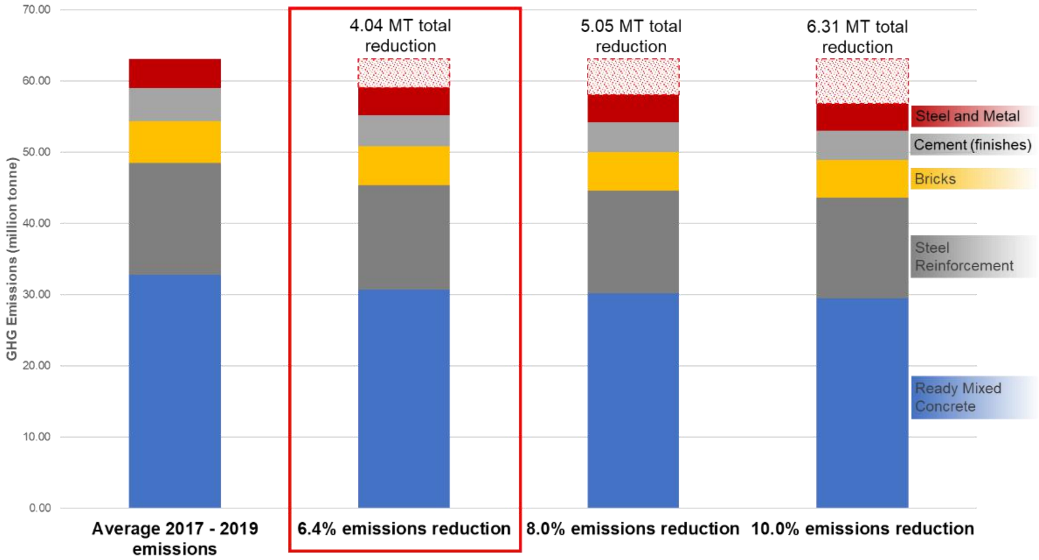


Figure g: Proposed reduction target for five (5) major construction material

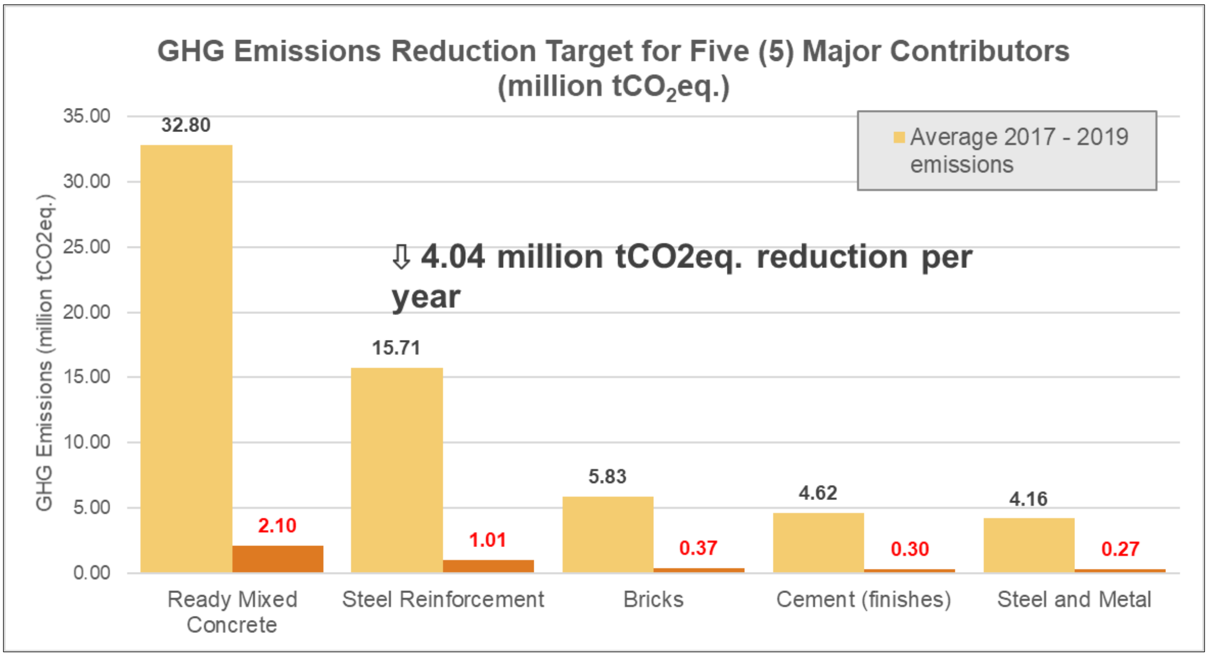


Figure h: GHG emissions reduction target for five (5) major contributors (million $tCO_2eq.$)

Incentive and Disincentive Mechanism

In the present circumstances, there are limited initiatives were taken by the construction material manufacturers as well as construction players to reduce their GHG emissions. Hence, drivers (incentive mechanisms) are needed to encourage the participation of the construction industry to engage in sustainable low carbon development in the construction sector. Similarly, a disincentive mechanism shall also be considered to discourage high GHG emissions intensity construction development. A compendium on related GHG reduction mechanism (incentive and disincentive) have been compiled and assessed for its feasibility in Malaysia's construction industry.

Potential incentive and disincentive mechanisms suitable for Malaysia were identified and explored through desktop research, focus group discussion (FGD), benchmarking visit to Singapore, engagement with stakeholders and interview with industrial players. The strategic thrusts of the CITP on environmental sustainability were also considered in the review of potential schemes.

To revolutionise the construction industry towards low carbon and sustainable practice, a summary of three (3) incentive and disincentive mechanisms recommended for consideration is tabulated in Table f.

The recommended implementation is based on the priority and timeframe which is listed as below:

- Short term : 1 – 2 years
- Medium term : 2 – 5 years
- Long term : > 5 years

Table f: Proposed incentive and disincentive mechanism

No	Recommended Incentive/Disincentive Mechanism	Potential Impact on GHG	Implementation Priority
GHG Reporting			
1.	a) Voluntary GHG reporting • Revive MYCarbon program – reporting framework	• Encourage stakeholders to track, monitor and reduce GHG emission	Short Term
	b) Mandatory GHG reporting • To extend the reporting requirement to the manufacturers who emit above a cap value of GHG emissions • Complementary with tax incentives •	• Encourage stakeholders to track, monitor and reduce GHG emission	Medium Term

No	Recommended Incentive/Disincentive Mechanism	Potential Impact on GHG	Implementation Priority
Low Carbon Construction Materials			
2.	a) <u>Market development</u> • Research and Development (R&D) research fund • Enhance acceptance of usage – e.g. material standards/ specifications/ certification • Include in Government Green Procurement requirement	• To establish market demand for low carbon materials in the construction industry • Wider acceptance and adoption of low carbon material, leading to direct emission reduction.	Short to Medium Term
	b) <u>Enhancing material usage</u> • Carbon labelling/ rating for material • Tax incentives for recycling of construction waste and usage of low carbon material	• Carbon labelling rating as a tool to benchmark the GHG intensity of material use – encourage adoption of low carbon construction material	Short to Medium Term
	c) <u>Mandatory material usage</u> • Progressive target for manufacturers • Progressive target for projects (e.g.% material must be low carbon)	• Manufacturer to lower the GHG intensity of their products through various innovations progressively	Medium to Long Term
Carbon Tax / Cap-and-trade System			
3.	a) <u>Create carbon mechanism</u> • Government to decide on whether to impose a carbon tax or introduce a cap-and-trade system	• Drives industries towards low carbon development to stay competitive • Carbon trading encourage more investment in the low carbon material selection	Medium to Long Term

Potential alternative construction materials with lower embodied carbon compared with the conventional construction materials used were preliminary identified. The detailed feasibility of these materials has to be further studied. Some examples are listed below:

Table g: Examples of potential alternative construction materials

Potential Alternative Material	Description/ Examples
Blended cement	• Increase the clinker substitution with supplementary cementitious materials (SCMs); • Mix bottom ash mixed with cement.
Innovative concretes	• Reutilise of waste and by-products such as industrial waste, demolition waste, and agricultural waste.
Alternative bricks	• Reutilise of waste such as fly ash from electricity generation power plant as the binder.
Timber	• Replace steel, cement and ceramic tiles in construction.
Rammed Earth Walls	• Replace wall structure that conventionally using concrete.
Bamboo	• Utilise as support for concrete and made into parts of building such as foundations, scaffolding, structural walls, column, floor and woven doors and windows.
Alternatives ceramic tiles	• Improve the spray drying and combustion process in ceramic tiles production; • Replace with hardwood flooring, laminated flooring, bamboo tiles, vinyl flooring, concrete finishing, etc.

Sustainable Carbon Rating and Labelling

A practical mechanism towards reducing GHG emissions is through the development and adoption of a carbon rating and labelling scheme for the material with high embodied carbon. The benchmarks of construction material proposed for the top five (5) major contributor was based on the review of local and international databases[6] available. An example of the proposed benchmark for five (5) types of major contributors for Malaysia is tabulated as below:

Table h: Proposed benchmark for five (5) major GHG contributors

Carbon Rating	EC (tCO_2eq/t)				
	Ready Mixed Concrete	Cement	Steel Reinforcement	Bricks	Steel & Metal
A	< 0.179	< 0.8557	< 0.99	< 0.229	< 1.078
B	0.179 ~ 0.199	0.8557 ~ 0.9657	0.99 ~ 1.39	0.229 ~ 0.249	1.078 ~ 1.478
C	0.199 ~ 0.219	0.9657 ~ 1.0857	1.39 ~ 2.41	0.249 ~ 0.279	1.478 ~ 2.498
D	0.219 ~ 0.239	1.0857 ~ 1.1957	2.41 ~ 2.81	0.279 ~ 0.299	2.498 ~ 2.898
E	> 0.239	> 1.1957	> 2.81	> 0.299	> 2.898

In view of the short-term goals and based on the average GHG emissions from the year 2017-2019 (76 million $tCO_2eq.$) and using the above benchmark as a guide, the government can reassess against the 4 million $tCO_2eq.$ target set under the CITP. Based on the current parameter, the embodied carbon rating of the material is roughly categorized within rating C. Should the rating of all five (5) material be improved to

[6] http://www.cic.hk/files/page/148/CICR06-14-A%20Comprehensive%20Hong%20Kong%20Based%20Carbon%20Labelling%20Scheme_RS_023.pdf

rating B i.e. a reduction in embodied carbon per ton of material used, it is estimated that a total reduction of 7.5 million tCO_2eq. (beyond the 4 million tCO_2eq. target) GHG emissions have to be achieved. Based on this estimation, the government can establish a gradual action plan towards the stage compliance with the rating over a period.

A preliminary feasibility assessment on the reduction of embodied carbon mentioned above was carried out and it is found that the average 14% reduction of the embodied carbon seems viable by comparing to international targets set on embodied carbon reduction, which is as high as 40%. It is recommended that a detailed assessment to be carried out on the local conditions to identify the embodied carbon reduction can be technically and financially feasible.

Other than the benchmarks proposed for the top five (5) major GHG contributors, the benchmarks for other minor GHG contributors also analysed and proposed. An example of the proposed benchmark for other minor contributors for Malaysia is tabulated as below:

Table i: Proposed benchmark for other minor GHG contributors

Carbon Rating	EC (tCO_2eq/t)				
	Sand	Aggregates	Plywood	Timber	Glass
A	< 0.0046	< 0.0043	< 1.772	< 0.176	< 0.93
B	0.0046 ~ 0.0049	0.0043 ~ 0.0047	1.772 ~ 1.882	0.176 ~ 0.266	0.93 ~ 1.04
C	0.0049 ~ 0.0053	0.0047 ~ 0.0050	1.882 ~ 1.992	0.266 ~ 0.346	1.04 ~ 1.16
D	0.0055 ~ 0.0056	0.0050 ~ 0.0054	1.992 ~ 2.102	0.346 ~ 0.436	1.16 ~ 1.27
E	> 0.0056	> 0.0054	> 2.102	> 0.436	> 1.27

Carbon Rating	EC (tCO_2eq/t)			EC (tCO_2eq/m^2)
	Paint	Roofing Tiles/Sheet	Sanitary Ware	Ceramic Tiles
A	< 2.00	< 1.79	< 0.70	< 0.0073
B	2.00 ~ 2.40	1.79 ~ 2.19	0.70 ~ 1.10	0.0073 ~ 0.0113
C	2.40 ~ 3.42	2.19 ~ 3.21	1.10 ~ 2.12	0.0113 ~ 0.0215
D	3.42 ~ 3.82	3.21 ~ 3.61	2.12 ~ 2.52	0.0215 ~ 0.0255
E	> 3.82	> 3.61	> 2.52	> 0.0255

The rating of all other minor materials to be improved from rating C to rating B i.e. a reduction in embodied carbon per ton of material used is estimated that a total reduction of 0.5 million tCO_2eq. GHG emissions can potentially be achieved.

Conclusions and Recommendations

The Study has concludes that the construction sector contributes significantly to GHG emissions in Malaysia. Based on the scope of the Study, the average GHG emissions from cradle-to-site from the year 2017 - 2019 was calculated to be 76 million tCO_2eq. which is equivalent to around a quarter (24%) of the total national GHG emissions.

The majority of the emissions from the cradle-to-site comes from the embodied carbon of the construction material (90%), where the emissions at construction site attribute to another 7% while the remaining 3% due to transport of construction material.

The projection of GHG emissions shows that by the year 2050, the baseline emission (business as usual) will grow by 92% if no mitigation measures are put in place.

In order to achieve the 4 million tCO_2eq. emission reduction target set under the CITP, it is recommended to focus on the embodied carbon of construction material as it contributes approximately 90% of the total GHG emissions. It can be narrowed down to the five (5) major GHG contributors i.e. ready mixed concrete, steel reinforcement, bricks, cement (finishes) and steel and metal whereby it is estimated the target can be achieved by reducing around 6-7% of the GHG emissions of these five (5) materials alone.

Three (3) main categories of incentive and disincentive mechanisms were introduced. It is recommended that the construction-related industries to start accounting and reporting their GHG emissions. Various support measures are suggested to be proposed in order to initiate the wide usage of low carbon construction material. The carbon tax or carbon cap-and-trade system is recommended in the medium to a longer-term to further encourage the market players to adopt low carbon investment.

Recommended Future Studies

The Study recommended follow-up researches to be carried out to establish "Low Carbon Construction Road Map" which including but not limited to following:

- Revision on the 4 mil tCO_2eq. GHG reduction target which set under CITP based on findings of this Study and set the reduction strategies;
- Detailed target setting plan for the potential reduction of the embodied carbon in consultation together with the stakeholders;
- Detailed study on benchmarking carbon labelling scheme for construction material;
- Detailed feasibility study on low carbon construction material replacement and recycling of C&D waste; and
- Detailed feasibility study of the proposed incentive and disincentive mechanisms that mentioned above, including pilot testing and implementation of the proposed measures.

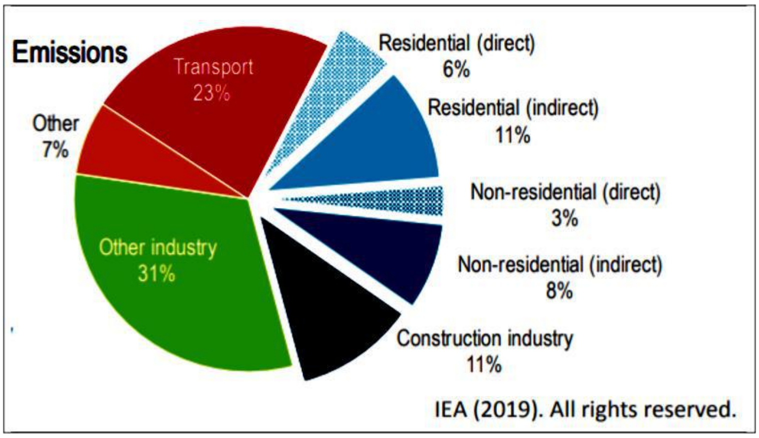
1.0 INTRODUCTION

1.1 Background

Greenhouse gas (GHG) emissions, often simplified as carbon emissions are one of the key factors that contribute to climate change and bringing negative impacts to the environment. In order to reduce GHG emissions, the international treaty has been signed and ratified to combat climate change as a common goal. National and sub-national governments are adopting and implementing a variety of climate change mitigation actions. Complete, consistent, transparent and accurate GHG emissions assessments are necessary to make sure these mitigation actions are achieving intended results and meeting domestic and international objectives.

Chapter 9: 9.3.9 Embodied energy and building materials lifecycle research published since AR4 confirms that the total lifecycle energy use of low-energy buildings is less than that of conventional buildings, despite generally greater embodied energy in the materials and energy efficiency features (Citherlet and Defaux, 2007; GEA, 2012). However, the embodied energy and carbon in construction materials is especially important in regions with high construction rates, and the availability of affordable low-carbon, low-energy materials that can be part of high-performance buildings determines construction-related emissions substantially in rapidly developing countries (Sartori and Hestnes, 2007; Karlsson and Moshfegh, 2007; Ramesh et al., 2010). A review of lifecycle assessment, lifecycle energy analysis, and material flow analysis in buildings (conventional and traditional) can be found in Cabeza et al. (2013a).

Global Status



The buildings and construction sector accounted for 39% of energy and process-related emissions in 2017[7] (see blue colour sectors in Figure 1).

Recent trends in energy consumption and energy-related GHG emissions for the global buildings and construction sector are varied, with increasing energy use but limited growth in building-related emissions. It shows that building construction and operation accounted for 36% of global final energy use and 39% of energy-related GHG emissions in 2017. Therefore, the building and construction sectors have the largest share of energy and emissions, even when excluding construction-related energy use for transport associated with the movement of materials to the construction sites.

[7] http://wedocs.unep.org/bitstream/handle/20.500.11822/30950/2019GSR.pdf?sequence=1&isAllowed=y

The building sector emissions appeared to have levelled off in the last few years, stabilising at around 9.5 Gigatonnes of carbon dioxide equivalent ($GtCO_2eq.$) annually in the years including and between 2015 – 2017. This equates to 28% of global energy-related GHG emissions (Figure 2).

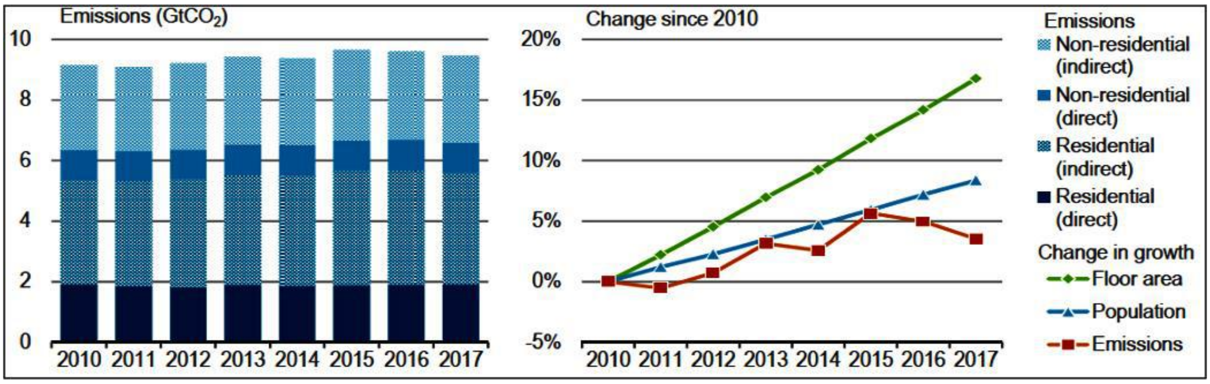


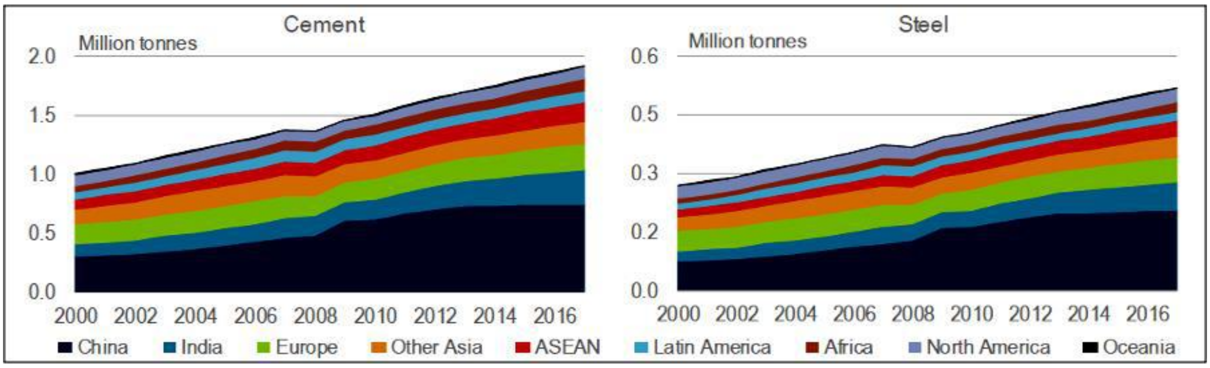
Figure 2: Global buildings energy-related emissions by building type and change in indicators, 2010-2017[8]

Material

GHG emissions from material use in buildings account for 28% of the building-related GHG emissions annually. Most of these emissions are a result of cement and steel manufacturing, which have high process emissions and are used in large quantities. Aluminum, glass and insulation materials are secondary contributors.

Material Demand Trends

Cement and steel used in buildings increased by 4% by weight annually from 2000 to 2015 due to the reason that the construction sector is developing rapidly in this emerging economy. This global trend is largely influenced by China, which accounts for nearly 40% of building material used by today, up from 30% in 2000 (see Figure 3). Other fast - growing markets have contributed to material demand growth, particularly those in India and Southeast Asia in recent years.



Note: *ASEAN* stands for the Association of Southeast Asian Nations; *North America* comprises Canada, the United States and Mexico.

Figure 3: Cement and steel demand for buildings by key region, 2000-2017[9]

Moving from concrete and steel construction to composite, timber or bio - based materials could potentially reduce the building-embodied carbon. There are multiple factors to consider in building material choice and intensity, including construction cost,

[8] Derived from IEA (2018a), World Energy Statistics and Balances 2018, www.iea.org/statistics and IEA Energy Technology Perspectives buildings model, www.iea.org/buildings

[9] Derived from IEA Energy Technology Perspectives buildings model, www.iea.org/buildings

cultural context, and applicability of construction techniques to certain building types and sustainability of material supply. Beyond material choice, improved building design, lifetime extension, construction material waste reduction, reuse and recycling are material efficiency strategies that can optimise material use and reduce embodied emissions in buildings.

Malaysia Status

Malaysia ratified the United Nations Framework Convention on Climate Change (UNFCCC) in July 1994. The primary objective of this multilateral agreement is to achieve the stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic activities from interfering with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable its development to proceed sustainably.

In accordance with decisions 1/CP.19 and 1/CP.20 of the UNFCCC, the Government of Malaysia has communicated its Intended Nationally Determined Contribution (INDC, now known as the NDC), together with relevant clarifying information to UNFCCC in November 2015. As part of the contribution, Malaysia intends to reduce its GHG emissions intensity of Gross Domestic Product (GDP) by 45% by 2030 relative to the emissions intensity of GDP in 2005. This consists of 35% on an unconditional basis and a further 10% is a condition upon receipt of climate finance, technology transfer and capacity building from developed countries (UNFCCC, 2018).

In terms of Articles 4.1(c), (j) and 12 of the Convention, countries are periodically required to submit reports to the Conference of the Parties (COP) on various topics regarding their attempts to address climate change. To fulfil these requirements, the first Malaysia National Communication (NC1) was submitted to the UNFCCC in the year 2000. The base year for the inventory during that period was 1994. Malaysia's total GHG emissions in 1994 were equivalent to 144 million tonnes of carbon dioxide equivalent ($tCO_2eq.$). Its net emissions, after accounting for sinks, totalled up to 76 million tonnes. On a per-capita basis, the emissions would be equivalent to 7.2 tonnes, or 3.7 tonnes if sinks were to be accounted for.

The Malaysian energy sector is currently highly dependent on fossil fuels. As a result, the fossil fuel sector has been responsible for a major share in the emissions, accounting for approximately 33%, 68%, 71%, 76% and 80% of the total emissions for the year 1994, 2000, 2005, 2011 and 2014 respectively (Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC)[10], 2018). Based on the Third National Communication (NC3) and Second Biennial Update Report (BUR2) to the UNFCCC, the major contributions of the total GHG emissions, 317,627 $GgCO_2eq.$ in 2014 included the energy sector (80%), waste sector (9%), industrial processes and product use (IPPU) sector (6%), agriculture, forestry and other land use (AFOLU) - agricultural sector (4%) and AFOLU -Land Use, Land Use Change and Forestry (LULUCF) sector (1%) (Figure 4).

[10] Now known as Ministry of Environment and Water (KASA)

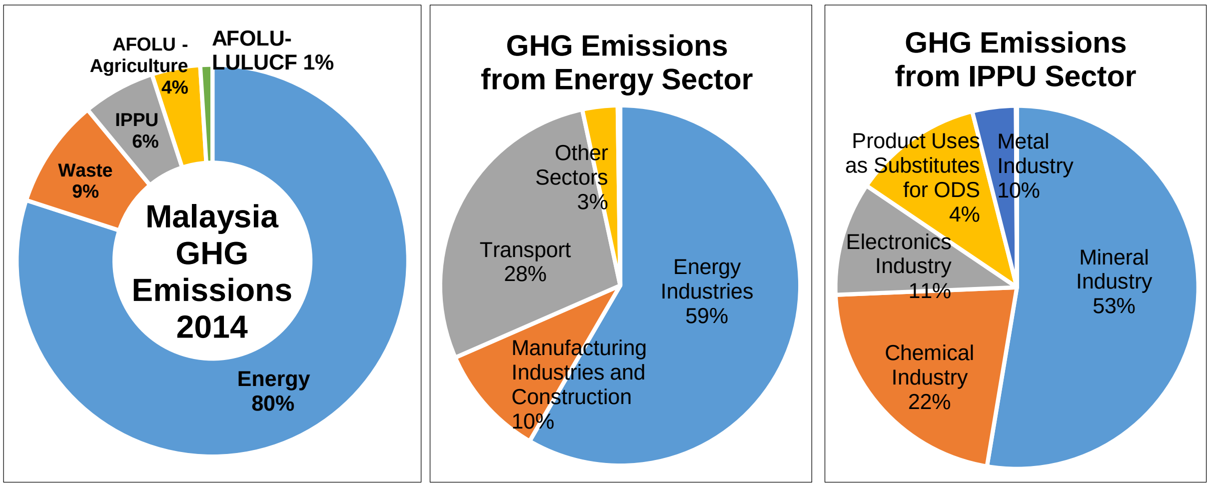


Figure 4: National GHG inventory for 2014[11]

Within the energy sector, electricity generation from fossil fuel is the largest source of GHG emissions at 59%. The transport sector is the second-largest source comprising 28% whilst emissions from manufacturing industries and construction are about 10%. GHG emissions will continue to rise in tandem with the growing demand for fossil fuel particularly in the energy sector unless there are concerted efforts to move towards cleaner fuels and/or there is a shift towards energy-efficient technology.

NC3/BUR2 also presented estimates of GHG emissions from the IPPU sector or "process emissions". Process emissions are emissions generated during the production process that are not energy-related. The emissions assessment for the industrial processes encompassed the inventories for production and consumption of mineral products, chemical products, metal, halocarbons, sulphur hexafluoride, and other products in Malaysian industries. In 2014, the mineral industry contributed the highest emissions (53%) followed by the chemical industry (22%) and metal industry (10%). The main contribution of GHG emissions by the mineral industry is from cement production (90%).

Despite current efforts by the Malaysian government to curb GHG emissions, in 2017 Malaysia was ranked as having the 29th highest national GHG emissions in the world[12]. In terms of the sectoral percentage of Malaysia's GHG emissions, 24% of total GHG emissions (without LULUCF) comes from the energy sector, particularly manufacturing industries and construction sector, highlighting the need for GHG reductions in this area as shown in Table 1.

[11] Malaysia NC3/BUR2
[12] https://en.wikipedia.org/wiki/List_of_countries_by_greenhouse_gas_emissions

Table 1: Approach 1 trend assessment for GHG inventory for 2014 (without LULUCF emissions)[13]

Sector	IPCC Category Code	IPCC Category	Gas	Based Year (2005) estimate (Gg CO_2eq)	2014 Year Estimate (Gg CO_2eq)	Trend Assessment	Percentage Contribution to Trend	Cumulative (%)
ENERGY	1A1	Energy Industries - Solid Fuels	CO_2	22,279.39	54,876.21	0.107	29.17%	29.17%
ENERGY	1A2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	17,297.09	4,606.48	0.071	19.20%	48.37%
ENERGY	1A3b	Road Transportation	CO_2	35,458.78	55,366.46	0.041	11.22%	59.59%
ENERGY	1A1	Energy Industries - Gaseous Fuels	CO_2	57,713.54	66,719.84	0.028	7.51%	67.09%
ENERGY	1B2b	Fugitive Emissions from Fuels - Natural Gas	CH_4	21,581.36	22,395.51	0.021	5.62%	72.71%
ENERGY	1A2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	12,480.19	11,428.40	0.018	4.93%	77.64%

Based on the third National Communication (NC) to the United Nations Framework Convention for Climate Change (UNFCCC) by Malaysia, the assessment of GHG emissions for the construction industry includes multiple sources. These sources range from energy use in the construction industry, industrial processes of construction materials or the building's electricity consumption. To provide a better understanding of the best possible combination of mitigation options based on available policies, plans and programs to achieve Malaysia's mitigation targets to the Paris Agreement, a GHG emissions assessment for the construction industry value chain in Malaysia needs to be conducted. The inventory will lend support to the assessment of potential mitigation measures.

In supporting the national commitment, the Construction Industry Transformation Programme (CITP) was launched by the Ministry of Works (KKR) and Construction Industry Development Board (CIDB) Malaysia in 2015. The CITP outlines four (4) Strategic Thrusts to guide the transformation and continued development of the construction industry. The objective of the strategic thrusts is to reduce GHG emissions in the construction industry by 4 million tCO_2eq. If achieved, the CITP will contribute towards one of the mitigation actions to reach Malaysia's national target (the NDC). The thrusts include; (1) Quality, Safety, and Professionalism, (2) Environmental Sustainability, (3) Productivity, and (4) Internationalisation.

Therefore, to provide a basis for the policymakers to formulate appropriate policies which reduce the industry-wide GHG emissions, it is important to understand and quantify the various sources of GHG emissions within the construction sector. Only after the sources of GHG emissions are identified, GHG reduction solutions can be put in place for the Malaysian construction industry.

The results will promote a better understanding of the relationship between the construction industry's emissions and economic development. This information can contribute to developing more effective policies for each stakeholder engaged in the

[13] Malaysia NC3/BUR2

construction industry. Furthermore, consistency and clarity in calculating emissions are important to compare emissions within and across sectors, and for the policymakers to plan and assess progress.

Eco-Ideal Consulting Sdn. Bhd. (ECO), in association with TNB Research Sdn. Bhd. (TNBR) are the appointed consultant to conduct the assessment of GHG emissions for the construction industry in Malaysia.

For this Study, the value chain included the manufacturing of the material, transportation of the material and construction activities on site. Results from the assessment will guide CIDB to reduce the impact on the environment, improve processes, and indirectly, create new business opportunities.

Section 1 of this report introduces the background and scope of this Study.

Section 2 of this report updates the current status of the construction industry.

Section 3 of this report elaborates on the approaches and methodologies used for assessment on potential GHG emissions from construction material value chain and embodied carbon.

Section 4 of this report calculates the GHG emissions and its projections.

Section 5 of this report elaborates on the proposed incentive and disincentive mechanism on reducing GHG in the construction sector.

Section 6 of this report provides the conclusions and way forward of this Study.

1.2 Objectives

The specific objectives of this Study are:

i. To identify a baseline of GHG emissions created from the manufacturing of the product to its arrival at the construction site (including sub-sectors of the manufacturing of construction materials);

ii. To identify a baseline of GHG emissions created during construction activities;

iii. To identify potential GHG reductions activities; and

iv. To recommend an incentive or disincentive model, which can be feasibly and practically implemented for the Malaysian construction industry.

1.3 Project Framework

At the initial stage, technical knowledge sessions which included discussions and meetings were conducted to gather data, inputs and experiences from various stakeholders.

ECOI and TNBR have been working closely with CIDB to conduct the assessment of the GHG emissions for the construction industry in Malaysia based on available and related international accepted methodologies.

This assessment took a holistic view of the GHG emissions that the construction industry has the ability to influence. Figure 5 shows the value chain of the construction phase. The value chain is the main scope of this Study and encompasses material extraction, material manufacturing, transportation of the material and construction on site. The boundary condition of this value chain is called "Cradle-to-Site". "Cradle-to-Site" is an extension of "Cradle-to-Gate" which includes transportation from the factory gate to the construction site and activities at construction sites. The detailed methodologies on the GHG calculation are presented in section 3.1.

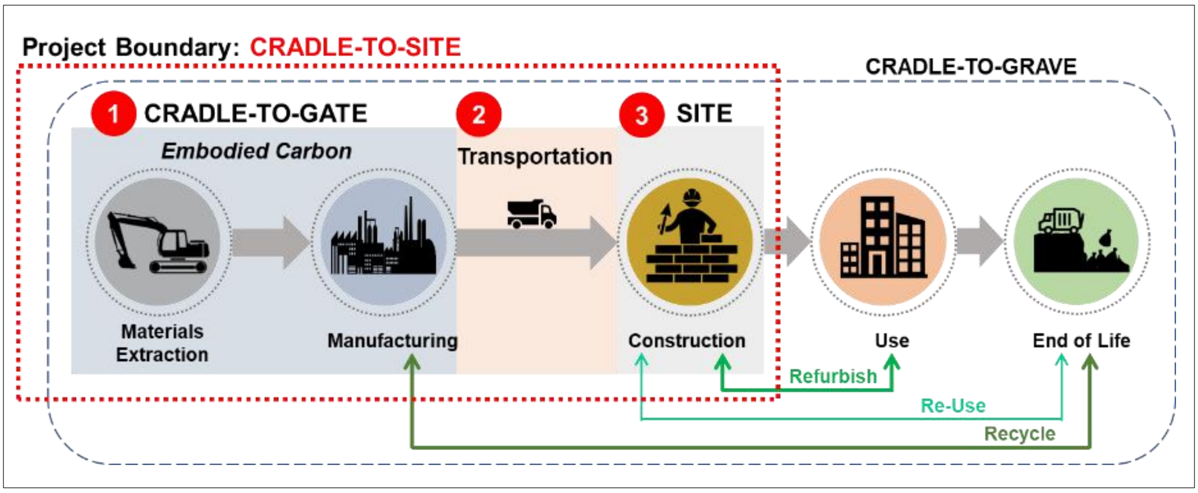


Figure 5: Study boundary

Fourteen (14) construction materials were selected for the "Cradle-to-Site" analysis. The selected materials are discussed in section 2.2.

The work scopes of this Study include:

Scope A: GHG Emission Assessment on Construction Industry Value Chain

i. Identify the activity data that are needed to estimate GHG emissions for the construction industry value chain in Malaysia;
ii. Identify nine (9) major materials, five (5) non-major materials, the appropriate data sources and references for the collection of the activity data, emission factors and other parameters required as well as identification of baseline year. Document any assumption made for this purpose;
iii. Data processing, according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines and other established methodology for the assessment of the GHG emissions;
iv. Assessment of each value chain's contribution and trends observed;
v. Develop baseline on approved years and GHG emissions scenarios for 2045;
vi. Identify and develop methods for overcoming the gap of inventory data if there is no available data;
vii. Identify barriers to obtaining existing data and propose solutions;
viii. Prepare the GHG emissions report for the construction industry value chain for the baseline year. In addition, describe procedures and arrangements

undertaken to collect data, as well as efforts to make this a continuous process including information on the role of the institutions involved;

ix. Provide recommendations on improving the national system for GHG data collection and management based on the experience under this exercise;
x. Finalise the report by incorporating reviews from the stakeholders and other setups;
xi. Provide training materials and facilitates workshops; and
xii. Adaptation of the quality assurance and control (QA/ QC) plan and carry out the assessment of uncertainty according to the guidelines set.

Scope B: GHG Emissions of Construction Industry in Malaysia

i. Defining the term of the construction industry from Malaysia's perspective and sub-sectors related to it;
ii. Determination of the GHG emissions for the manufacturing of construction materials based on item stated in Scope A;
iii. Determination of the amount and type of fuels (cumulatively) which are being used to transport the construction materials from production to the construction site (including the fuel used to transport the material via ships) from overseas;
iv. Determination of the amount energy and water consumed during construction of projects;
v. Determination of the carbon emissions forms the usage of energy and water during the design of the construction projects;
vi. Determination of the construction industry value-chain GHG emissions trends and hotspots; and
vii. Suggestions for ways of reducing and minimising GHG emissions.

Scope C: Framework on the Implementation of Incentive and Disincentive Mechanism

i. Identify the incentive and disincentive related to construction material readily available in Malaysia;
ii. Identify the incentive and disincentive related to material readily available in other countries;
iii. Assessment of incentive and disincentive feasibility to be carried out in the construction industry context;
iv. Develop an incentive or disincentive mechanism with industry feedback and syndication; and
v. Prepare recommendations on possible incentives or disincentives based on GHG emissions assessment to relevant authority/ authorities.

2.0 CURRENT STATUS OF CONSTRUCTION INDUSTRY IN MALAYSIA

2.1 Construction Sub-Sectors and Its Volume

In accordance with the construction category of CIDB, the construction projects can be categorised into four (4) categories as listed follows:

i. **Residential** which comprises of apartment and condominium, bungalow, semi-detached, terrace, and others;
ii. **Non-residential** which comprises of commercial, industrial, administrative/ office space, travel and leisure, and others;
iii. **Social amenities** which comprises of education, health, public amenity, and others; and
iv. **Infrastructure** which comprises of transport, utility, drainage and sewerage, and disaster prevention.

The number of projects awarded for the year 2010 – 2019 is presented in Figure 6. On average, the total number of construction projects by category, are well distributed among residential (27%), non-residential (37%) and infrastructure (26%). The smallest contribution is social amenities (10%). As shown in Figure 6, the proportion of construction projects by category remains fairly consistent across the ten (10) years.

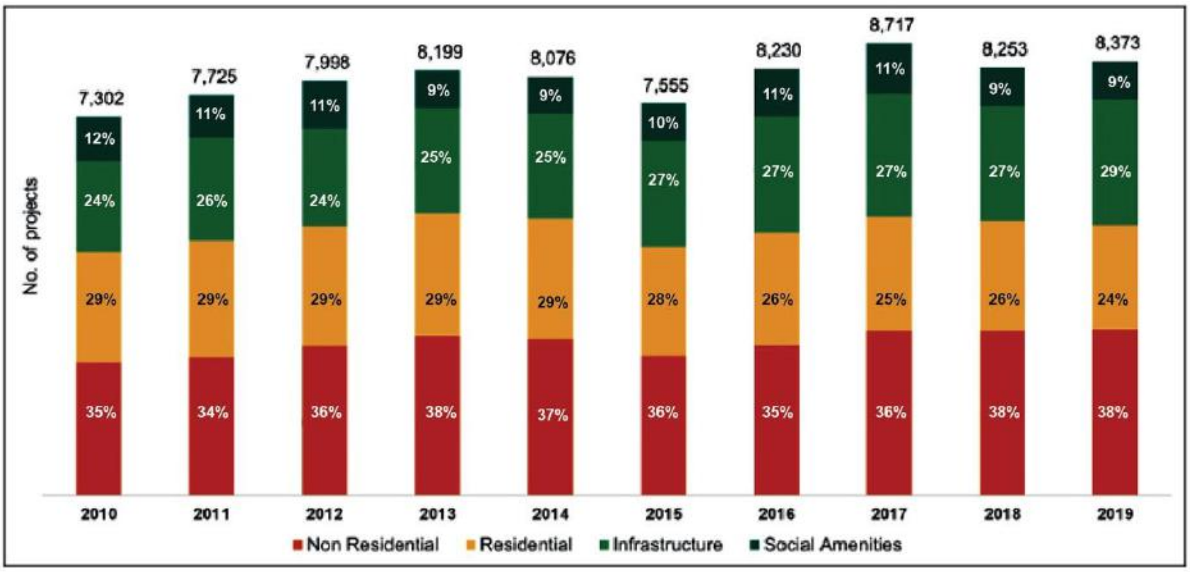


Figure 6: Number and categories of construction in Malaysia[14]

The value of projects awarded for the year 2010 – 2019 are presented in Figure 7. Unlike the data on the number of construction projects, the project value by project type varies over the years. The construction activities in the year 2016 appear to be higher than in other years (especially in social amenities) and the value of infrastructure projects was the highest among the years.

[14] Data source: CIDB, 2019

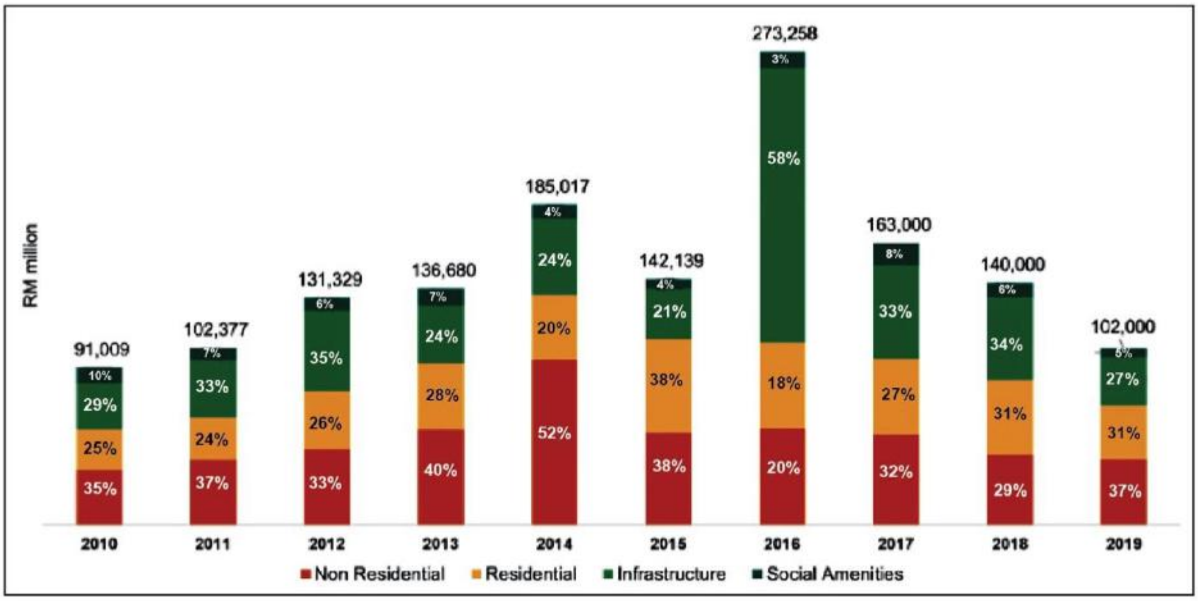


Figure 7: Total project value in RM million[15]

2.2 Construction Materials and Its Volume

A total number of fourteen (14) construction materials were selected and prioritised for the "Cradle-to-Site" analysis. Nine (9) major and (5) non-major construction materials included are tabulated in Table 2.

Table 2: Selected major and non-major construction materials

Major Construction Materials	Non-Major Construction Materials
1) Steel Reinforcement	1) Aggregate
2) Ready Mixed Concrete	2) Roofing Tiles/ Sheet
3) Plywood	3) Steel and Metal
4) Bricks	4) Timber
5) Paint	5) Sanitary Ware
6) Sand (finishes)	
7) Glass	
8) Cement (finishes)	
9) Ceramic Tiles	

2.2.1 Major Construction Materials

In the year 2018, CIDB initiated a special methodology for the projection of construction and material demand for the project awarded, namely PROJEXIS. The PROJEXIS is used to project the construction material demand based on the information derived from projects awarded from 2016 until 2019. Forty-one (41) types of construction materials are accounted in PROJEXIS. In order to determine constants for the utilisation of major construction materials, CIDB has analysed different construction stages with varying materials being used and identified the eight (8) major construction materials demand in most construction projects. Therefore, the identified eight (8) major construction materials demand is adopted as the major materials to be assessed in this Study (Table 3).

[15] Data source: CIDB, 2019

Table 3: Eight (8) major construction materials[16]

No	Type of Construction Material	Specification
1	Steel Reinforcement	Mild Steel Round Bar R10, MS146 Mild Steel Round Bar R12, MS146 Mild Steel Round Bar R16, MS146 High Tensile Deformed Bar – Y10, MS146 High Tensile Deformed Bar – Y12, MS146 High Tensile Deformed Bar – Y16, MS146 High Tensile Deformed Bar – Y20, MS146 High Tensile Deformed Bar – Y25, MS146 High Tensile Deformed Bar – Y32, MS146 High Tensile Deformed Bar – Y40, MS146
2	Ready Mixed Concrete	Ready Mix Concrete – Normal Mix – Grade 20, Granite
3	Plywood	Plywood – Shuttering Board, 4' x 8' x 12mm
4	Bricks	Common Clay Bricks
5	Paint	Paint-ICI Dulux standard colour – external acrylic emulsion, weather shield, 5 Litre
6	Sand (finishes)	Normal River Sand-Ex
7	Glass	Clear Float Glass 5mm Thick, Local/Imported
8	Cement (finishes)	Ordinary Portland Cement, 50 kg bag

During the first progress meeting conducted on the 18th of October 2019, it was requested by the committee to include ceramic tiles as one of the major construction materials. It is believed that ceramic tile manufacturing is a highly energy-intensive production process and one of the main contributors to GHG emissions since it contains several stages in which the products are subjected to thermal treatment[17]. However, ceramic tiles are not included under PROJEXIS, as a result, the quantity of ceramic tiles was obtained from the import data published by the Department of Statistic Malaysia (DOSM).

2.2.2 Non-Major Construction Materials

During the second progress meeting conducted on the 18th of November 2019, a committee member requested to identify another five (5) non-major construction materials to be included in the main list. Therefore, the five (5) non-major materials that are commonly used are identified and listed below in Table 4.

[16] CIDB

[17] http://www.qualicer.org/recopilatorio/ponencias/pdfs/2010239.pdf

Table 4: Five (5) non-major construction materials

No	Type of Construction Materials	Specification
1	Aggregate	Granite Aggregate 3/4"
2	Roofing Tiles/Sheet	Interlocking Concrete Tiles - Standard Duotone Colour 420mm x 330mm Malaysian Standards (MS) Decking – Step Roofing M350 G24, 0.53mm Total Coated Thickness (TCT), Clean Colourbond MS Decking - Ajiya AP Rib Hi-Tensile G26, 0.47mm TCT, Clean Colourbond (Comercial) MS Decking - Ajiya AP Rib Hi-Tensile G24, 0.53mm TCT, Clean Colourbond (Comercial) MS Decking - Ajiya Euro Step Roofing M350 G28, 0.40mm TCT, Clean Colourbond MS Decking - Ajiya Euro Step Roofing M350 G26, 0.47mm TCT, Clean Colourbond MS Decking - Ajiya AP Rib Hi-Tensile G28, 0.40mm TCT, Clean Colourbond (Commercial) MS Decking-Lysaght Colourbond-Spandex Hi- Ten 0.47mm TCT MS Decking-Lysaght Colourbond-Trimdex Hi-Ten 0.47mm TCT MS Decking-Lysaght Colourbond-Kliplok Hi-Ten 0.53mm TCT Corrugated Roofing Sheet-76mm Double Width, 1065mm x 2440mm x 4mm (Hume/Malex/UAC) MS Decking -Spandec Hi-Ten 0.47mm TCT, Clean Colourbond Corrugated Roofing Sheet-3.0mm x 1024mm Primaflex Corrugated Roofing Sheet-610mm x 1220mm x 3.2mm
3	Steel and Metal	Square hollow sections-12mm x 12mm x 1.0mm (0.339kg/m) Square Hollow Sections - 50mm x 50mm x 3.0mm (4.25kg/m) Square Hollow Sections -150mm x 150mm x 4.0mm (20.20kg/m) Universal beams-102mm x 102mm x 8.76mm (19.35kg/m) Universal beams-400mm x 400mm (140kg/m) Equal angles-38mm x 38mm x 3.8mm (2.17kg/m) Equal angles-50mm x 50mm x 4mm (3.06kg/m) Sheet Pile - friction stir processing (FSP) IIIA, 400mm x 150mm x 13.1mm (58.4kg/m x 12mL) Square Hollow Sections -150mm x 150mm x 4.5mm (20.20kg/m)

No	Type of Construction Materials	Specification
		Square Hollow Sections - 150mm x 150mm x 5.0mm (22.30kg/m) Square Hollow Sections - 19mm x 19mm x 1.6mm (0.857kg/m)
4	Timber	General Market Specification (GMS) Heavy Hardwood, Balau 1 GMS light Hardwood, Dark Red Meranti GMS Medium Hardwood, Kapur Scantling Medium Hardwood, Kapur Scantling Mixed Medium Hardwood GMS Heavy Hardwood, Balau 2 MLHW 3"x 6"x 8' up - Grade C Timber Plank 2"x 8"x 14' - Grade C MLHW 3"x 4"x 8' up - Mix Wood MLHW 3"x 5"x 8' up - Grade C MLHW 2"x 4"x 8' up - Mix Wood MLHW 3"x 3"x 8' up - Grade C MLHW 2"x 3"x 8' up - Mix Wood MLHW 2"x 2"x 8' up (Hard Tanalised) Grade C MLHW 2"x 2"x 8' up (Soft Tanalised) Grade C MLHW 2"x 2"x 8' up (Soft) Grade C MLHW 1"x 2"x 8' up - Local/ Grade B MLHW 1"x 2"x 8' up - Local/ Mix Wood
5	Sanitary Ware	Wash Hand Basin-560mm x 406mm, white colour, Jacqueline WB, Claytan Water Closet Western Type- Windsor with push button 6L cistern, standard colour, Johnson-Windsor 140 Water Closet Western Type-WC 644, white colour without cistern, claytan Water Closet Eastern Type-Bengal ACBL-000 without cistern, white colour, johnson-suisse Urinal Bowl, santana 320 c/w hanger, flange, ceramic waste & cleaning set, johnson-suisse Claywood Squatting Pan, includes Integral 'S' Trap (White) - 585mm x 310mm x 320mm, Johnson-Suisse Wash Hand Basin - 460mm x 365mm x 825mm, Neptune Wall Hung Basin, Claytan Water Closet Luton Type with push button 3L or 6L Cistern, Standard Colour, Johnson-Suisse

2.2.3 Historical Construction Material Demand

2.2.3.1 Major Construction Material

The historical data on the major construction material demand were respectively extracted from PROJEXIS and DOSM, compiled and tabulated in Table 5.

Table 5: Major materials demand[18]

No	Construction Material	Unit	2016	2017	2018	2019
1	Steel Reinforcement	tonne	5.70	8.90	8.80	7.10
2	Ready Mixed Concrete	m^3	39.12	67.50	69.40	59.30
3	Plywood	piece	55.90	66.60	75.40	70.70
4	Bricks	pallet	9.70	10.80	13.00	17.90
5	Paint	5 L	4.80	5.40	11.70	17.90
6	Sand (finishes)	tonne	10.40	14.00	22.90	38.40
7	Glass	m^2	9.70	9.10	14.60	25.10
8	Cement (finishes)	tonne	1.50	2.40	4.60	6.50
9	Ceramic Tiles	m^2	22.77	36.44	33.60	30.94

The units for ready mixed concrete, plywood, bricks, paint, glass, and ceramic tiles were converted into tonnes by multiplying the density or weight of the materials. The conversion table for specific construction material is tabulated in Table 6.

Table 6: Conversion table

Ready Mixed Concrete	2,400	kg/m^3
Density = 2400kg/m^3[19]	2.4	tonne/m^3
Bricks	1	pallet
1 brick = 2.2kg[20]	720	no
	1,584	kg/pallet
	1.584	tonne/pallet
Paint	6.5	kg/5 Liter
5 Liter = 6.5kg[21]	0.0065	tonne/5 Liter
Plywood (12mm)	20.4	kg/piece
Average density = 572kg/m^3[22]	0.0204	tonne/piece
1 piece (4' x 8') = 32 sq ft = 2.973m^2		
Glass (5mm)		
Density = 2.5t/m^2 [23]	0.0125	tonne/m^2
Ceramic tiles		
Average weight = 15.09 kg/m^2[24]		kg/m^2

[18] CIDB
[19] http://engineering.utm.my/civil/mjce/wp-content/uploads/sites/40/2016/04/Vol-281-Paper-4.pdf
[20] https://www.ewarehouse.my/Common-Bricks-720-PCS-PALLET
[21] https://vodoprovod.blogspot.com/2017/12/convert-kg-paint-to-liters-online.html
[22] https://www.woodproducts.fi/content/plywood
[23] https://uk.saint-gobain-building-glass.com/en-gb/architects/physical-properties
[24] https://www.scribd.com/doc/91713808/Tile-and-Adhesive-Weight-Per-Square-Metre-Weight-Per-Sq-Metre

The converted data is presented in Table 7 below. From the data, it is evident that all the construction materials demand is gradually increasing from the year 2016 to 2019. The most significant change is the increase in cement which increased by 77% from 2016 to 2019. The highest quantity of major material in 2019 is ready mixed concrete (63.2%), followed by sand (17.1%), bricks (12.6%) and steel reinforcement (3.2%) (Figure 9).

Table 7: Major materials demand in million tonne

No.	Construction Material	Demand (million tonne)			
		2016	2017	2018	2019
1	Steel Reinforcement	5.70	8.90	8.80	7.10
2	Ready Mixed Concrete	93.89	162.00	166.56	142.32
3	Plywood	1.14	1.36	1.54	1.44
4	Bricks	15.36	17.11	20.59	28.35
5	Paint	0.03	0.04	0.08	0.12
6	Sand (finishes)	10.40	14.00	22.90	38.40
7	Glass	0.12	0.11	0.18	0.31
8	Cement (finishes)	1.50	2.40	4.60	6.50
9	Ceramic Tiles	0.34	0.55	0.51	0.47
	Total (million tonne)	**128.48**	**206.47**	**225.76**	**225.01**

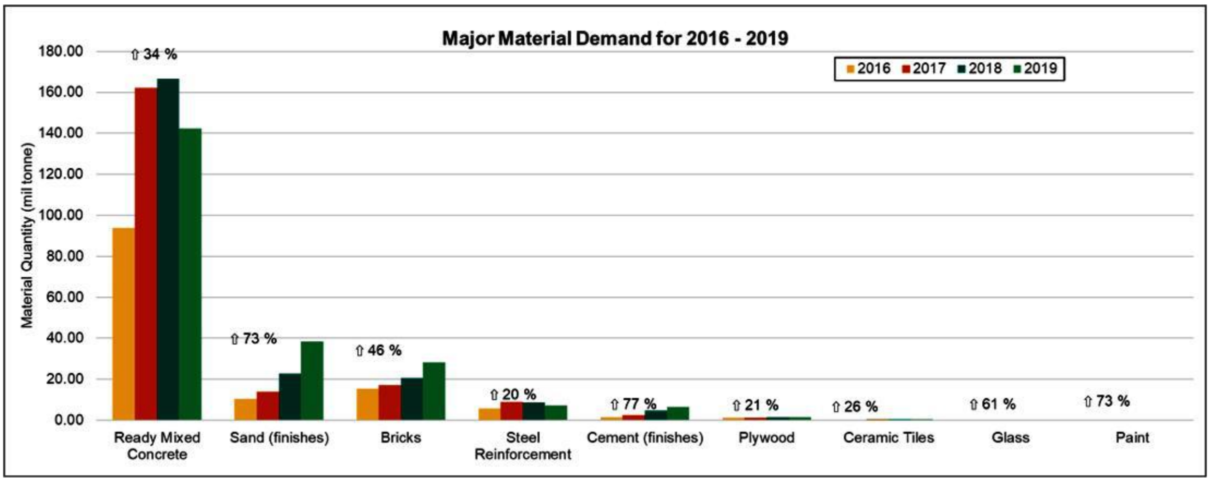


Figure 8: Major material demand for year 2016 to 2019

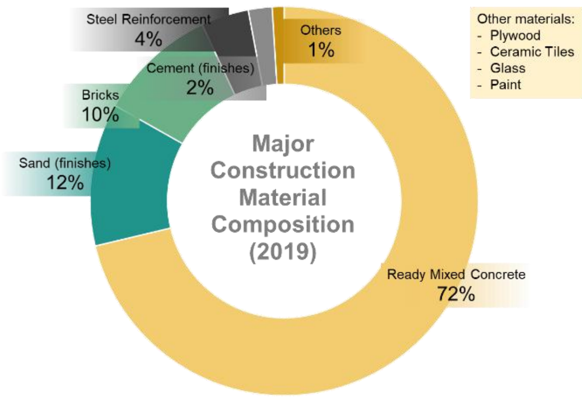


Figure 9: Average major material demand composition for year 2017 - 2019

2.2.3.2 Non-Major Construction Material

Only one (1) non-major construction material i.e. aggregate can be obtained from PROJEXIS. Due to insufficient information available, the other four (4) materials i.e. roofing tiles/sheet, steel and metal, timber and sanitary ware were chosen from the list of "*Pengiraan Purata Keseluruhan Peratus Kos Bahan Binaan untuk Keseluruhan Kategori Bangunan untuk Menjadi Jumlah Keseluruhan adalah 100%*" provided by the by the Business and International Division of CIDB Malaysia.

The list showed the average percentage of the cost for seventeen (17) types of construction materials, labor and plant which from its sum up will equal the total (i.e. 100%) building project cost. The average percentages of cost for respected material multiply with the building project value in order to estimate the building material cost. The building materials price from the National Construction Cost Centre (myN3C) database[25] was extracted and converted into tonnes and its average value was further used as per the equation below to estimate the material quantity (see Table 8 for the raw data used).

$$\text{Quantity (million tonne)} = \frac{\text{Building Material Cost (\%) x Building Project Value (RM million)}}{\text{Building Materials Price (RM/tonne)}}$$

Table 8: Raw data to estimate materials quantity

Construction Material	Average Percentage of Building Material Cost	Building Project Value (RM million)				Building Materials Price (RM/tonne)			
		2016	2017	2018	2019	2016	2017	2018	2019
Roofing Tiles/Sheet	2.25%	115,017	109,210	92400	74460	8,700.67	8,656	6,075	6,319
Steel and Metal	7.17%					3,199.34	3,178	3,155	3,078
Timber	4.02%					3,239.38	3,277	1,339	1,380
Sanitary Ware	0.81%					7,886.80	8,098	22,901	24,404

The estimated data is presented in

Table *9* below together with construction material demand data. The data shows that the construction materials quantity is increases and decreases in a fluctuating manner. The most significant change being the decrease in sanitary ware which decreased by 79% in 2019 compared to 2016. This might due to the decrease in the number of residential projects. The total number of projects for residential decrease by 7% in 2019 compared to 2016. The highest average quantity of non-major materials for 2017 - 2019 is aggregate (89%), followed by steel and metal (5%), and timber (5%).

[25] http://myn3c.cidb.gov.my/cidb_n3c/progress/index.php

Table 9: Non-major materials quantity in million tonne

No.	Construction Material	Materials Quantity (million tonne)			
		2016	2017	2018	2019
1	Aggregate	7.10	27.80	33.30	43.90
2	Roofing Tiles/Sheet	0.30	0.28	0.34	0.27
3	Steel and Metal	2.58	2.46	2.10	1.73
4	Timber	1.43	1.34	2.77	2.17
5	Sanitary Ware	0.12	0.11	0.03	0.02
Total (million tonne)		**11.52**	**32.00**	**38.55**	**48.09**

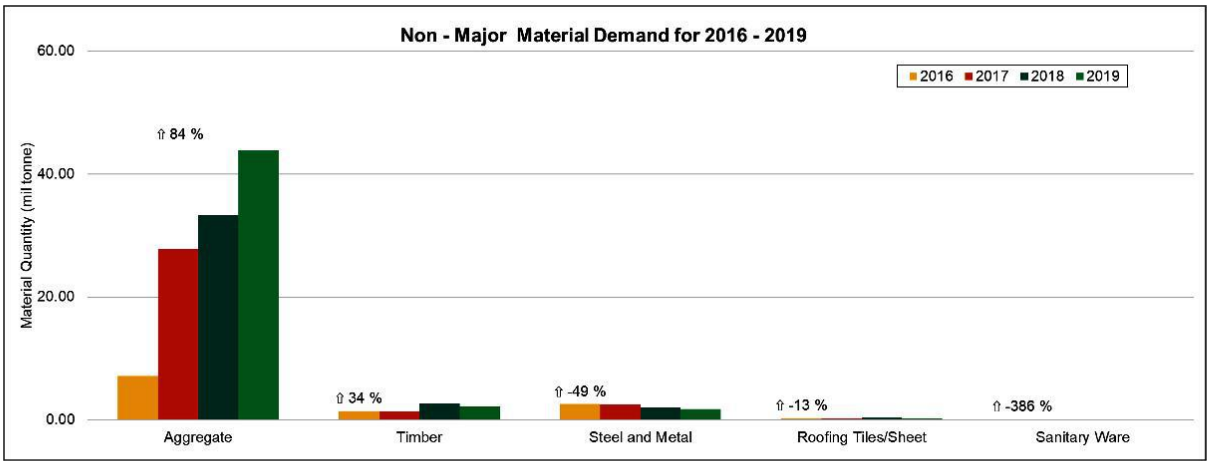


Figure 10: Non-major material demand for year 2016 to 2019

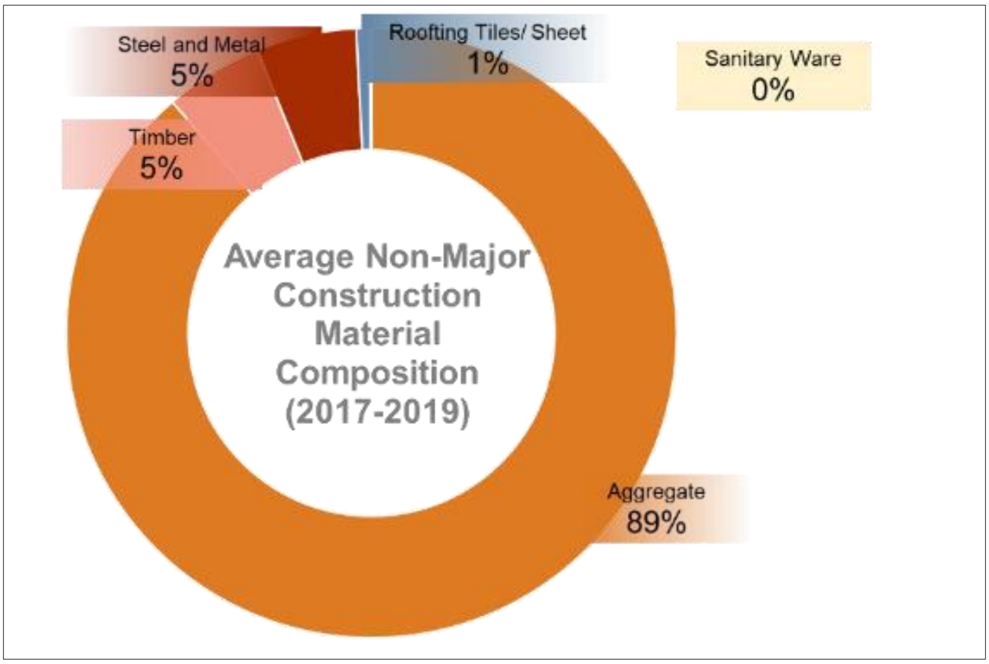


Figure 11: Non-major material demand composition for year 2019

2.3 Summary of Construction Materials Demand

The summary of construction material demand is tabulated as below:

Table 10: Summary of construction materials quantity in million tonnes

No.	Construction Material	Materials Quantity (million tonne)			
		2016	2017	2018	2019
1	Steel Reinforcement	5.70	8.90	8.80	7.10
2	Ready Mixed Concrete	93.89	162.00	166.56	142.32
3	Plywood	1.14	1.36	1.54	1.44
4	Bricks	15.36	17.11	20.59	28.35
5	Paint	0.03	0.04	0.08	0.12
6	Sand (finishes)	10.40	14.00	22.90	38.40
7	Glass	0.12	0.11	0.18	0.31
8	Cement (finishes)	1.50	2.40	4.60	6.50
9	Ceramic Tiles	0.34	0.55	0.51	0.47
10	Aggregate	7.1	27.8	33.3	43.9
11	Roofing Tiles/Sheet	0.30	0.28	0.34	0.27
12	Steel and Metal	2.58	2.46	2.10	1.73
13	Timber	1.43	1.34	2.77	2.17
14	Sanitary Ware	0.12	0.11	0.03	0.02
	Total (million tonne)	**140.02**	**238.58**	**264.11**	**273.11**

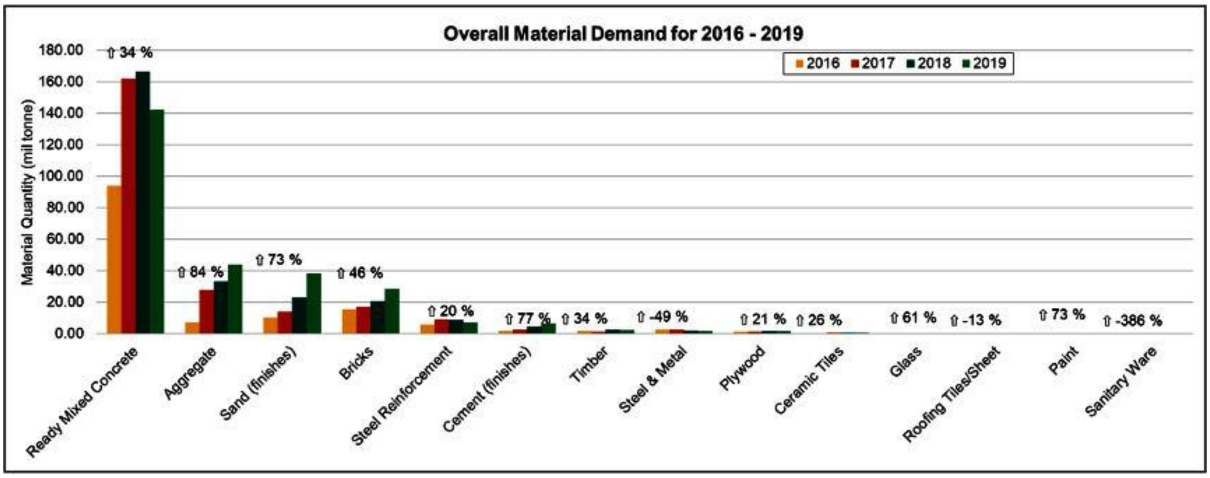


Figure 12: Summary of material demand for year 2016 to 2019

As shown in Table 10 above, the quantity of construction material in 2016 was very low compared to 2017 – 2019, therefore, the average of the data obtained from the year 2017 – 2019 was used for the analysis, comparison and reporting purposes.

As shown in Figure 13 below, the highest average quantity of construction material consumed from 2017 – 2019 is ready mixed concrete (61%) followed by aggregate (14%), sand (10%), bricks (9%), steel reinforcement (3%), cement (2%) and other (3%) respectively.

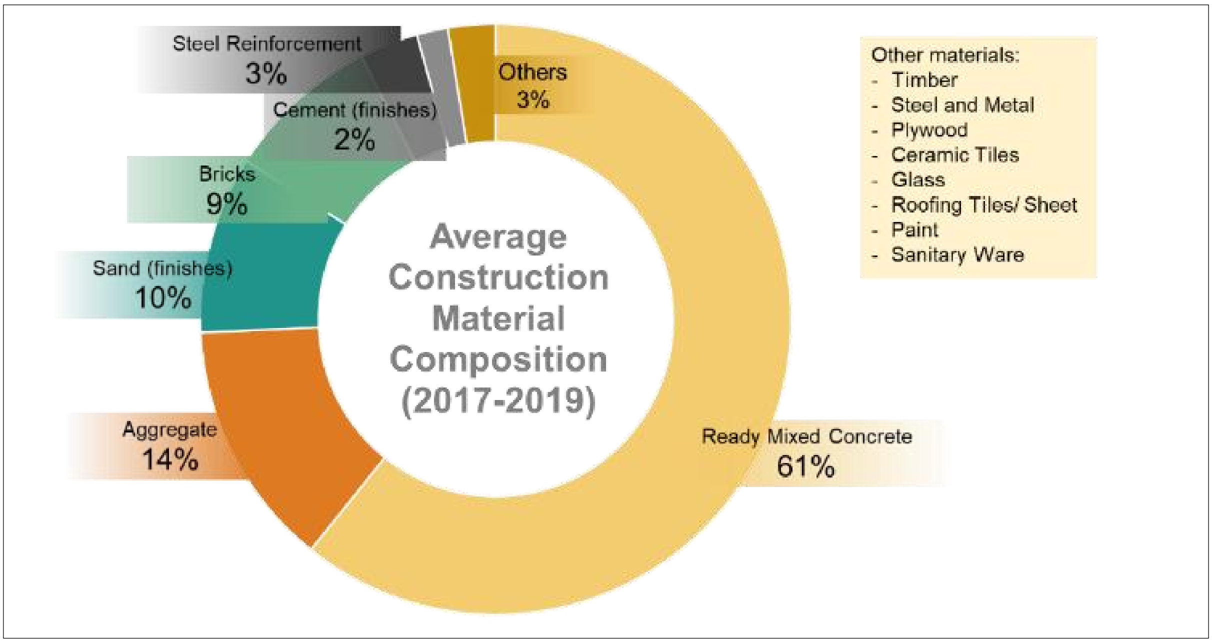


Figure 13: Average of material demand composition for year 2017 to 2019

Under this Study, a survey on actual completed construction projects was carried out to further verify and support the input values and assumptions used in the GHG assessment. In terms of composition for major material consumed by the construction sector, the results from the survey of actual projects are comparable to the data compiled from CIDB and other sources (refer to Table 11 for comparison).

Table 11: Comparison of the average material demand composition with survey result

No.	Construction Material	Composition (%)		
		CIDB	Survey (this Study)	Difference
1	Steel Reinforcement	3%	2%	1%
2	Ready Mixed Concrete	61%	55%	6%
3	Cement (finishes)	2%	2%	0%
4	Bricks	9%	7%	2%

3.0 FRAMEWORK FOR EMISSION FACTORS AND GHG EMISSIONS CALCULATION

3.1 General Methodologies and Approaches

Measuring and reporting of GHG emissions caused by the activities in the given time frame is a very important stage in defining the mitigation strategies. Quantification methodologies prescribed by international GHG programme can be classified into the following options:

a. Calculation-based approach
   - GHG activity data multiplied by GHG emissions or removal factors;
   - the use of models;
   - facility-specific correlations; and
   - mass balance approach.

b. Measurement, either
   - continuous; or
   - intermittent.

c. Combination of measurement and calculation.

The most commonly used method of accounting for GHG emissions, which is also adopted for this Study, is using consumption data and emission/conversion factors (Option a).

Other methods such as using an emissions monitoring system are allowed provided the system meets strict calibration and maintenance regime, and the readings are periodically assessed against the calculated emissions using the *calculation-based approach*.

Apart from that, an international organization for standardisation (ISO) 14064 - GHG[26] denotes that the *quantification methodologies selected and used are reasonably minimising the uncertainty and yield accurate, consistent and reproducible results.* The ISO standard allows in choosing the quantification method for its GHG accounting programme, but the method shall be fixed throughout. It also specified that *the selection of quantification methodologies shall be explained as well as any changes to quantification methodologies previously used (if any).*

In general, the steps in identifying and calculating the GHG emissions are as follows:

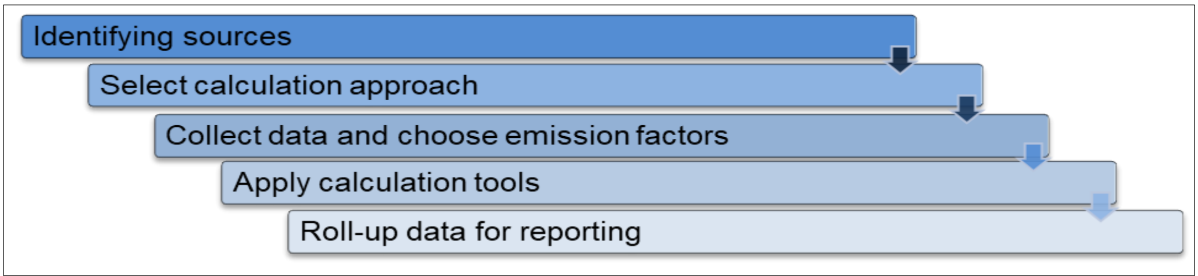


Figure 14: Steps in identifying and calculating GHG emissions

[26] ***ISO 14064*** is an international standard for quantifying and reporting greenhouse gas emissions.

The IPCC guidelines provide three (3) methodological tiers for estimating GHG emissions and provide the following definition "*A tier represents a level of methodological complexity. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate*".

Example of the difference in data requirements for the three (3) tiers are summarised as follows:

Tier 1 Data from national/international energy statistics and default emission factors;

Tier 2 Data from national energy statistics, together with country-specific emission factors, where possible, derived from national fuel characteristics; and

Tier 3 Statistics and data on combustion technologies applied together with technology-specific emission factors; this includes the use of models and facility-level emission data where available.

The recommended approach by IPCC is based on data availability. The ISO 14064 and GHG Protocol do not recommend calculation methods by any Tier, but they do outline *accuracy* as one of their principles.

In-line with the *intended use* of this assessment, the decision tree in Figure can be referred to in determining the approach undertaken. The diagram indicates which Tier of information is adopted, based on site-specific information. If site-specific information is available, it directly falls under Tier 2 or 3; otherwise, it is Tier 1.

In accordance with the *2006 IPCC Guidelines and Good Practices,* the most common simple methodological approach is to combine information on the extent to which human activity takes place (called *activity data* or *AD*) with coefficients which quantify the emissions or removals per unit activity (called *emission factors or EF)*. The basic equation is this:

$$\boxed{Emissions = AD \cdot EF}$$

Based on the emissions sources identified, AD was collected from relevant data suppliers and respective emissions factors were applied accordingly to calculate GHG emissions. As mentioned earlier, a survey on actual construction projects completed in Malaysia was also carried out to provide further verification and support to the AD and assumptions used.

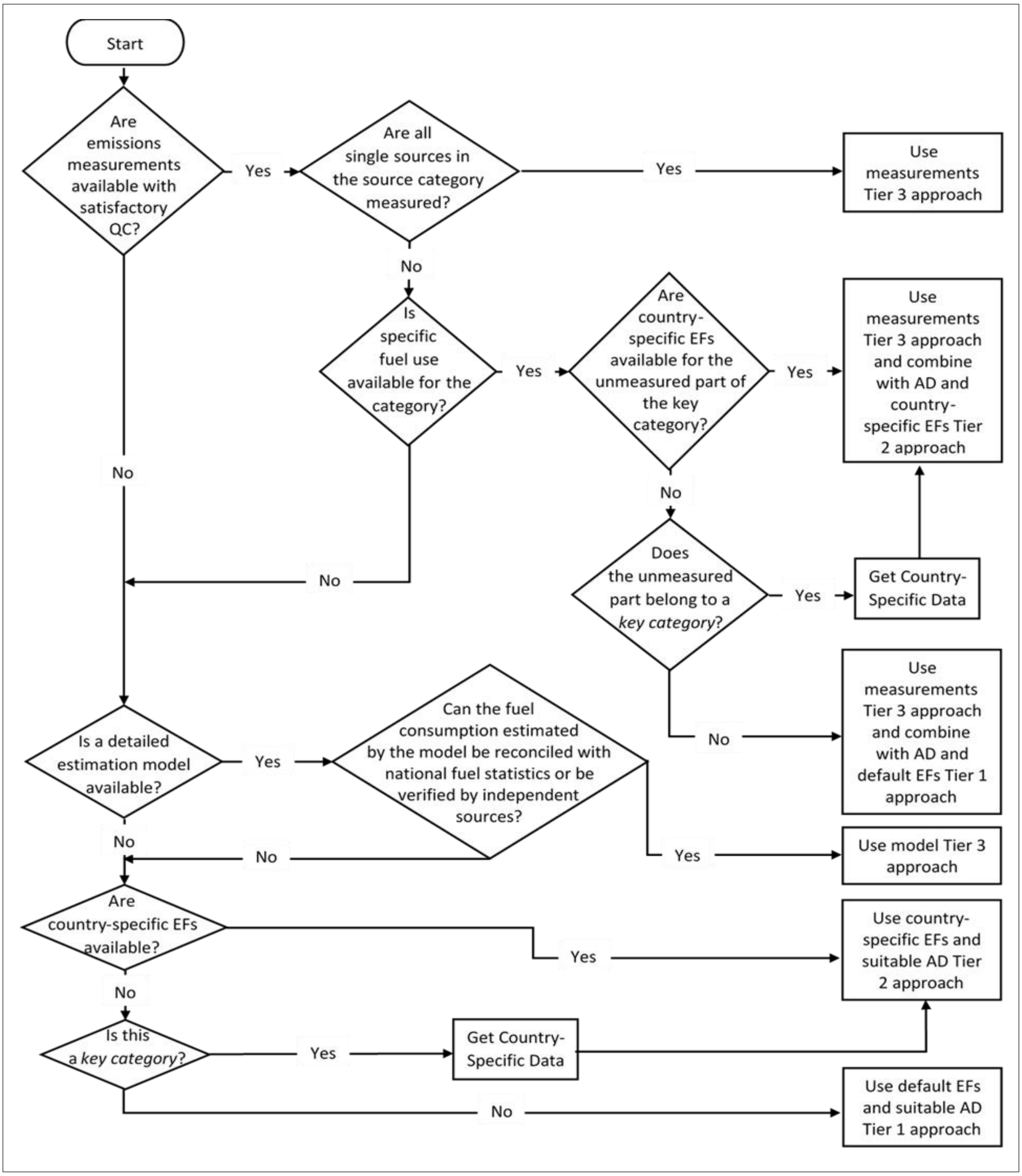


Figure 15: Decision tree for estimating GHG emissions[27]

3.2 Activity Data (AD)

As mentioned in section 1.3, the boundary of this Study was set as cradle-to-site, covering the partial product life cycle from raw material extraction until the product has reached the point of use (i.e., the construction site). Thus, the AD for this Study is presented in Figure 16.

[27] IPCC 2006 Vol. 2 Ch. 1, Figure 1.2

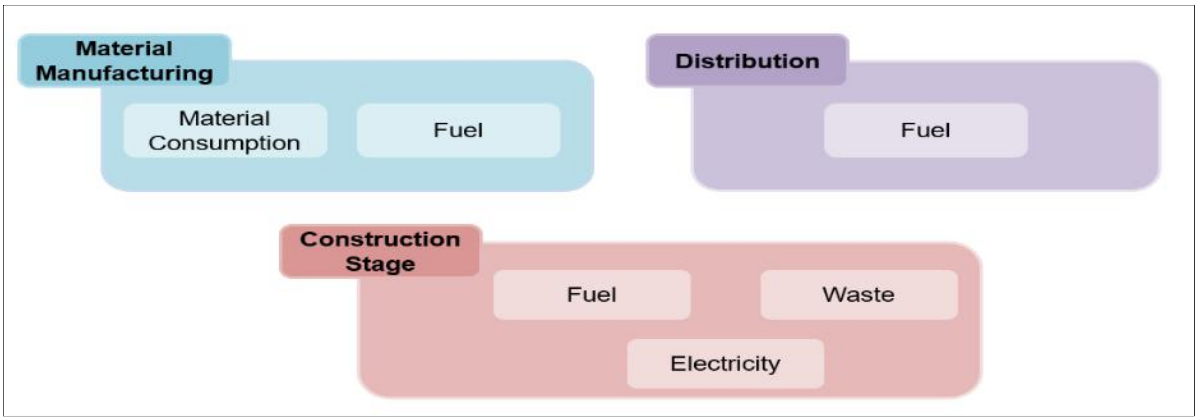


Figure 16: Activity data

3.2.1 Material consumption data

The major material consumption data from 2016 until 2019 were extracted from material demand, CIDB PROJEXIS[28] list and imported material list, ceramic tiles are not included under PROJEXIS, and as a result, the quantity of ceramic tiles was obtained from the import data published by DOSM. Only one (1) non-major construction material i.e. aggregate can be obtained from PROJEXIS. Due to insufficient information available, the other four (4) materials i.e. roofing tiles/sheet, steel and metal, timber and sanitary ware were chosen from the list of "Pengiraan Purata Keseluruhan Peratus Kos Bahan Binaan untuk Keseluruhan Kategori Bangunan untuk Menjadi Jumlah Keseluruhan adalah 100%" provided by the Business and International Division of CIDB Malaysia. (Section 2.2.3.2).

3.2.2 Distribution

The transport distance was estimated using Geographic Information System (GIS) software. For this Study, the distribution is only estimated for local manufacturing material, and imported material from the port to the construction site. The emission from the distribution of material from the origin country to Malaysia is excluded from the calculation.

3.2.2.1 Local Manufacturing Material

The average distance from manufacturers to construction site was calculated based on the distance from the manufacturer to the project central point identified based on the density of construction site (mostly are the main town of each district). The construction site is located and mapped based on the address extracted from the list of projects for the year 2016 obtained from CIDB. On the other hand, the location of the local manufacturer was determined based on *Direktori Pengeluar Bahan Binaan Tempatan 2016* published by CIDB Malaysia. The exercise was done for all the states in Malaysia. The example of the distance estimation for Kuala Lumpur is presented in Figure 17.

[28] Projection of Construction and Material Demand for Projects Awarded

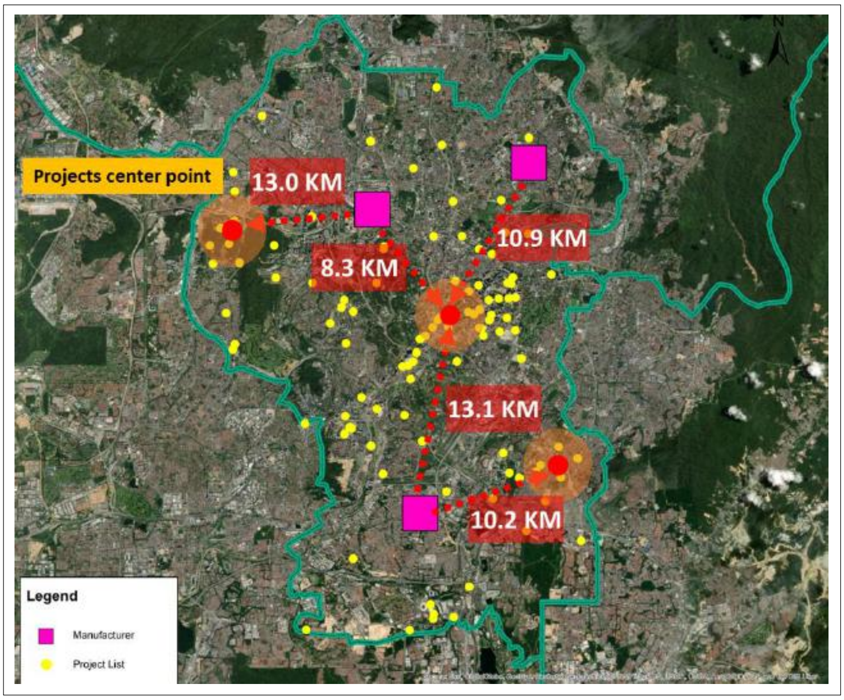


Figure 17: Average distance calculation for Kuala Lumpur project area

3.2.2.2 Imported Material

Similar to local manufacturing material, the average distance from the port[29] to the construction site was calculated based on the distance from the port to the main town of each district.

3.2.3 Construction Stage

3.2.3.1 Fuel

Construction activities also consume a significant amount of fuel at the construction site. The activities such as moving, flattening, excavating, elevating, compressing, and blending in construction sites.

In this Study, relevant data for the fuel consumption by the construction sector were extracted from National Energy Balance (NEB) published by Energy Commission. The data for NEB preparation are provided by energy suppliers and consumers in Malaysia consisting of Petroleum Refineries, Gas Processing Plant, and Electricity Power Producers, Independent Power Producer's (IPP), Energy Marketing companies, Primary Energy Production companies and Coal Mining/ Consuming Industries.

According to the Energy Commission, the main fuels used during the construction activities are diesel, Liquefied Petroleum Gases (LPG) and non-energy. Diesel used mainly for machinery or equipment. The excavating processes include both surface and deep excavation of soil and often involve the movement of excavated soil from one place to another. The machines used in this process are divided into two (2); excavators (such as face shovel, skimmer, dragline, crane and grab, pile driving and drilling and tractors (trench digger, scraper, bulldozer, grader, trenching machine, and mechanical auger) and mostly powered by diesel.

[29] http://www.smeinfo.com.my/export/ports-in-malaysia

The non-energy covers the use of products resulting from the transformation process for non-energy purpose i.e. bitumen and lubricants that are produced from oil refineries. It is generally found in natural reserves underground and is produced while refining crude petroleum. The basic and most primary usage of bitumen and lubricants is in the road construction industry.

Bitumen is a key component in road construction that sticky, viscous black and semisolid forms of petroleum. It is also actively used as a strong binder, glue, and sealant adhesive compound. Bitumen is composed of structured hydrocarbons and is effectively used as waterproofing products and roofing. The binder, i.e., bitumen, is mixed thoroughly with aggregates and additives to make asphalt that is used in road construction.

Naturally, bitumen is very thick and heavy requiring heating or dilution before it will flow. For the bitumen to be applied, it needs to be heated first and LPG is used to heat the bitumen. LPG which constitutes of propane and butane, is a flammable hydrocarbon fuel that is used to reheat and melt bitumen packed in drums. LPG bitumen melters can be fitted to installation such as coating plants or bitumen binder production plants. These melters can also be mounted on road trailers or semi-trailers for easy, fast transportation.

For this Study, data from NEB 2016 until 2017 were used which includes the final use of LPG, diesel, bitumen and lubricants. Data for the year 2018 until 2019 is yet to be published by Energy Commission. The data for 2018 is expected to be published in July 2020. The fuel consumption data available is in kilotonnes of oil equivalent (ktoe). Therefore, conversion to a common energy unit (terajoule, TJ) was done using conversion coefficients that are also available in the NEB report.

Under the NEB, the energy consumption data comprises seven (7) categories, i.e. residential, commercial, industrial, transport, agriculture, fishing and non-energy use. However, under the energy balance format, the industry category consists of a very broad-based sector ranging from manufacturing to mining and construction and the available data set was not segregated into a specific type of industry.

Based on NEB, no specific diesel and LPG consumption data for the construction industry in Malaysia. This data gap for fuel consumption has been highlighted and discussed during the Focus Group Discussion (FGD) on the 7th of January 2020. The representative from Energy Commission also acknowledged that this data is not available specifically for the construction sector.

Therefore, the total of diesel and LPG consumption by the construction industry was estimated using the GDP for the constructor sector. As mentioned previously, fuel consumption data for the years 2018 and 2019 are yet to be published. Therefore, estimation was done using the GDP annual growth rate published by the Economic Planning Unit (EPU) (2016). This projection data was also applied by the MESTECC for GHG emission projection assumptions in National Third National Communication and Biennial Update Report to the UNFCCC.

Besides, a survey was also conducted by sending the questionnaire and on-site visits to obtain the relevant AD such as fuel to verify with the assumption made above.

3.2.3.2 Electricity

In Malaysia, there are three (3) main power generator which are Tenaga Nasional Bhd (TNB) supplying electricity in Peninsular Malaysia, Sabah Electricity Sdn. Bhd. (SESB) in Sabah and Sarawak Energy Berhad in Sarawak. Apart from that, there are several IPPs that also supply power to the nation. The total energy generated in the year 2017 was 160,634 Gigawatt hours (GWh) with Peninsular Malaysia contributing 127,236 GWh (79.2%), while Sabah and Sarawak about 6,557 GWh (4.1%) and 26,841 GWh (16.7%) respectively.

The demand of the three (3) utilities amounted to 146,524 GWh, of which 53% was for the industrial consumers, 28% for commercial, 18% for domestic and 1% for others. The total number of customers for the three (3) utilities was 5.6 million with 84% from the domestic sector, 15% from commercial, 0.5% from industrial and the remaining 0.5% from other customers.

Data on electricity consumption (in GWh) from the year 2016 until 2019 were received from Billing and Customer Relationship Management (BCRM), TNB for Peninsular Malaysia and Jabatan Pengurusan Komersil, SESB for Sabah and Customer Retail, Sarawak Energy Berhad (SEB) for Sarawak.

In general, TNB and SESB electricity tariff classification was based on consumer business activity at the said premised and its supply voltage level. Summary of tariff classification as follows:

- Domestic
- Commercial
- Industrial
- Mining
- Street lighting
- Agriculture

While for SEB, the construction is classified under the "Commercial" category. The "Commercial tariff" is applicable to supply of energy to premises having commercial activities such as office block, shop houses, restaurant, school, hotel, boarding house, farms, estate, port, broadcasting and telecommunication installations, cinemas and entertainment locations, military and Government installation and hospital, and any supply used in the construction or building activities, but not for private dwellings and industrial premises.

Unlike TNB and SESB, SEB defined the "Industry" category as energy supply to premises used for industrial operation such as manufacturing, quarrying, mining, shipbuilding business, and to consumers who utilize energy for the purpose of pumping water, in which electric motors and plants are used in connection therewith. The total motor loads should be a minimum of 80% of the total wattage of all the installations.

Based on the above classification, there is no specific tariff or premises group under the "Construction" category under the respective utility system. For Peninsular Malaysia, a meeting was conducted with the key personnel of the Billing and Customer

Relationship Management (BCRM) system to discuss this data gap and possible data source of the electricity consumption by the construction industry in Peninsular Malaysia. It was suggested that the project team extract the consumption data (kWh) based on the "temporary supply" tagging in the BCRM system. However, the migration and upgrading process to the BCRM system took place in the year 2016. Therefore, the electricity consumption data only available from July 2016 onwards resulting in the total for the year 2016 significantly lower compared to other years.

In addition, the total electricity consumption for Sabah in the year 2017 also showed a significant reduction compared to other years. According to data provider, this happened due to the implementation of data cleansing for customers under the industry category. Previously, premises such as hotel, petrol station has been included in this category. Data cleansing was done to ensure the right type of business according to the right category.

According to the 2006 IPCC Guideline, all emissions estimates in a time series should be estimated consistently as using different methods and data in a time series could introduce bias. This means that as far as possible, the time series should be calculated using the same method and data sources in all years. Therefore, the recalculation of electricity consumption for Peninsular Malaysia in the year 2016 and Sabah in the year 2017 was done to maintain consistency. It is also a *good practice* to correct errors incomplete or missing data that happened due to changes and gaps in data availability.

The recalculation was done using linear interpolation by assuming a constant annual growth in electricity consumption from 2016-2019. This technique is appropriate for the overall trend analysis, and it is unlikely that actual data for 2016 (Peninsular Malaysia and 2017 (Sabah) are substantially different from the values predicted through interpolation.

For Sabah and Sarawak regions, the proportion by type of sector was applied to quantify the electricity consumption by construction. This was based on the available data set of segregation of GDP sourced from DOSM. Table 12 shows the assumption for proportions by type of economic activities for Sabah and Sarawak.

Table 12: Proportions of fuel by type of economic activities

Type	2016	2017	2018	2019[e]	2016	2017	2018	2019[e]
	RM million				Percentage [%]			
Sabah								
Agriculture	13,369.54	13,979.96	13,947.05	14,343.03	16%	15%	15%	15%
Mining and quarrying	21,992.32	25,440.57	24,024.17	25,850.87	26%	28%	26%	27%
Manufacturing	7,292.55	7,657.86	7,876.29	8,192.64	9%	8%	9%	9%
Construction	2,478.01	2,458.15	3,032.28	3,166.75	3%	3%	3%	3%
Services	38,419.20	40,501.58	42,876.27	45,056.09	46%	45%	47%	46%
Import duties	378.47	498.95	441.50	502.66	0.5%	0.6%	0.5%	0.5%
Total	83,930.08	90,537.07	92,197.55	97,112.04	100%	100%	100%	100%

Type	2016	2017	2018	2019[e]	2016	2017	2018	2019[e]
	RM million				Percentage [%]			
Sarawak								
Agriculture	16,631.88	16,687.23	16,461.54	16,423.21	13%	13%	12%	12%
Mining and quarrying	29,252.87	30,213.55	29,483.07	29,880.03	23%	23%	22%	22%
Manufacturing	33,566.58	34,811.03	35,579.07	36,664.71	27%	27%	27%	27%
Construction	3,633.39	4,354.59	4,403.48	4,544.16	3%	3%	3%	3%
Services	40,981.96	43,519.59	46,267.24	48,874.87	33%	33%	35%	36%
Import duties	446.27	520.21	470.17	502.78	0%	0.4%	0.4%	0.4%
Total	124,512.95	130,106.20	132,664.56	136,889.76	100%	100%	100%	100%

Note:
[e] GDP data for the year 2019 for Sabah and Sarawak was estimated using linear regression as the ratio of every economic activities or no significant different from the year 2016 until 2018 (DOS)

Besides, a survey was also conducted by sending the questionnaire and on-site visits to obtain the relevant AD such as electricity consumption data to verify with the assumption made above.

3.2.3.3 Waste

There are two (2) types of GHG emissions under waste which are emission from waste treatment (landfilling) and transportation of waste to landfill.

3.2.3.1.1. Waste Treatment (Landfilling)

There is a very limited information available on construction waste in Malaysia mainly because there is no official requirement for the construction waste generator to submit data to the authority. Most of the contractors surveyed found it is difficult to provide data on construction waste because there is no proper handling of the data. Due to the fact that no local construction waste data was properly captured by most of the players, the survey results were not sufficient for the estimation of total construction waste generation in Malaysia. As such, an alternative method of construction waste estimation is proposed to approximate the total construction waste for Malaysia. There is no standard methodology for the estimation of construction wastes in Malaysia, however, there is a sub-section in the "Malaysian Standard (MS 2673:2017) on Construction Solid Waste Management – Code of Practice" published by the Department of Standards Malaysia, that explains estimation of construction waste generated from construction materials used.

Construction waste generation can be estimated by using several different methodologies, subject to the availability of data required for such estimations. In this Study, the methodology identified to estimate the construction waste is based on the total quantity of construction materials consumed. The total quantity of the construction material consumed was obtained from CIDB, refer to Section 2.2.

For other types of waste such as paper, plastic, kitchen and garden waste, the estimation is based on the total number of construction site worker obtained from

Economic Census 2016 published by DOSM, multiply by the waste generation rate of 0.76[30] kg/cap/day for Malaysia, and the composition of different type of waste.

The GHG emission from the construction waste generation is calculated by using the quantity of construction material consumed and the quantity of other types of waste generated multiply by the average wastage published by Construction Research Institute of Malaysia (CREAM) and CIDB[31], and the emission factor published by The Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST). The formula to calculate the GHG emission is presented below:

Construction material consumption	=	Total amount of construction materials consumption (million tonne)	X	Average wastage of respective construction materials (%)	X	Emission factor for landfilling of waste
Paper, plastic and kitchen & garden waste	=	Total amount of paper, plastic and kitchen & garden waste (million tonne)	X	Average wastage of respective waste type (%)	X	Emission factor for landfilling of waste

3.2.3.1.2. Transportation

The average distance from the construction site to landfill is estimated using the location of the project central point to the landfill for all the states.

3.3 Emission Factors (EF)

3.3.1 Fuel

For fuel consumption, all the emission factors (EF) used were adopted wholly from the IPCC guidelines as local emission factors were not available. This was confirmed by a review/reference exercise carried out by going through some documentation provided for local conditions. The EF were used to convert activity data into GHG emissions in CO_2eq. Table 13 tabulated the EFs used in this Study.

Table 13: EF for stationary combustion[32]

Fuel Type	CO_2 ($kgCO_2$/TJ)	CH_4 ($kgCH_4$/TJ)	N_2O (kgN_2O/TJ)
Gas/Diesel Oil	74,100	3.0	0.6
Residual Fuel Oil	77,400	3.0	0.6
Coking Coal	94,600	1.0	1.5
Other Bituminous Coal	94,600	1.0	1.5
Sub-Bituminous Coal	96,100	1.0	1.5
Natural Gas	56,100	1.0	0.1
LPG	63,100	1.0	0.1
Naphtha	73,300	3.0	0.6
Bitumen	80,700	3.0	0.6

[30] https://jpspn.kpkt.gov.my/resources/index/user_1/Sumber_Rujukan/kajian/Final_Report_REVz.pdf
[31] https://www.researchgate.net/publication/316682486_PROFESSIONALS'_VIEWS_ON_MATERIAL_WASTAGE_LEVEL_AND_CAUSES_OF_CONSTRUCTION_WASTE_GENERATION_IN_MALAYSIA
[32] IPCC 2006 Vol. 2 Ch. 2, Table 2.2 and Table 2.6

Table 14: EF for mobile combustion

Fuel Type	CO_2[33] ($kgCO_2/TJ$)	CH_4[34] ($kgCH_4/TJ$)	N_2O[34] (kgN_2O/TJ)
Gasoline	69,300	25.0	8.0
Diesel	74,100	3.9	3.9

The following Table 15 includes the 100-year time horizon global warming potentials (GWP) relative to CO_2. This Table is adapted from the IPCC Fifth Assessment Report, 2014 (AR5).

Table 15: GWP of the selected GHGs under the Kyoto Protocol[35] covered under this Study

GHG	GWP* (IPCC AR4)	GWP* (IPCC AR5)
CO_2	1	1
CH_4	25	28
N_2O	298	265

Note:
* 100-year Time Horizon. Values from the IPCC Second Assessment Report (SAR (2001)) are valid during the first commitment period under the Kyoto Protocol. The first commitment period ends in 2012 and since no official decision has been made yet by the IPCC on what GWP values will be used, the latest values from IPCC AR4 will be used since their values are a more conservative estimate than the values from IPCC SAR.

3.3.2 Electricity

The grid EF was sourced from the Clean Development Mechanism (CDM) Electricity Baseline for Malaysia, published by Malaysian Green Technology Corporation (GreenTech Malaysia). A meeting with the Climate Change Division of MESTECC (now KASA) was conducted on the 11th of March 2020 to identify the suitable grid EF to be applied for this Study. MESTECC (now KASA) has no objection to applying CDM EF for the calculation, it is advised to clearly specify the source in the report. Also, the Energy Commission is in the midst of calculating the national grid EF based on the Grid System Operator (GSO) report. The EF only will be available by September 2020 (upon finalisation of BUR). Table 16 below shows the summary of grid EFs according to Peninsular Malaysia, Sabah and Sarawak.

Table 16: Grid EF ($tCO_2eq./MWh$) for the year 2016 and 2017

Regions	Electricity Baseline's EFs ($tCO_2eq./MWh$)	
	2016	2017
Peninsular Malaysia	0.667	0.585
Sabah	0.551	0.525
Sarawak	0.364	0.330

Due to the unavailability of grid emission factor from the year 2018 onwards, the grid EF applied in the calculation from the year 2018 to 2050 is using the grid EF for the year 2017.

[33] IPCC 2006 Vol. 2 Ch. 1, Table 1.4
[34] IPCC 2006 Vol. 2 Ch. 3, Table 3.2.2
[35] IPCC Technical Assessment Report

3.3.3 Waste

The EF for landfilling of waste is obtained from the MyCREST.

Table 17: EF (tCO_2/t) for construction waste

Waste Type	Emission Factor (tCO_2/t)
Wood	0.792
Glass	0.026
Metal	0.02
Paper	0.58
Plastic	0.034
Kitchen and Garden	0.213

3.4 Embodied Carbon

As this Study covers the GHG emissions of the construction material value chain (cradle-to-gate), therefore, the embodied carbon (EC) for each material used were accounted. Local EC was applied to locally manufacturing material (where applicable) while for the construction materials that were imported from other countries, EC derived from countries supplying the material were used (where applicable) or else the most suitable references were applied. The EC adopted and used in this Study are the average EC of the material in general (e.g. EC for paint is average EC for all type of paint). This limitation is due to the lack of the consumption data for specific type of materials.

What is EC?

EC is defined as the sum impact of all the GHG emissions attributed to the materials throughout their life cycle (extracting from the ground, manufacturing, construction, maintenance and end of life/disposal)[36]. EC can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical EC datasets used globally are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO_2eq. per kilogram of product or material[37].

3.5 Projection

3.5.1 General

This section presents an assessment of the Construction Industry's GHG emission projection. The assessment had been carried out concerning the business-as-usual (BAU) baseline projections from 2020 until 2050 that focus on historical activity data and development trends.

GHG emissions projections by using GDP as an economic driver have been reported in many previous studies. Kerdporn et al. (2013) evaluated the impact of technology on energy consumption in the intermediate steel industry in Thailand during 2011–2030. The previous data indicated the linear relationship between growth rates of the steel industry and the economic growth. The United States Agency for International Development (USAID) studied GHG emissions in Bangladesh by using GDP as an

[36] http://www.carbonleadershipforum.org/about/why-embodied-carbon/
[37] https://www.globalabc.org/uploads/media/default/0001/01/5214e617d8b555f132431aeddfc95e3907d41b2d.pdf

economic driver. The results showed that the growth rates of Bangladesh's GDP over 1990–2012 were proportional to the rates of GHG emissions (USAID 2016).

The government of Canada reported Canada's GHG emissions projections from 2016 to 2030. This report provided a reference case of Canada's GHG emissions through 2030 by using GDP as an economic driver. The result showed that GDP growth had a direct and significant impact on GHG emissions (Government of Canada 2017).

The construction industry is one of the crucial pillars of the Malaysian economy. The construction industry contributes about 3% of Malaysia's GDP in recent years. Thus, this Study used GDP as an economic driver for the projection of construction materials, electricity consumption, fuel consumption and GHG emission in the future. The assumptions and data collection approaches are elaborated below.

The EF were based on the recommended EF of IPCC Guidelines and locally available sources; EC were based on the locally available sources as well as other country's references where applicable.

3.5.2 Assumption and Approach

Secondary data on activities and consumption patterns associated with GHG emissions for the past few years were collected. The main thrust of the data collection effort is not so much on collecting primary data but on collating secondary data and establishing a consistent data set suitable for analysis within the selected framework. In the case of data gaps, local data was supplemented with judiciously selected data from other countries.

The emissions projection was estimated according to the established guidelines and aggregated as shown in Figure 18.

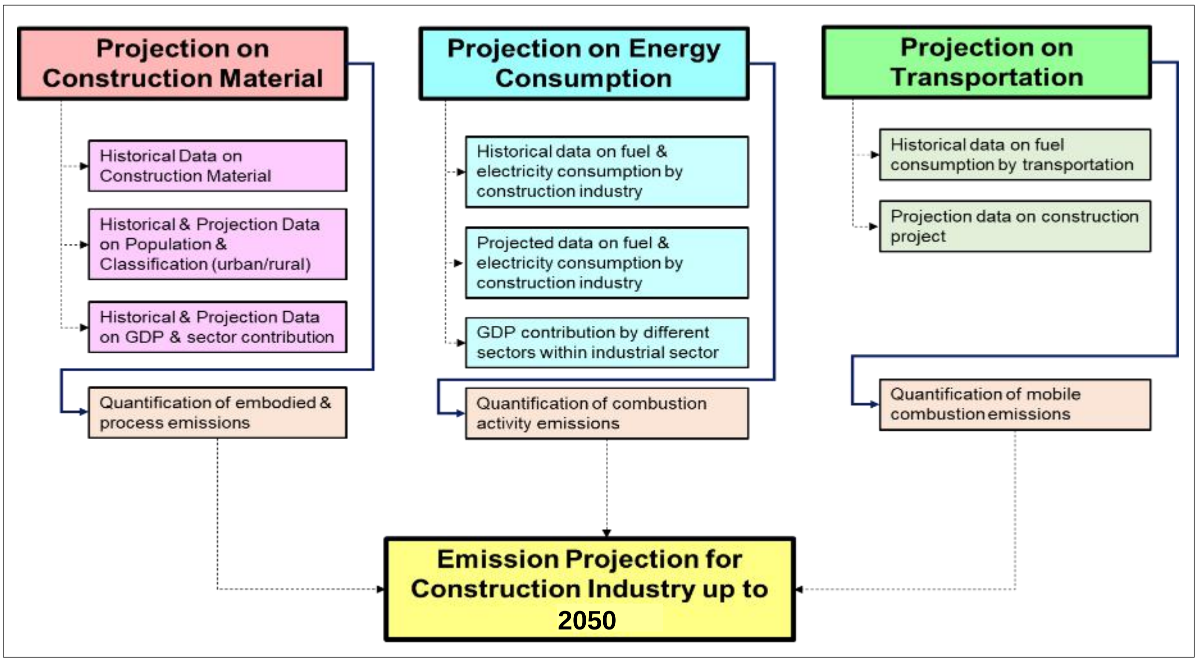


Figure 18: Schematic of the analytical framework for the emissions projection

The socio-economic profile of any country forms the basis of its development trajectory and has an important bearing not only on the level of emissions associated with its development, but also on the choices available to the country and various user groups in the economy. Socio-economic parameters such as GDP are the most relevant driving forces influencing patterns of growth, lifestyles, production and consumption choices and consequently the related environmental implications.

The per capita income for Malaysia was considered in this Study using GDP at purchaser's price. The rapid increase in per capita income is likely to have implications on future demands, energy use, consumption patterns and consequently on the level of emissions.

The continuous increase in end-use energy consumption in Malaysia could be possible attributed to the economy. The healthy growth in the industrial sector results in a healthy increase in GDP, which consequently also affects the demand over energy supply and consumption. On the demand side, the sectors that consume energy can broadly be classified as residential, commercial, industrial, transport, agriculture and non-energy use. The share of each of the sectors in total energy consumption has remained largely unchanged over the past three (3) decades. Industrial and transport sectors are the major end-use consumption sectors accounting for more than 80% of the total energy use.

The relationship was established through the appropriate statistical analysis using the quantity of produced construction materials compared against historical data of the Malaysian population, income per capita and GDP. The emissions for 2020-2050 were estimated by extrapolation based on expected materials, electricity and fuel consumption within the construction industry. Besides, information on the sector-wise GDP was analysed to identify the construction industry's GDP contribution.

Figure 19 below shows the correlation between GDP and GDP by the construction sector which it has a positive high correlation (0.96). This association indicates as the GDP increases, the GDP by Construction Sector increases too.

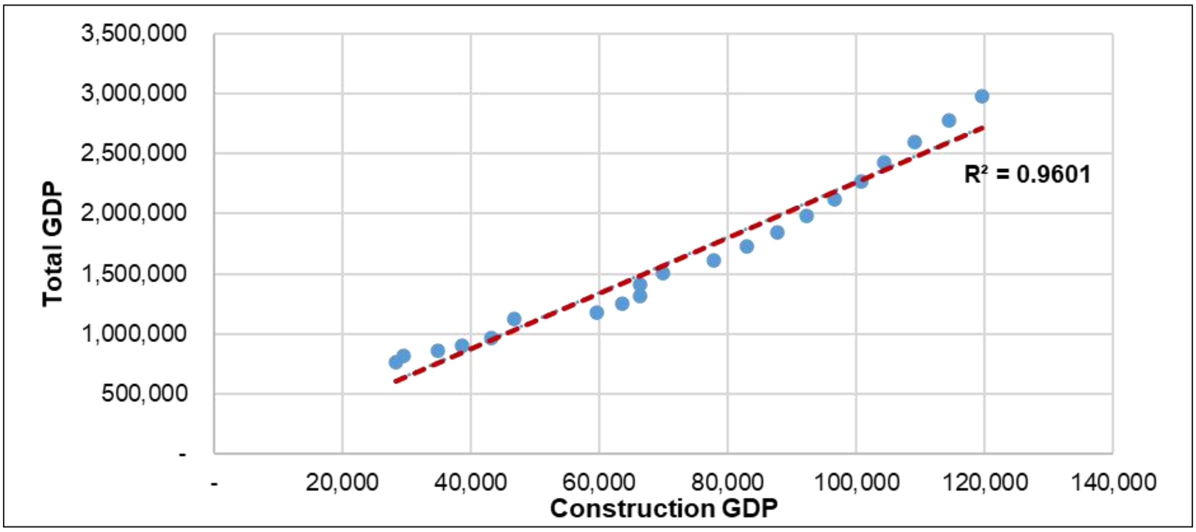


Figure 19: Correlation between total GDP and GDP by construction industry

Also, Figure 20 shows the relationship between the quantity of construction materials and GDP of Malaysia for the year 2016 to 2019. All construction materials show high positive correlation across the years. The graph indicated the linear relationship with the coefficient of determination (R2) of 0.81 to 0.99. A positive correlation indicates that as the GDP increases one unit, the quantity of material is possible to increase too. Therefore, GDP was selected as an economic driver for the projection of ceramic tableware production in the future.

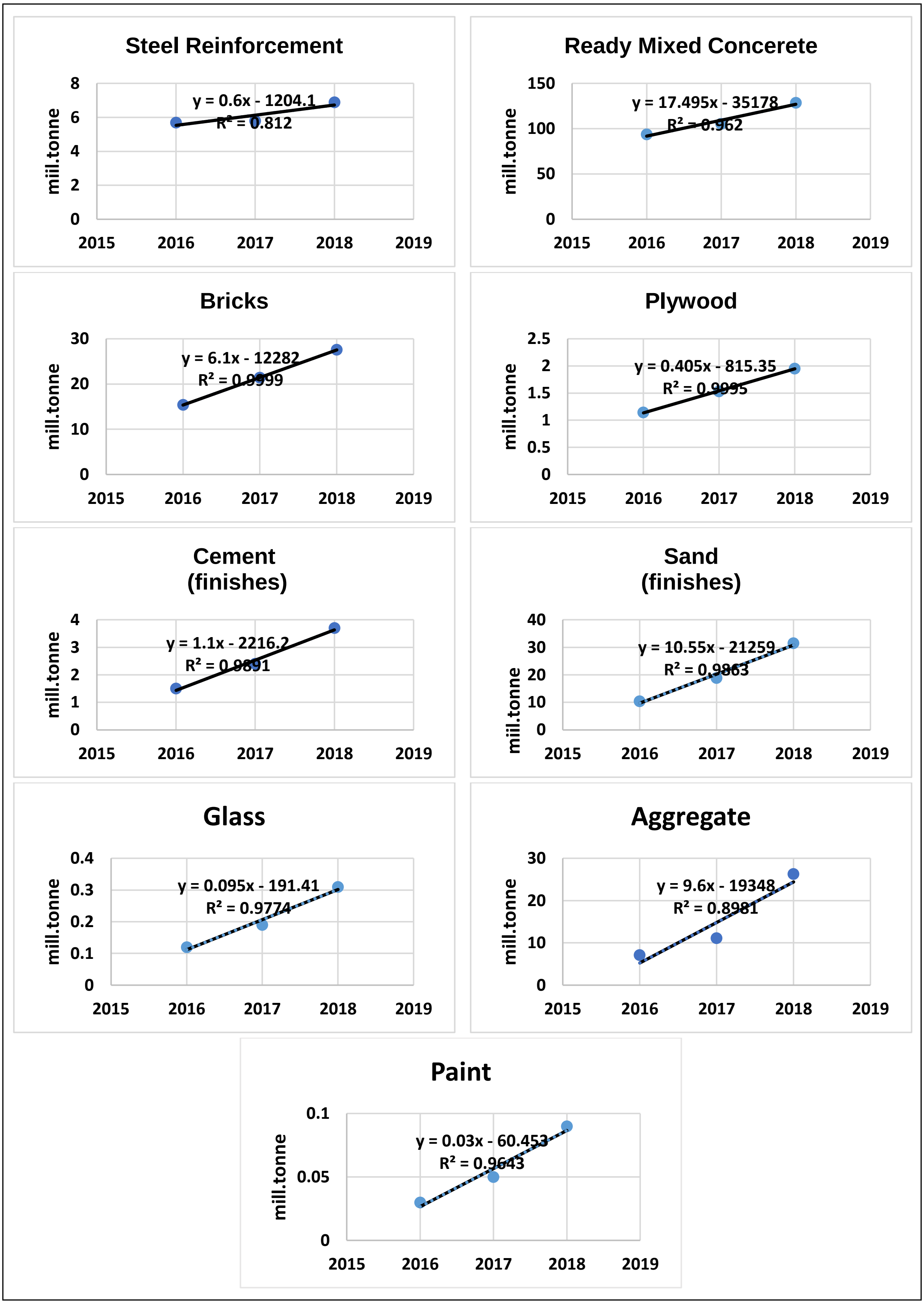


Figure 20: Linear relationship between the construction materials and GDPs during the year 2016-2019

One of the main drivers of the modelling assumption is GDP growth rates. The GDP growth rates assumption forecast was based on IHS2[38] data from a study conducted by the EPU) of Malaysia (IHS Energy Insight, 2016[39]). However, the GDP growth rates only available until 2040. Thus, linear extrapolation was done for the GDP growth rates from 2041-2050. Table 18 shows the assumptions of GDP growth rates by sector.

Table 18: GDP growth assumptions by sector to 2050 (% per year)

Annual Growth Rate (%)	2016 - 2020	2020	2021	2022 - 2025	2026 - 2030	2031- 2035	2036- 2040	2041- 2045	2046- 2050
Agriculture	2.16			2.26	2.09	1.91	1.74	1.57	1.23
Mining & Quarrying	0.01			1.01	3.03	3.74	5.17	6.60	9.46
Manufacturing	3.55			3.16	2.77	2.47	2.30	2.13	1.79
Construction	3.44	2.69	1.94	3.01	2.54	2.26	2.09	1.92	1.58
Services	4.41			4.42	3.67	3.07	2.67	2.27	1.47
Total GDP	3.88			3.77	3.19	2.74	2.43	2.12	1.50

Note: 2016 - 2040 are projected values; 2041 – 2050 was estimated using extrapolation analysis, Economic Planning Unit, (IHS Report, 19 October 2016)

Linear extrapolation provides a good result when a point to be predicted is not too far from the given data. The two (2) endpoints of a linear graph (x_1, y_1) and (x_2, y_2) are considered where the value of the point 'x' is to be extrapolated, the extrapolation formula is as follows:

$$y(x) = y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1)$$

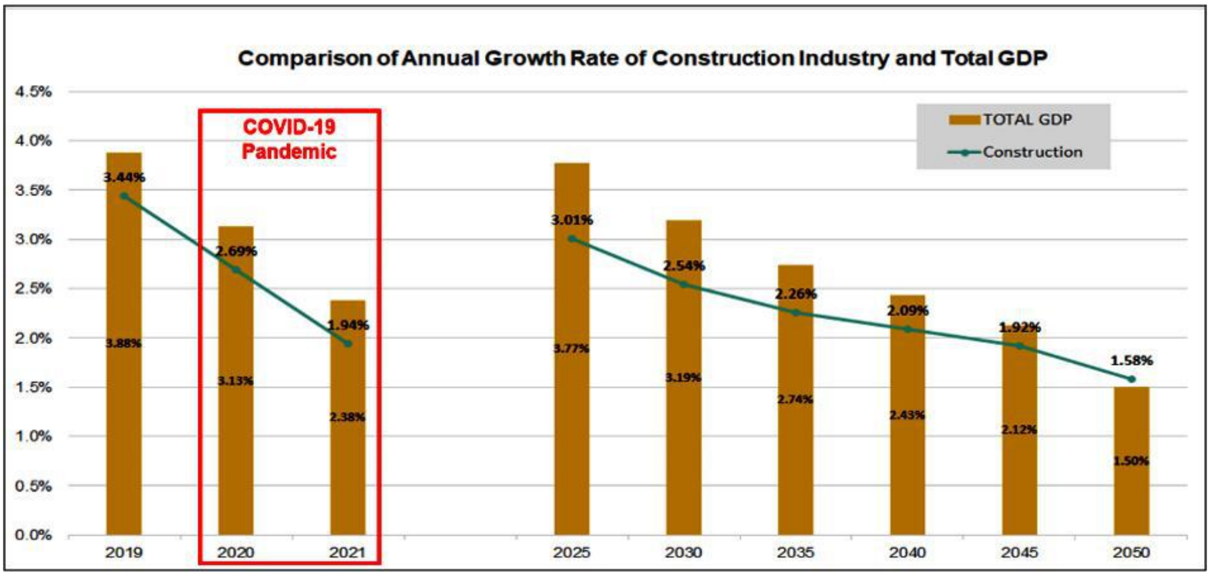


Figure 21: Comparison of annual growth rate of construction industry and total GDP

Based on Table 18, it can be observed that the growth rate for the GDP of the construction sector decreased by every five (5) years from the year 2016 until 2050. The trend is in-line with the decreased annual growth rate of the Malaysian population as shown in *Table 19* below. In addition, Figure 22 shows the relationship between

[38] IHS Markit Ltd is a London-based global information provider that was formed in 2016 when IHS Inc. and Markit Ltd. merged.

[39] A Study to Formulate an Energy Policy for Malaysia (2013– 2050), Putrajaya: EPU.

the total population and GDP of the construction sector with a high positive correlation until the year 2050. The graph indicated the linear relationship with the coefficient of determination (R2) of 0.94. This association indicates as the growth rate for population decrease; the growth rate for GDP also will decrease, which directly impact the material consumptions, fuel and electricity consumption.

Based on the projection of the population starting 2040 onwards, the assumption is based on the information by the DOSM which stated that the average population growth rate decreases by 0.05% per year.

Table 19: Projected Malaysia population until 2050[40]

Year	2020	2025	2030	2035	2040	2045	2050
Malaysia	33,782.40	36,022.70	38,062.20	39,879.30	41,503.10	41,606.96	41,711.08
Population Annual Growth Rate	1.36%	1.22%	1.03%	0.87%	0.75%	0.50%	0.25%

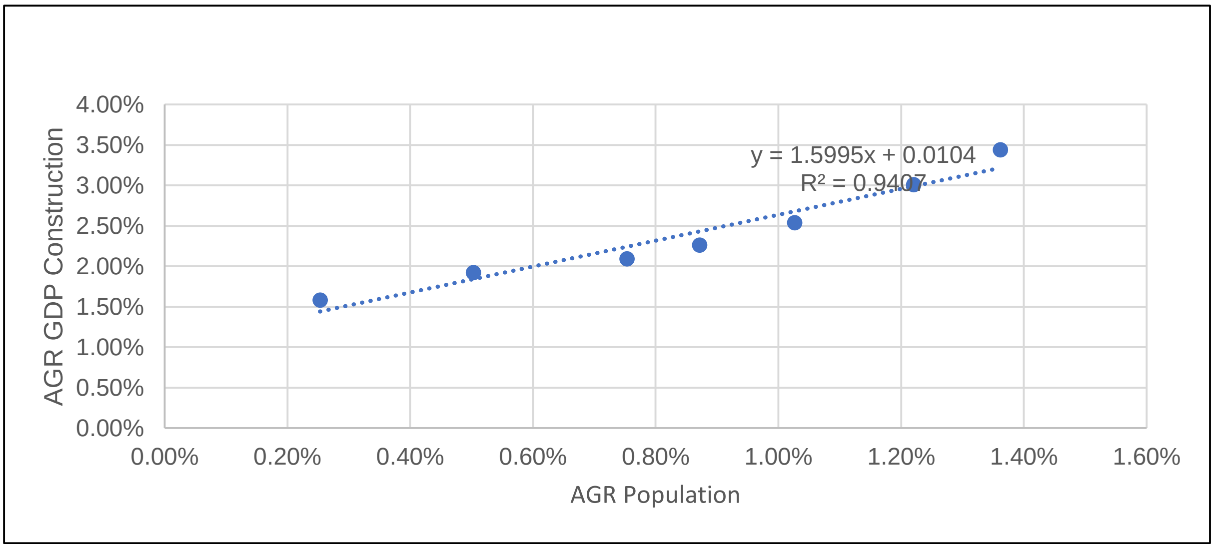


Figure 22: Correlation between GDP for construction sector and population

However, Malaysia's GDP is projected to be between -2.0% and +0.5% in 2020, due to the COVID-19 crisis by Bank Negara Malaysia. World Bank estimated that Malaysia is likely to recover in the fourth quarter (Q4) of the year before bouncing back into smoother momentum in the year 2021. Therefore, under this Study, the average projected figure (between -2.0% and +0.5% which is -0.75%) by the Bank Negara was applied for the year 2020-2021. For the year 2022 – 2050, the projected material consumptions, electricity and fuel consumption are using the annual growth rate of GDP.

[40] DOSM

4.0 GHG EMISSIONS FOR CONSTRUCTION INDUSTRY VALUE CHAIN

This Study focused on the GHGs which are converted into carbon dioxide equivalent ($tCO_2eq.$) as covered by the Kyoto Protocol. GHGs covered in this Study include the following three (3) types of gases, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which have been found to have a direct impact on global warming (United Nations, 1997).

As mentioned in Section1.3, the cradle-to-site GHG emissions can be categorised into three (3) groups as tabulated below:

Table 20: GHG emissions contribution from construction industry

GHG Emission Aspects	Main Sources of GHG Emissions
Embodied Carbon in Material Demand for construction materials such as cement, concrete, steel reinforcement, etc.	This material consumes energy and produces GHG during the extraction and manufacturing process which is commonly referred to as **EC** (cradle-to-gate)
Transportation of Material Distribution of construction material to the construction site	The transportation of construction material to the site consumes **fossil fuel** such as diesel. GHG emissions from transportation of material included GHG emissions from the production, processing and delivery of fuel (Well-to-Tank[41]) and fuel combustion
Emissions at Construction Site Use of equipment and machinery during construction, maintenance and renovation as well as waste generated from the construction site	Construction stage utilises various machinery and equipment which consume **fossil fuel and/or electricity**. GHG is also emitted from the degradable **waste** disposed. GHG emission from utilisation of fossil fuel from machinery and equipment included GHG emission from production, processing, and delivery of fuel and fuel combustion

[41] A Well-to-Tank emissions factor, known as upstream or indirect emissions, is an average of all the GHG emissions released into the atmosphere from the production, processing and delivery of a fuel or energy vector (https://www.lowcvp.org.uk/Hubs/leb/TestingandAccreditation/WTTFactors.htm).

4.1 GHG Emissions from Construction Materials Used in Malaysia's Construction Industry (EC Cradle-to-Gate) (Year 2016 to 2019)

The EC of the identified construction materials were compiled for the calculation of GHG emissions. Globally, there are various studies on the EC of construction materials. Some of the major life cycle GHG inventories are compiled and tabulated in Table 21.

Table 21: Major life cycle GHG inventories around the world

Region	Name of Database	System Boundary
United Kingdom (UK)	Inventory of Carbon and Energy (ICE)	Cradle-to-Gate
Europe	European reference Life Cycle Database (ELCD)	Cradle-to-Gate
China	Chinese reference Life Cycle Database (CLCD)	Cradle-to-Gate
Switzerland	Ecoinvent	Gate-to-Gate
Japan	Carbon Footprint of Product (CFP) Database	Cradle-to-Gate
Hong Kong	Embodied Carbon of Construction Material (ECO-CM)	Cradle-to-Gate Cradle-to-Site
Malaysia	Malaysia Life Cycle Inventory Database (MY-LCID) SIRIM	Cradle-to-Gate

Most of the inventories required payment to access the database. The accessible and available of the EC inventories from different sources are compiled and tabulated below in Table 22.

Table 22: EC compilation from different inventories (cradle-to-gate)

Construction Material	EC ($tCO_2eq./t$)				EC Foshan Case (kg/m^2)
	ECO-CM Hong Kong (2013)[42]	ICE UK V3.0 (Nov 2019)	CHINA (2019)[43]	Malaysia SIRIM (2013 – 2018)	
Steel Reinforcement	1.900	1.99	2.617		
Ready Mixed Concrete		0.209	0.134		
Plywood	1.932	0.681			
Bricks	0.265	0.213	0.219		
Paint		2.91			
Sand		0.0051	0.0028		

[42] http://cejcheng.people.ust.hk/ec/carbonInventoryLocalized.html.
[43] http://www.tanpaifang.com/tanjiliang/2019/0430/63792.html

Construction Material	EC ($tCO_2eq./t$)				EC Foshan Case (kg/m^2)
	ECO-CM Hong Kong (2013)[42]	ICE UK V3.0 (Nov 2019)	CHINA (2019)[43]	Malaysia SIRIM (2013 – 2018)	
Glass	1.095	1.44	1.072		
Cement	0.906	0.912	0.741	1.0257	
Aggregates		0.00493	0.00243		
Ceramic Tiles	1.270	0.78			16.42
Roofing Tiles/Sheet		3.045			
Steel and Metal	1.988	1.55			
Timber (Hardwood)		0.306			
Sanitary Ware		1.61			

Note: From the roof specifications obtained from CIDB, the most common roof material that is used in the construction industry are the steel roof, which is lighter and flexible than the concrete or clay roof. The average EC obtained from ICE which is steel, electrogalvanized steel for roofing applications (3.03 $tCO_2eq./t$) and steel, organic coated sheet for the roof (3.06 $tCO_2eq./t$) was applied in the calculation.

The request of EC from MY-LCID SIRIM for cement was obtained on the 13th of March 2020. SIRIM provided the EC for CEM I 32.5 and CEM I 42.5 which is tabulated as below:

Table 23: EC for cement extracted from MY-LCID SIRIM

Type of Cement	EC ($tCO_2eq./t$)
CEM I 32.5	1.0175
CEM I 42.5	1.0339
Average	**1.0257**

The EC was compared with ECO-CM Hong Kong and ICE UK V3.0, it was found that the EC of MY-LCID SIRIM (1.0257$tCO_2eq./t$), ECO-CM Hong Kong (0.906$tCO_2eq./t$) and ICE UK V3.0 (0.912$tCO_2eq./t$) respectively differ approximately 12%. The differences might due to the different technology applied in the manufacturing processes and the EF applied in the calculation.

Locally available EC was applied to locally manufacturing material while for the construction materials that were imported from other countries, EC derived from countries supplying the material are considered or else other country references will be considered. The selected EC to be applied in this Study is tabulated in Table 24.

Table 24: Selected EC for calculation (cradle-to-gate)

Construction Material	EC Applied	Unit	Reference
Steel Reinforcement	1.9	$tCO_2eq./t$	ECO-CM Hong Kong 2013
Ready Mixed Concrete	0.209	$tCO_2eq./t$	ICE (Nov 2019)
Plywood	1.932	$tCO_2eq./t$	ECO-CM Hong Kong 2013
Bricks	0.265	$tCO_2eq./t$	ECO-CM Hong Kong 2013
Paint	2.91	$tCO_2eq./t$	ICE (Nov 2019)
Sand	0.0051	$tCO_2eq./t$	ICE (Nov 2019)
Glass	1.095	$tCO_2eq./t$	ECO-CM Hong Kong 2013
Cement	1.0257	$tCO_2eq./t$	MY-LCID SIRIM Malaysia
Aggregates	0.00493	$tCO_2eq./t$	ICE (Nov 2019)
Roofing Tiles/Sheet	3.045	$tCO_2eq./t$	ICE (Nov 2019)
Steel & Metal	1.988	$tCO_2eq./t$	ECO-CM Hong Kong 2013
Timber (Hardwood)	0.306	$tCO_2eq./t$	ICE (Nov 2019)
Sanitary Ware	1.61	$tCO_2eq./t$	ICE (Nov 2019)
Ceramic Tiles	16.42	kg/m^2	Foshan Case China

The GHG emissions from the fourteen (14) construction materials are calculated by multiplying the quantity of the materials used with EC and the results are tabulated in Table 25 and illustrated in Figure 23.

Table 25: GHG emissions from construction materials used in Malaysia's construction industry (EC cradle-to-gate) (year 2016 to 2019)

No.	Construction Material	GHG Emissions (million $tCO_2eq.$)			
		2016	2017	2018	2019
1	Ready Mixed Concrete	19.62	33.86	34.81	29.74
2	Steel Reinforcement	10.83	16.91	16.72	13.49
3	Bricks	4.07	4.53	5.46	7.51
4	Cement (finishes)	1.54	2.46	4.72	6.67
5	Steel & Metal	5.13	5.03	4.02	3.45
6	Plywood	2.20	2.63	2.97	2.79
7	Roofing Tiles/Sheet	0.91	0.88	1.00	0.81
8	Timber (Hardwood)	0.44	0.42	0.82	0.66
9	Ceramic Tiles	0.37	0.60	0.55	0.51
10	Glass	0.13	0.12	0.20	0.34
11	Paint	0.09	0.10	0.22	0.34
12	Aggregate	0.04	0.14	0.16	0.22
13	Sand (finishes)	0.05	0.07	0.12	0.20
14	Sanitary Ware	0.19	0.18	0.05	0.04
	Total (million $tCO_2eq.$)	**45.63**	**67.93**	**71.82**	**66.76**

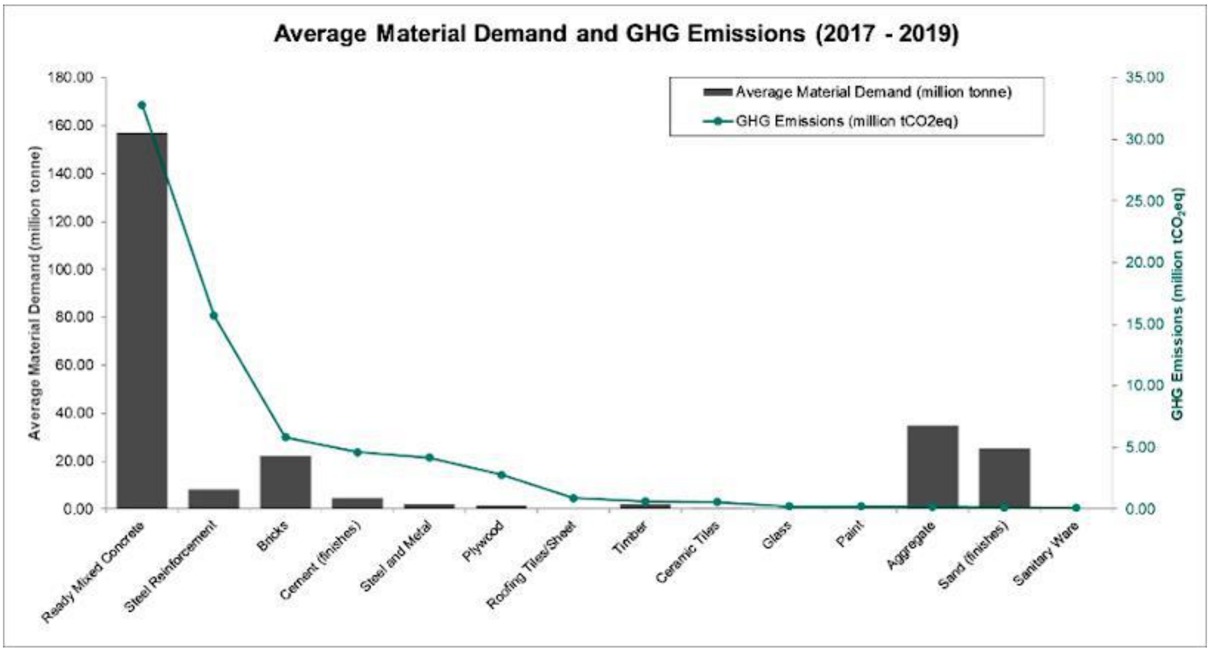


Figure 23: Average GHG emissions from construction materials used in Malaysia's construction industry (EC cradle-to-gate) (year 2017 - 2019)

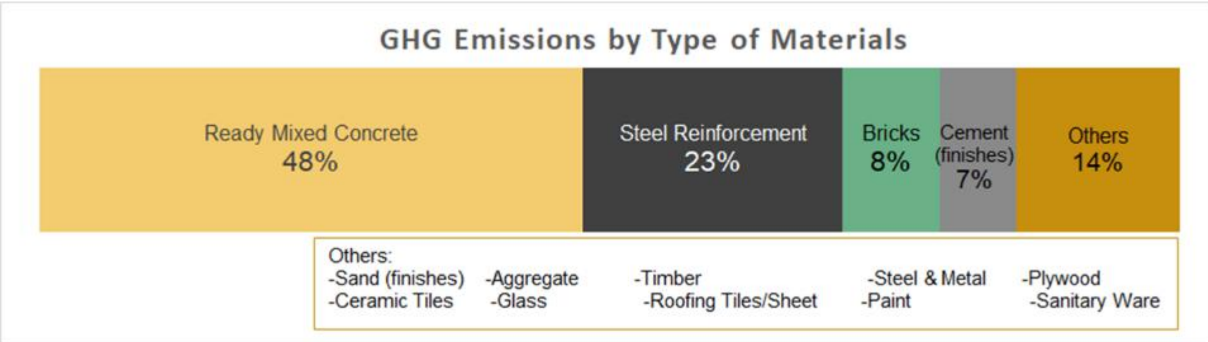


Figure 24: GHG emissions by type of materials

It can be observed that the quantity of GHG emitted from the use of ready mixed concrete (48%) is the highest compared to other types of construction material. followed by steel reinforcement (23%), bricks (8%) and cement (7%).

4.2 GHG Emissions from Transport of Construction Materials to Construction Site

The GHG emissions from the transport of construction materials to the construction site depends on the haul distance and mode of transport.

4.2.1 Average Distance

The average distance from a local manufacturer to construction site was estimated for all the states throughout Malaysia and tabulated in Table 26.

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Table 26: Average distance from local manufacturer to construction site

State	Average Distance (km)
Johor	101.5
Kedah	61.0
Kelantan	61.7
Melaka	22.7
N. Sembilan	47.9
Pahang	143.5
Penang	24.7
Perak	93.3
Perlis	14.8
Sabah	173.8
Sarawak	201.4
Selangor	48.3
Terengganu	64.4
Kuala Lumpur	11.5
Average	**76.5**

For the imported material, only the transport distance from the port to major cities is accounted in the calculation. Any transportation distance from the origin country to Malaysia is excluded from the calculation. The average distance from port to major cities is estimated for all the states and tabulated in Table 27.

Table 27: Average distance from port to major cities

Port	Major Cities	Average Distance (km)
Johor Port	Johor Bahru	30.7
	Segamat	194.0
	Kluang	124.0
	Mersing	138.0
Tanjung Pelepas Port, Johor	Johor Bahru	33.8
	Batu Pahat	116.0
	Muar	174.0
Tanjung Bruas Port, Melaka	Bandar Melaka	15.0
Port Dickson	Seremban	31.5
Kuantan Port	Kuantan	39.7
Lumut Port	Ipoh	82.1
Port Klang	Klang	8.2
	W.P Kuala Lumpur	45.6

Port	Major Cities	Average Distance (km)
	Putrajaya	53.0
Kertih Port	Kuala Terengganu	129.0
Kemaman Port	Kuala Terengganu	169.0
Langkawi Port	Langkawi	14.7
Penang Port	Georgetown	29.2
Kuala Perlis Port	Kangar	11.7
Sabah Port	Kota Kinabalu	21.0
Sandakan Port	Sandakan	6.6
Tawau Port	Tawau	4.4
Kuching Port	Kuching	4.7
	Kota Samarahan	22.9
	Serian	58.1
	Sri Aman	190.0
Rajang Port, Sibu	Sibu	2.6
	Sarikei	63.4
	Betong	163.0
	Kanowit	54.6
Miri Port	Miri	26.6
Bintulu Port	Bintulu	14.1
	Mukah	155.0
Samalaju Port, Bintulu	Bintulu	78.5
Average		**67.8**

The average distance calculated from this exercise is comparable with the result obtained from the survey. The average distance calculated from the survey is 74.1km.

4.2.2 Transport Capacity and Fuel Consumption

The capacity of the truck to transport the construction material from manufacturer to construction site range from fifteen (15) to thirty-six (36) tonnes depending to the different type of construction material transported. For calculation purposes, an assumption was made by using the maximum load of the truck capacity. The fuel consumption for a different type of truck was obtained for calculation. The maximum load of the truck capacity and fuel consumption for a different type of construction material is tabulated as below:

Table 28: Maximum capacity of truck (tonne) and fuel consumption (liter/km)

Construction Material	Fuel Consumption (liter/km)[44]	Maximum Load Capacity (tonne)
Steel Reinforcement	0.410	36
Ready Mixed Concrete	0.410	20
Bricks	0.410	20
Paint	0.174	15
Plywood	0.174	15
Cement (finishes)	0.410	20
Sand (finishes)	0.174	15
Glass	0.174	15
Aggregate	0.174	15
Roofing Tiles/Sheet	0.410	20
Steel & Metal	0.410	36
Timber	0.410	36
Sanitary Ware	0.174	15
Ceramic Tiles	0.174	15

Note:
1. Fuel consumption for maximum load capacity > 15 tonne is 0.410 liter/km.
2. Fuel consumption for maximum load capacity < 15 tonne is 0.174 liter/km.

4.2.3 Density, Calorific Value, and Emission Factor

The default value applied in the calculation is tabulated as below:

Table 29: Default value applied in calculation

Type of Default Value	Default Value	Unit
Diesel Density	0.8538[45]	Kg/l
Diesel Calorific Value	43[46]	GJ/t diesel
Diesel EF	0.0741[47]	tCO_2/GJ
CO_2 emissions from diesel production	0.23991[48]	$kgCO_2$/kg diesel
CH_4 emissions from diesel production	0.00555651[48]	$kgCH_4$/kg diesel
N_2O emissions from diesel production	0.00000391735[48]	kgN_2O/kg diesel
GHG emissions from Lubricant (well to tank)[49]	0.0196	$kgCO_2e/TJ$
GHG emissions from LPG (well to tank)	0.3693[50]	tCO_2e/t
GHG emissions from Bitumen (cradle to gate)	0.326[51]	tCO_2e/t

[44] https://en.wikipedia.org/wiki/Fuel_efficiency#cite_note-10
[45] https://iopscience.iop.org/article/10.1088/1757-899X/257/1/012036/pdf
[46] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
[47] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf
[48] SIRIM MY-LCID
[49] Department for Business, Energy and Industrial Strategy from UK, 2019 Government GHG Conversion Factors for Company Reporting - Methodology Paper for EF
[50] https://www.lowcvp.org.uk/Hubs/leb/TestingandAccreditation/WTTFactors.htm
[51] ICE Nov 2019 (Polymer modified bitumen (PMB))

The CO_2 emissions from transportation are calculated as below:

Diesel Production

Table 30: GHG emissions from transportation from Diesel Production (year 2016 to 2019)

Construction Material	2016						2017					
	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)
Steel Reinforcement	0.0000086	0.0085	0.23991	0.00555651	0.00000391735	0.00336	0.0000134	0.0132	0.23991	0.00555651	0.00000391735	0.00525
Ready Mixed Concrete	0.0002539	0.2514	0.23991	0.00555651	0.00000391735	0.09970	0.0004382	0.4338	0.23991	0.00555651	0.00000391735	0.17203
Bricks	0.0000416	0.0411	0.23991	0.00555651	0.00000391735	0.01632	0.0000463	0.0458	0.23991	0.00555651	0.00000391735	0.01817
Paint	0.0000000	0.0000	0.23991	0.00555651	0.00000391735	0.00002	0.0000001	0.0001	0.23991	0.00555651	0.00000391735	0.00002
Plywood	0.0000017	0.0017	0.23991	0.00555651	0.00000391735	0.00069	0.0000021	0.0021	0.23991	0.00555651	0.00000391735	0.00082
Cement (finishes)	0.0000041	0.0040	0.23991	0.00555651	0.00000391735	0.00159	0.0000065	0.0064	0.23991	0.00555651	0.00000391735	0.00255
Sand (finishes)	0.0000159	0.0158	0.23991	0.00555651	0.00000391735	0.00625	0.0000214	0.0212	0.23991	0.00555651	0.00000391735	0.00841
Glass	0.0000002	0.0002	0.23991	0.00555651	0.00000391735	0.00007	0.0000002	0.0002	0.23991	0.00555651	0.00000391735	0.00007
Aggregate	0.0000109	0.0108	0.23991	0.00555651	0.00000391735	0.00427	0.0000425	0.0421	0.23991	0.00555651	0.00000391735	0.01670
Roofing Tiles/Sheet	0.0000008	0.0008	0.23991	0.00555651	0.00000391735	0.00032	0.0000008	0.0008	0.23991	0.00555651	0.00000391735	0.00031
Steel & Metal	0.0000039	0.0038	0.23991	0.00555651	0.00000391735	0.00152	0.0000038	0.0038	0.23991	0.00555651	0.00000391735	0.00149
Timber	0.0000021	0.0021	0.23991	0.00555651	0.00000391735	0.00084	0.0000021	0.0021	0.23991	0.00555651	0.00000391735	0.00081
Sanitary Ware	0.0000002	0.0002	0.23991	0.00555651	0.00000391735	0.00007	0.0000002	0.0002	0.23991	0.00555651	0.00000391735	0.00007
Ceramic Tiles	0.0000005	0.0005	0.23991	0.00555651	0.00000391735	0.00018	0.0000007	0.0007	0.23991	0.00555651	0.00000391735	0.00029
Total Emission from CO_2, CH4 and N_2O (million tCO_2eq)						0.14						0.23

Construction Material	2018						2019					
	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)
Steel Reinforcement	0.00001322	0.01309	0.23991	0.00555651	0.00000391735	0.00519	0.00001067	0.01056	0.23991	0.00555651	0.00000391735	0.00419
Ready Mixed Concrete	0.00045050	0.44604	0.23991	0.00555651	0.00000391735	0.17687	0.00038494	0.38112	0.23991	0.00555651	0.00000391735	0.15113
Bricks	0.00005570	0.05514	0.23991	0.00555651	0.00000391735	0.02187	0.00007669	0.07593	0.23991	0.00555651	0.00000391735	0.03011
Paint	0.00000012	0.00012	0.23991	0.00555651	0.00000391735	0.00005	0.00000018	0.00018	0.23991	0.00555651	0.00000391735	0.00007
Plywood	0.00000235	0.00233	0.23991	0.00555651	0.00000391735	0.00092	0.00000221	0.00219	0.23991	0.00555651	0.00000391735	0.00087
Cement (finishes)	0.00001244	0.01232	0.23991	0.00555651	0.00000391735	0.00488	0.00001758	0.01741	0.23991	0.00555651	0.00000391735	0.00690
Sand (finishes)	0.00003505	0.03470	0.23991	0.00555651	0.00000391735	0.01376	0.00005877	0.05819	0.23991	0.00555651	0.00000391735	0.02307
Glass	0.00000028	0.00028	0.23991	0.00555651	0.00000391735	0.00011	0.00000048	0.00048	0.23991	0.00555651	0.00000391735	0.00019
Aggregate	0.00005096	0.05046	0.23991	0.00555651	0.00000391735	0.02001	0.00006719	0.06652	0.23991	0.00555651	0.00000391735	0.02638
Roofing Tiles/Sheet	0.00000089	0.00088	0.23991	0.00555651	0.00000391735	0.00035	0.00000072	0.00071	0.23991	0.00555651	0.00000391735	0.00028
Steel & Metal	0.00000304	0.00301	0.23991	0.00555651	0.00000391735	0.00119	0.00000261	0.00258	0.23991	0.00555651	0.00000391735	0.00102
Timber	0.00000401	0.00397	0.23991	0.00555651	0.00000391735	0.00158	0.00000326	0.00323	0.23991	0.00555651	0.00000391735	0.00128
Sanitary Ware	0.00000005	0.00005	0.23991	0.00555651	0.00000391735	0.00002	0.00000004	0.00004	0.23991	0.00555651	0.00000391735	0.00001
Ceramic Tiles	0.00000069	0.00068	0.23991	0.00555651	0.00000391735	0.00027	0.00000063	0.00063	0.23991	0.00555651	0.00000391735	0.00025
Total Emission from CO_2, CH4 and N_2O (million tCO_2eq)						0.25						0.25

Diesel Combustion

Table 31: CO_2 emissions from transportation (year 2016 to 2019

Construction Material	Average Distance Travelled (km) - Round Trip	Diesel Consumption (liter/km)	Max. Load Capacity (tonne)	$NCV_{l,y}$ Weighted Average Net Calorific Value (GJ/t diesel)	$EFCO_{2,l,y}$ Weighted Average CO_2 Emission Factor (tCO_2/GJ)	EF_{Diesel} CO_2 Emission Coefficient (tCO_2/tdiesel)	D_{Diesel} Diesel Density (kg/l)	CO_2 Emission Factor (tCO_2/km)	2016 Material Quantity (million tonne)	2016 CO_2 Emission (million tCO_2eq)	2017 Material Quantity (million tonne)	2017 CO_2 Emission (million tCO_2eq)	2018 Material Quantity (million tonne)	2018 CO_2 Emission (million tCO_2eq)	2019 Material Quantity (million tonne)	2019 CO_2 Emission (million tCO_2eq)
Steel Reinforcement	153.00	0.410	36	43	0.0741	3.1863	0.8538	0.0011154	5.70	0.0270	8.90	0.0422	8.80	0.0417	7.10	0.0337
Ready Mixed Concrete	153.00	0.410	20	43	0.0741	3.1863	0.8538	0.0011154	93.89	0.8011	162.00	1.3823	166.56	1.4212	142.32	1.2144
Bricks	153.00	0.410	20	43	0.0741	3.1863	0.8538	0.0011154	15.36	0.1311	17.11	0.1460	20.59	0.1757	28.35	0.2419
Paint	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	0.03	0.0002	0.04	0.0002	0.08	0.0004	0.12	0.0006
Plywood	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	1.14	0.0055	1.36	0.0066	1.54	0.0074	1.44	0.0070
Cement (finishes)	153.00	0.410	20	43	0.0741	3.1863	0.8538	0.0011154	1.50	0.0128	2.40	0.0205	4.60	0.0393	6.50	0.0555
Sand (finishes)	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	10.40	0.0502	14.00	0.0676	22.90	0.1106	38.40	0.1854
Glass	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	0.12	0.0006	0.11	0.0005	0.18	0.0009	0.31	0.0015
Aggregate	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	7.10	0.0343	27.80	0.1342	33.30	0.1608	43.90	0.2120
Roofing Tiles/Sheet	153.00	0.410	20	43	0.0741	3.1863	0.8538	0.0011154	0.30	0.0026	0.29	0.0025	0.33	0.0028	0.27	0.0023
Steel & Metal	153.00	0.410	36	43	0.0741	3.1863	0.8538	0.0011154	2.58	0.0122	2.53	0.0120	2.02	0.0096	1.73	0.0082
Timber	153.00	0.410	36	43	0.0741	3.1863	0.8538	0.0011154	1.43	0.0068	1.38	0.0065	2.67	0.0127	2.17	0.0103
Sanitary Ware	153.00	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	0.12	0.0006	0.11	0.0005	0.03	0.0001	0.02	0.0001
Ceramic Tiles	135.60	0.174	15	43	0.0741	3.1863	0.8538	0.0004734	0.34	0.0015	0.55	0.0024	0.51	0.0022	0.47	0.0020
Total Emission from CO_2 (million tCO_2eq)										**1.0864**		**1.8239**		**1.9853**		**1.9747**

The CH_4 and N_2O emissions from transportation are calculated as below:

Table 32: CH_4 and N_2O emissions from transportation (year 2016 to 2019)

Year 2016

Construction Material	Fuel Consumption (liter) per truck	2016						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	62.73	5.70	0.16	9.93	0.0000086	0.000364	0.000040	0.000376
Ready Mixed Concrete	62.73	93.89	4.69	294.48	0.0002539	0.010791	0.001178	0.011153
Bricks	62.73	15.36	0.77	48.19	0.0000416	0.001766	0.000193	0.001825
Paint	26.62	0.03	0.00	0.06	0.0000000	0.000002	0.000000	0.000002
Plywood	26.62	1.14	0.08	2.02	0.0000017	0.000074	0.000008	0.000077
Cement (finishes)	62.73	1.50	0.08	4.70	0.0000041	0.000172	0.000019	0.000178
Sand (finishes)	26.62	10.40	0.69	18.46	0.0000159	0.000676	0.000074	0.000699
Glass	26.62	0.12	0.01	0.22	0.0000002	0.000008	0.000001	0.000008
Aggregate	26.62	7.10	0.47	12.60	0.0000109	0.000462	0.000050	0.000477
Roofing Tiles/Sheet	62.73	0.30	0.02	0.94	0.0000008	0.000034	0.000004	0.000036
Steel & Metal	62.73	2.58	0.07	4.50	0.0000039	0.000165	0.000018	0.000170
Timber	62.73	1.43	0.04	2.49	0.0000021	0.000091	0.000010	0.000094
Sanitary Ware	26.62	0.12	0.01	0.21	0.0000002	0.000008	0.000001	0.000008
Ceramic Tiles	23.59	0.34	0.02	0.54	0.0000005	0.000020	0.000002	0.000020
Total Emission from CH4 and N_2O (million tCO_2eq)							**0.001598**	**0.015125**

Year 2017

Construction Material	Fuel Consumption (liter) per truck	2017						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	62.73	8.90	0.25	15.51	0.000013	0.000568	0.000062	0.000587
Ready Mixed Concrete	62.73	162.00	8.10	508.11	0.000438	0.018620	0.002033	0.019244
Bricks	62.73	17.11	0.86	53.66	0.000046	0.001966	0.000215	0.002032
Paint	26.62	0.04	0.00	0.06	0.000000	0.000002	0.000000	0.000002
Plywood	26.62	1.36	0.09	2.41	0.000002	0.000088	0.000010	0.000091
Cement (finishes)	62.73	2.40	0.12	7.53	0.000006	0.000276	0.000030	0.000285
Sand (finishes)	26.62	14.00	0.93	24.85	0.000021	0.000911	0.000099	0.000941
Glass	26.62	0.11	0.01	0.20	0.000000	0.000007	0.000001	0.000008
Aggregate	26.62	27.80	1.85	49.34	0.000043	0.001808	0.000197	0.001869
Roofing Tiles/Sheet	62.73	0.29	0.01	0.91	0.000001	0.000033	0.000004	0.000034
Steel & Metal	62.73	2.53	0.07	4.41	0.000004	0.000162	0.000018	0.000167
Timber	62.73	1.38	0.04	2.40	0.000002	0.000088	0.000010	0.000091
Sanitary Ware	26.62	0.11	0.01	0.20	0.000000	0.000007	0.000001	0.000007
Ceramic Tiles	23.59	0.55	0.04	0.87	0.000001	0.000032	0.000003	0.000033
Total Emission from CH4 and N_2O (million tCO_2eq)							**0.002683**	**0.025392**

Year 2018

Construction Material	Fuel Consumption (liter) per truck	2018						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	62.73	8.80	0.24	15.33	0.00001322	0.00056193	0.000061	0.000581
Ready Mixed Concrete	62.73	166.56	8.33	522.42	0.00045050	0.01914439	0.002091	0.019786
Bricks	62.73	20.59	1.03	64.59	0.00005570	0.00236684	0.000258	0.002446
Paint	26.62	0.08	0.01	0.13	0.00000012	0.00000495	0.000001	0.000005
Plywood	26.62	1.54	0.10	2.73	0.00000235	0.00010007	0.000011	0.000103
Cement (finishes)	62.73	4.60	0.23	14.43	0.00001244	0.00052872	0.000058	0.000546
Sand (finishes)	26.62	22.90	1.53	40.64	0.00003505	0.00148940	0.000163	0.001539
Glass	26.62	0.18	0.01	0.32	0.00000028	0.00001187	0.000001	0.000012
Aggregate	26.62	33.30	2.22	59.10	0.00005096	0.00216580	0.000237	0.002238
Roofing Tiles/Sheet	62.73	0.33	0.02	1.04	0.00000089	0.00003793	0.000004	0.000039
Steel & Metal	62.73	2.02	0.06	3.52	0.00000304	0.00012899	0.000014	0.000133
Timber	62.73	2.67	0.07	4.65	0.00000401	0.00017049	0.000019	0.000176
Sanitary Ware	26.62	0.03	0.00	0.05	0.00000005	0.00000195	0.000000	0.000002
Ceramic Tiles	23.59	0.51	0.03	0.80	0.00000069	0.00002923	0.000003	0.000030
Total Emission from CH4 and N_2O (million tCO_2eq)							**0.002920**	**0.027638**

Year 2019

Construction Material	Fuel Consumption (liter) per truck	2019						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	62.73	7.10	0.20	12.37	0.00001067	0.00045337	0.000050	0.000469
Ready Mixed Concrete	62.73	142.32	7.12	446.39	0.00038494	0.01635825	0.001786	0.016906
Bricks	62.73	28.35	1.42	88.93	0.00007669	0.00325896	0.000356	0.003368
Paint	26.62	0.12	0.01	0.21	0.00000018	0.00000757	0.000001	0.000008
Plywood	26.62	1.44	0.10	2.56	0.00000221	0.00009384	0.000010	0.000097
Cement (finishes)	62.73	6.50	0.33	20.39	0.00001758	0.00074711	0.000082	0.000772
Sand (finishes)	26.62	38.40	2.56	68.15	0.00005877	0.00249750	0.000273	0.002581
Glass	26.62	0.31	0.02	0.56	0.00000048	0.00002041	0.000002	0.000021
Aggregate	26.62	43.90	2.93	77.91	0.00006719	0.00285522	0.000312	0.002951
Roofing Tiles/Sheet	62.73	0.27	0.01	0.83	0.00000072	0.00003047	0.000003	0.000031
Steel & Metal	62.73	1.73	0.05	3.02	0.00000261	0.00011074	0.000012	0.000114
Timber	62.73	2.17	0.06	3.78	0.00000326	0.00013847	0.000015	0.000143
Sanitary Ware	26.62	0.02	0.00	0.04	0.00000004	0.00000161	0.000000	0.000002
Ceramic Tiles	23.59	0.47	0.03	0.73	0.00000063	0.00002691	0.000003	0.000028
Total Emission from CH4 and N_2O (million tCO_2eq)							**0.002905**	**0.027492**

Note:

1. 1 tonne of diesel is equivalent to 1.010 toe[52]
2. Conversion factor for diesel from ktoe to TJ is 42.496 TJ/ktoe obtained from NEB report
3. The emission factor for CH_4 and N_2O is 3.9 Kg/TJ[53]
4. GWP for CH_4 is 28 $tCO_2eq./tCH_4$, and N_2O is 265 $tCO_2eq./tN_2O$ obtained from IPCC Technical Assessment Report

[52] https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Tonnes_of_oil_equivalent_%28toe%29

[53] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

The summary of GHG emissions from transportation is tabulated as below:

Table 33: GHG emissions from transportation (year 2016 to 2019)

Year	Fuel Production (million tCO_2eq)	Fuel Combustion (million tCO_2eq)	Total GHG Emission (million tCO_2eq)
2016	0.1352	1.1031	1.2383
2017	0.2270	1.8520	2.0790
2018	0.2471	2.0158	2.2629
2019	0.2458	2.0051	2.2509

4.3 GHG Emissions from Construction Site

GHG emissions from construction site consist of emissions contributed from fuel and electricity consumption as well as waste disposal. The GHG emitted are CO_2, CH_4 and N_2O. The fuel and electricity consumption released mainly CO_2, while CH_4 and N_2O released as the by-product due to incomplete combustion. The waste disposal released mainly CH_4.

4.3.1 Fuel Consumption

There is four (4) type of fuels included in the calculation which are LPG, diesel, lubricant, and bitumen. Data from NEB 2016 and 2017 were used which includes the final use of total LPG, and diesel for all sectors, while bitumen and lubricants are only from the construction industry. Data for the year 2018 and 2019 is yet to be published by Energy Commission. The 2018 data is expected to be officially published in July 2020. Therefore, the estimation for 2018 and 2019 was done by multiplying the GDP annual growth rate published by EPU (2016) and the fuel consumption in 2017 as shown in Table 34 below:

Table 34: GDP growth assumptions by sector to 2020 (% per year)

Annual Growth Rate (%)	2005 - 2010	2016 - 2020
Agriculture	2.68%	2.16%
Mining & Quarrying	-0.17%	0.01%
Manufacturing	2.60%	3.55%
Construction	1.49%	3.44%
Services	7.19%	4.41%
Total GDP	4.34%	3.88%

Note: 2016 - 2020 are projected values.

Source: EPU, (IHS Report, 19 October 2016)

Total fuel consumption for LPG and diesel is estimated by using the total GDP annual growth rate of 3.88%. On the other hand, the fuel consumption by the construction industry for lubricants and bitumen is estimated by using GDP for the construction industry with an annual growth rate of 3.44%. The fuel consumption is tabulated in Table 35.

Table 35: Fuel consumption

Year	Fuel Consumption (ktoe)			
	Total Consumption		Construction Industry	
	LPG	Diesel	Lubricants	Bitumen
2016	3,497	9,254	186	464
2017	3,514	9,388	171	545
2018[e]	3,650	9,752	177	563
2019[e]	3,792	10,131	183	583

Note: [e] Estimated value, refer to above explanation on the estimation

As mentioned in Section 3.2.3.1, there is no specific diesel and LPG consumption data for the construction industry in Malaysia. Therefore, the total of diesel and LPG consumption by the construction industry in Malaysia was estimated using the GDP for the construction industry multiply the total diesel and LPG consumption in Malaysia (Table 36 and Table 37).

Table 36: Proportions of fuel by type of economic activities

Year	Total GDP (RM Million)	GDP of Construction Industry (RM Million)	GDP Contribution by Construction industry (%)
2016	1,213,400	59,500	4.9%
2017	1,281,800	63,500	4.9%
2018	1,345,500	66,200	4.9%
2019	1,404,800	66,300	4.7%
		Average	**4.9%**

The fuel consumption for the construction industry is calculated and tabulated as below:

Table 37: Fuel consumption by construction industry

Year	LPG (ktoe)	Diesel (ktoe)	Lubricants (ktoe)	Bitumen (ktoe)
2016	171	454	186	464
2017	174	465	171	545
2018	180	480	177	563
2019	179	478	183	583

The diesel consumption by the construction industry estimated in Table 37 above was compared to the survey result. The estimated diesel consumption for the year from 2017-2019 from the survey is tabulated in Table 38. The average percentage proportion of diesel consumption of the construction industry obtained from the survey is 5.1%. This is comparable to the 4.9% GDP contribution of the construction industry in Malaysia as shown in Table 36.

Table 38: Percentage of diesel consumption over total diesel consumption in Malaysia (year 2017 to 2019)

Year	Diesel Consumption Obtained from Survey (ktoe)	Total Diesel Consumption in Malaysia (ktoe)	Percentage of Diesel Consumption over Total Diesel Consumption in Malaysia (%)
2017	593	9,388	6.3%
2018	511	9,752	5.2%
2019	367	10,131	3.6%
		Average	**5.1%**

As shown in Table 37 above, the fuel consumption data available is in kilotonnes of oil equivalent (ktoe), therefore, conversion to a common energy unit (TJ) was done using conversion coefficients that are available in the NEB report. According to the 2006 IPCC Guidelines, it is recommended to use locally available information in the estimation of GHG emissions and in the meantime maintain consistency in view of the fact that most of the data used were obtained from NEB. Table 39 below shows the conversion coefficients used to give apparent consumption in TJ.

Table 39: Conversion coefficients

Fuel	Conversion Factor (TJ/ktoe)[54]
LPG	45.5440
Diesel	42.4960
Lubricants	42.1401
Bitumen	41.8000

The GHG emissions for fuel consumption are calculated as shown in next page.

[54] National Energy Balance, Energy Commission, https://meih.st.gov.my/documents/10620/9a9314a1-cf11-4640-a9de-3b31f336a416

4.3.1.1 LPG

During road construction, LPG is used to reheat and melt bitumen packed in drums. Figure 25 shows the GHG estimated from the LPG consumption resulted in 0.56 to 0.58 million tCO_2eq. of GHG emissions from the year 2016 until 2019.

Table 40: GHG emissions from LPG consumption (year 2016 to 2019)

Year	LPG Consumption (ktoe)	Conversion Factor (TJ/ktoe)	LPG Consumptio n (TJ)	LPG Consumption (tonne)	WtT Emission Factor tCO_2e/t	GHG Emission from LPG Production (million tCO_2eq)	CO_2 Emission Factor $kgCO_2/TJ$	CH_4 Emission Factor $kgCH_4/TJ$	N_2O Emission Factor kgN_2O/TJ	GHG Emission from LPG Combustion (million tCO_2eq)	Total GHG Emission from LPG Consumption (million tCO_2eq)
2016	171.48	45.544	7,809.80	171,478	0.3693	0.063	63,100	1.00	0.10	0.49	0.56
2017	174.08	45.544	7,928.42	174,083	0.3693	0.064	63,100	1.00	0.10	0.50	0.57
2018	179.60	45.544	8,179.73	179,601	0.3693	0.066	63,100	1.00	0.10	0.52	0.58
2019	178.96	45.544	8,150.72	178,964	0.3693	0.066	63,100	1.00	0.10	0.51	0.58

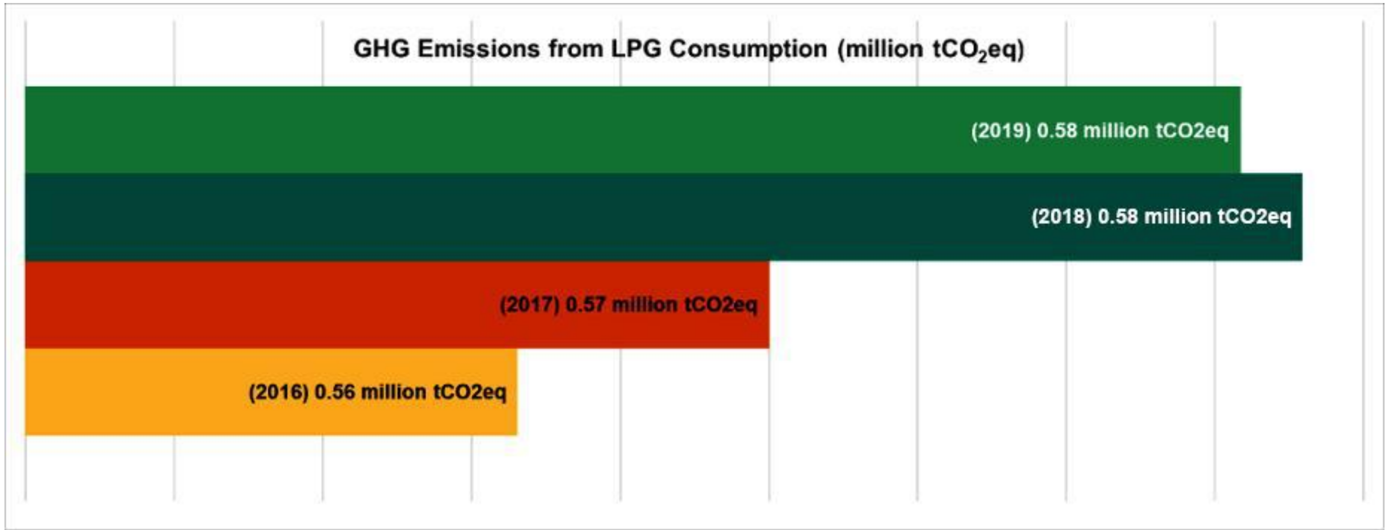

Figure 25: GHG emissions from LPG consumption (year 2016 to 2019)

4.3.1.2 Diesel

Diesel is mainly used for machinery or equipment such as face shovel, skimmer, dragline, crane and grab, pile driving and drilling and tractors (trench digger, scraper, bulldozer, grader, trenching machine, and mechanical auger). Table below shows the GHG estimated from the diesel consumption in the construction site, resulted in 1.63 to 1.72 million tCO_2eq. from the year 2016 until 2019.

Table 41: GHG emissions from Diesel consumption (year 2016 to 2019)

Year	Diesel Consumption (ktoe)	Conversion Factor (TJ/ktoe)	Diesel Consumption (TJ)	Diesel Consumption (tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)	CO_2 Emission Factor $kgCO_2/TJ$	CH_4 Emission Factor $kgCH_4/TJ$	N_2O Emission Factor kgN_2O/TJ	GHG Emission from Diesel Combustion (million tCO_2eq)	Total GHG Emission from Diesel Consumption (million tCO_2eq)
2016	453.78	42.496	19,283.71	449,284	0.23991	0.00555651	0.00000391735	0.178	74,100	3.9	3.9	1.45	1.63
2017	465.08	42.496	19,763.99	460,474	0.23991	0.00555651	0.00000391735	0.183	74,100	3.9	3.9	1.49	1.67
2018	479.82	42.496	20,390.48	475,070	0.23991	0.00555651	0.00000391735	0.188	74,100	3.9	3.9	1.53	1.72
2019	478.12	42.496	20,318.14	473,385	0.23991	0.00555651	0.00000391735	0.188	74,100	3.9	3.9	1.53	1.72

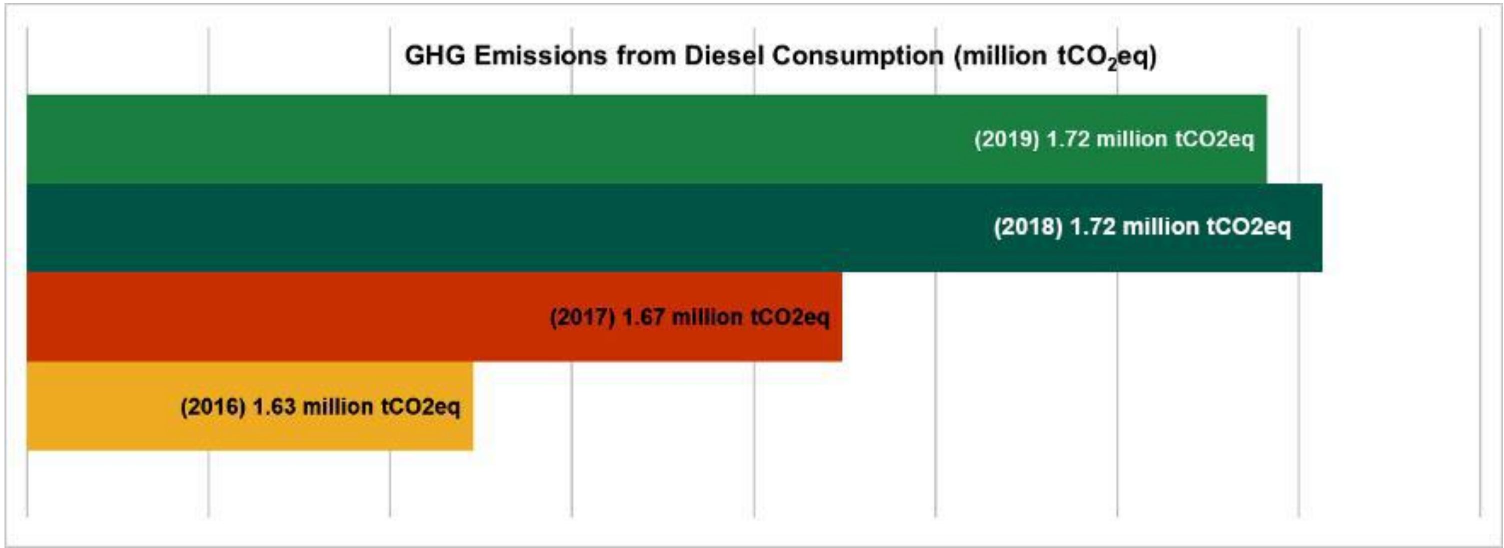

Figure 26: GHG emissions from diesel consumption (year 2016 to 2019)

4.3.1.3 Lubricant

Figure 27 shows the GHG estimated from the lubricants consumption resulted to 0.58 to 0.57 million tCO_2eq. of GHG emissions from the year 2016 until 2019.

Table 42: GHG emissions from lubricant consumption (Year 2016 to 2019)

Year	Lubricant Consumption (ktoe)	Conversion Factor (TJ/ktoe)	Lubricant Consumption (TJ)	CO_2 Emission Factor $kgCO_2/TJ$	CH_4 Emission Factor $kgCH_4/TJ$	N_2O Emission Factor kgN_2O/TJ	GHG Emission from Lubricant Production (million tCO_2eq)	GHG Emission from Lubricant Combustion (million tCO_2eq)	Total GHG Emission from LPG Consumption (million tCO_2eq)
2016	186.34	42.1401	7,852.39	73,300	3.00	0.60	0.00000015	0.58	0.58
2017	171.49	42.1401	7,226.61	73,300	3.00	0.60	0.00000014	0.53	0.53
2018	177.39	42.1401	7,475.20	73,300	3.00	0.60	0.00000015	0.55	0.55
2019	183.49	42.1401	7,732.35	73,300	3.00	0.60	0.00000015	0.57	0.57

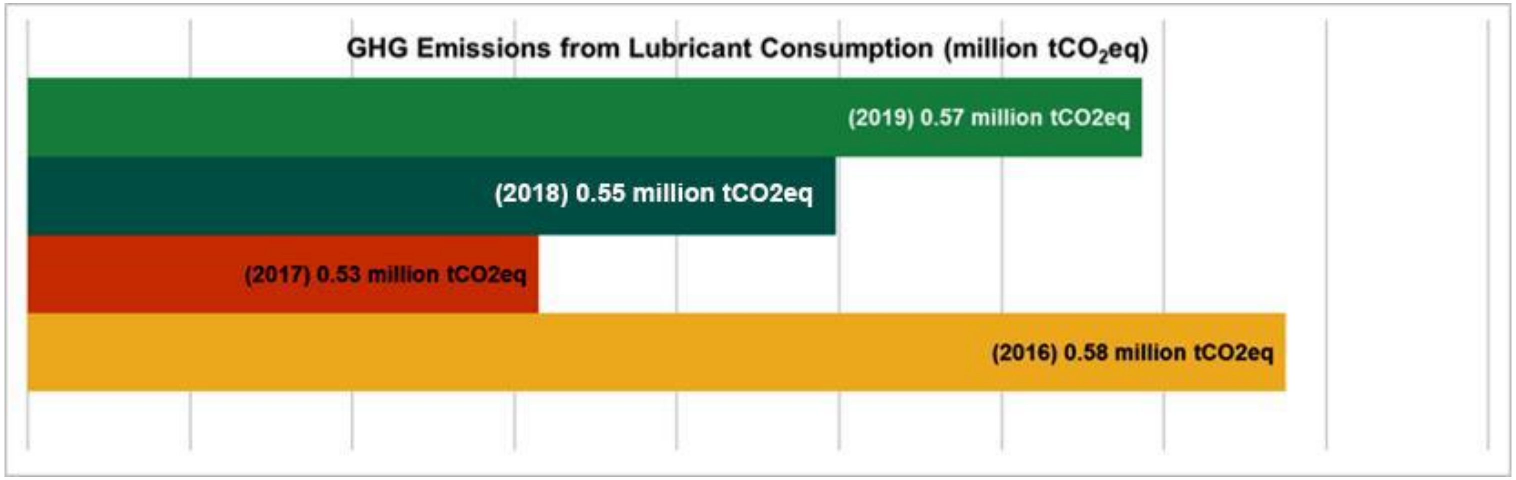

Figure 27: GHG emissions from lubricants consumption (year 2016 to 2019)

4.3.1.4 Bitumen

The basic and most primary usage of bitumen and lubricants is in the road construction industry. Bitumen is mixed thoroughly with aggregates and additives to make asphalt that is used in road construction. Figure 28 shows the GHG estimated from the Bitumen consumption resulted in 1.72 to 2.16 million tCO_2eq. of GHG emissions from the year 2016 until 2019.

Table 43: GHG Emissions from bitumen consumption (year 2016 to 2019)

Year	Bitumen Consumption (ktoe)	Conversion Factor (TJ/ktoe)	Bitumen Consumption (TJ)	Bitumen Consumption (tonne)	WtT Emission Factor tCO_2e/t	GHG Emission from Bitumen Production (million tCO_2eq)	CO_2 Emission Factor $kgCO_2/TJ$	CH_4 Emission Factor $kgCH_4/TJ$	N_2O Emission Factor kgN_2O/TJ	GHG Emission from Bitumen Consumption (million tCO_2eq)	Total GHG Emission from Bitumen Consumption (million tCO_2eq)
2016	463.66	41.8	19,380.99	463,660	0.3260	0.151	80,700	3.00	0.60	1.57	1.72
2017	544.60	41.8	22,764.28	544,600	0.3260	0.178	80,700	3.00	0.60	1.84	2.02
2018	563.33	41.8	23,547.37	563,334	0.3260	0.184	80,700	3.00	0.60	1.91	2.09
2019	582.71	41.8	24,357.40	582,713	0.3260	0.190	80,700	3.00	0.60	1.97	2.16

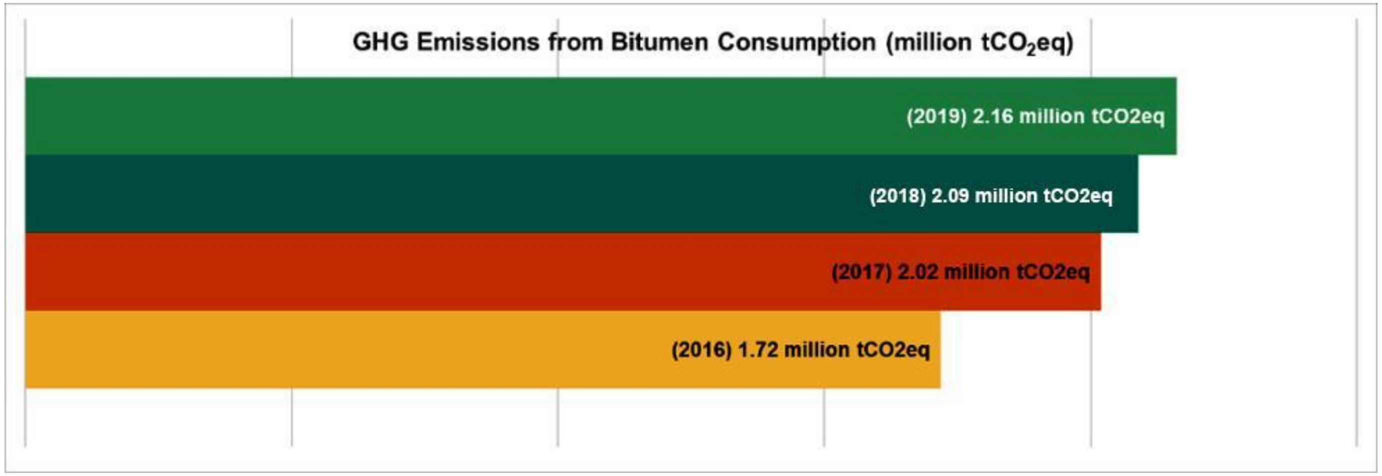

Figure 28: GHG emissions from bitumen consumption (year 2016 to 2019)

4.3.1.5 The Summary of Fuel Consumption

The summary of the GHG emissions from fuel consumption is tabulated as below:

Table 44: GHG emissions from fuel consumption (year 2016 to 2019)

Year	GHG Emission from Fuel Consumption (million tCO_2eq)				Total GHG Emission from Fuel Consumption (million tCO_2eq)
	Diesel	LPG	Lubricant	Bitumen	
2016	1.63	0.56	0.58	1.72	**4.48**
2017	1.67	0.57	0.53	2.02	**4.79**
2018	1.72	0.58	0.55	2.09	**4.94**
2019	1.72	0.58	0.57	2.16	**5.03**
Total	**6.74**	**2.29**	**2.23**	**7.99**	**19.24**

Referring to Figure 29, it can be observed at at the construction site, the average quantity of GHG (million tCO_2eq.) for the year 2017 – 2019 emitted from bitumen (42%) and diesel (35%) is among the highest compared to other types of fuel. These situations may caused by higher consumption and carbon content. The remaining contributors were from lubricants (12%) and LPG (11%).

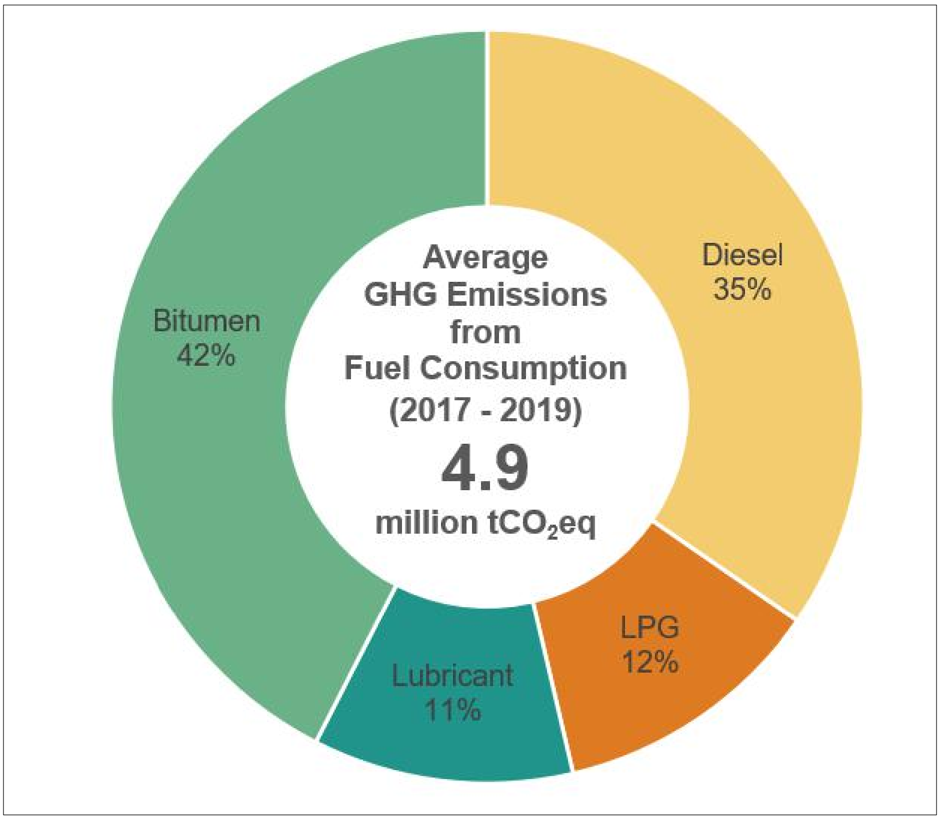

Figure 29: Average GHG emissions from fuel consumption (year 2017 – 2019)

In general, the GHG emissions from LPG, diesel, bitumen and lubricants consumptions increased throughout the year 2016 to 2019 as many of infrastructure projects initiated being intensely implemented major high impact civil engineering projects in transportation and road networks for examples 2,300km Pan Borneo Highway project located in Sabah and Sarawak; the 390km Central Spine Road in Pahang; the Mass Rapid Transit 2 (MRT2); the Light Rail Transit 3 (LRT3); Damansara - Shah Alam Elevated Expressway (DASH); and Sungai Besi-Ulu Kelang Elevated Expressway (SUKE).

4.3.2 Electricity Consumption

Data on electricity consumption (in GWh) from the year 2016 until 2019 were received from BCRM of TNB for Peninsular Malaysia and *Jabatan Pengurusan Komersil* of SESB for Sabah and Customer Retail of SEB for Sarawak. Table 45 shows the electricity consumption received from the year 2016 until 2019.

Table 45: Electricity consumption for Peninsular, Sabah and Sarawak

Year	Electricity Consumption (MWh)					
	Peninsular Malaysia (Construction Industry)	Sabah (Total Industry)	Sabah[a] (Construction Industry)	Sarawak (Commercial)	Sarawak[b] (Construction Industry)	Total Electricity Consumption from Construction Industry (MWh) for Malaysia
2016	239,233.34[c]	1,065,884.49	83,156.03	2,512,351.18	204,601.03	526,990.40
2017	298,799.26	1,091,779.89[c]	75,478.62	2,574,653.02	234,188.17	608,466.04
2018	341,202.51	1,117,675.28	97,017.98	2,660,141.76	231,176.59	669,397.08
2019	339,809.06	1,146,881.09	99,553.14	2,761,198.02	251,629.19	690,991.39

Notes:

[a] Electricity consumption data by construction industry in Sabah was estimated using the ratio of GDP construction with GDP industry. GDP industry = GDP (Manufacturing + Mining + Construction).

[b] Electricity consumption data by construction industry in Sarawak was estimated using the ratio of GDP construction with GDP commercial. GDP commercial = GDP (Service + Construction).

[C] Data for Peninsular Malaysia (year 2016) and Sabah (year 2017) was recalculated to ensure consistency.

The electricity consumption by the construction industry estimated in Table 45 above was compared to the survey result which is tabulated in Table 46.

Table 46: Comparison of electricity consumption from construction industry estimated by using GDP and survey results

Year	Annual Electricity Consumption of Construction Industry in Malaysia (MWh)			Percentage Proportion of Construction Industry's Electricity Consumption to Total in Malaysia (%)	
	Average by GDP (MWh)	Average from Survey [a] (MWh)	Total Electricity Consumption in Malaysia [b] (MWh)	GDP's over Total Malaysia (%)	Survey's over Total Malaysia (%)
2017	608,466	779,208	146,607,780	0.42%	0.53%
2018	669,397	649,076	152,325,483	0.44%	0.43%
2019	690,991	486,565	158,266,177	0.44%	0.31%
Average				**0.43%**	**0.42%**

Note:

[a] Electricity consumption for the construction industry from the survey was estimated by using the annual total project value of all construction projects obtained from CIDB multiply with the unit amount of electricity consumption (RM/MWh).

[b] Total electricity consumption of Malaysia from 2017 – 2018 was obtained from NEB, 2018 & 2019 is forecasted value with Total GDP annual growth rate of 3.9% from Economic Planning Unit, (IHS Report, 19 October 2016).

Table 46 presented the average total electricity consumption by the construction industry that is estimated by using the GDP for the construction industry compared to the total electricity consumption of all sectors in Malaysia for the year 2017 to 2019 is 0.43%. This average is comparable with the average electricity consumption of the construction industry obtained from the survey for the year 2017 to 2019 with an average of 0.42% of the total electricity consumption of all sectors in Malaysia.

The GHG emissions for electricity consumption are calculated as below:

4.3.2.1 Peninsular Malaysia

Table 47: GHG emissions from electricity consumption for Peninsular Malaysia (year 2016 to 2019)

Year	Electricity Consumption for Construction Industry (MWh)	Grid Emission Factor ($tCO_2eq./MWh$)	GHG Emission (million $tCO_2eq.$)
2016	239,233.34	0.667	0.16
2017	298,799.26	0.585	0.17
2018	341,202.51	0.585	0.20
2019	339,809.06	0.585	0.20

4.3.2.2 Sabah

Table 48: GHG emissions from electricity consumption for Sabah (year 2016 to 2019)

Year	Electricity Consumption for Construction Industry (MWh)	Grid Emission Factor ($tCO_2eq./MWh$)	GHG Emissions (million $tCO_2eq.$)
2016	83,156.03	0.551	0.05
2017	75,478.62	0.525	0.04
2018	97,017.98	0.525	0.05
2019	99,553.14	0.525	0.05

4.3.2.3 Sarawak

Table 49: GHG emissions from electricity consumption for Sarawak (rear 2016 to 2019)

Year	Electricity Consumption for Construction Industry (MWh)	Grid Emission Factor ($tCO_2eq./MWh$)	GHG Emissions (million $tCO_2eq.$)
2016	204,601.03	0.364	0.28
2017	234,188.17	0.330	0.29
2018	231,176.59	0.330	0.33
2019	251,629.19	0.330	0.33

4.3.2.4 The Summary of Electricity Consumption

The summary of the GHG emissions from electricity consumption is tabulated as below:

Table 50: GHG emissions from electricity consumption (year 2016 to 2019)

Year	GHG Emission from Electricity Consumption (million $tCO_2eq.$)			Total GHG Emissions from Electricity Consumption (million $tCO_2eq.$)
	Peninsular	Sabah	Sarawak	
2016	0.16	0.05	0.07	0.28
2017	0.17	0.04	0.08	0.29
2018	0.20	0.05	0.08	0.33
2019	0.20	0.05	0.08	0.33

Figure 30 shows the GHG emissions from electricity consumption in the construction site with Peninsular Malaysia is highest compared to Sabah and Sarawak regions with 57 – 61 % throughout the year 2016 to 2019. This is also in line with the highest number of construction projects in Peninsular Malaysia compared to the other two regions.

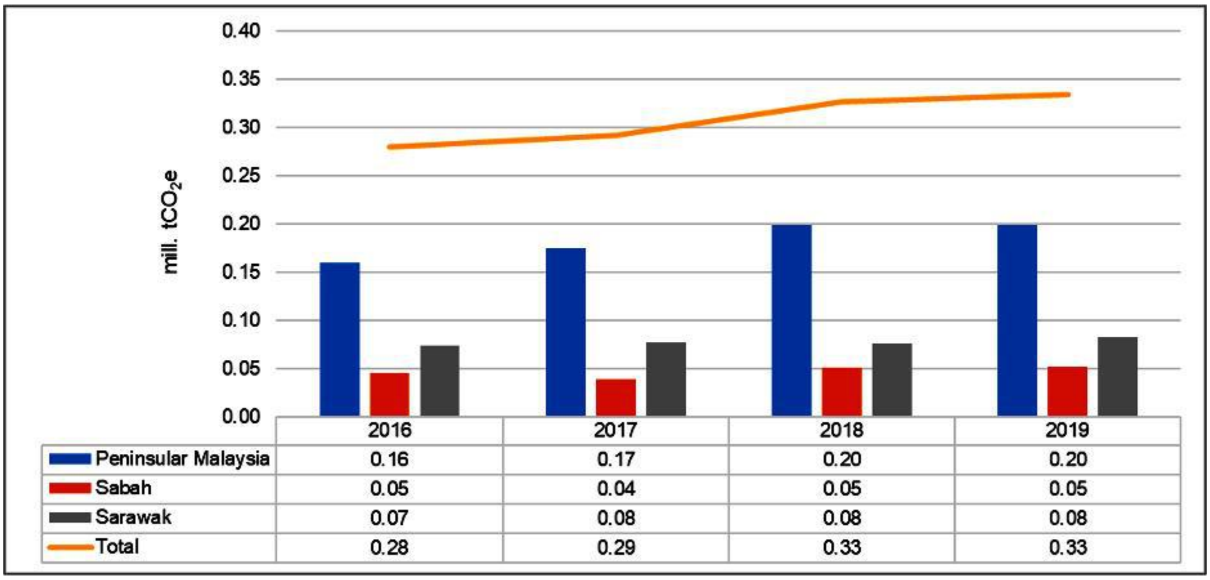

Figure 30: GHG emissions from electricity consumption (year 2016 to 2019)

4.4 Waste

4.4.1 Waste Treatment (Landfilling)

The estimation of construction waste generated (2016 – 2019) from the construction material consumption by multiplying the available average wastage is calculated and tabulated as below:

Table 51: Construction waste generation (year 2016 to 2019)

Waste Type	Average Wastage (%)	Material Quantity (million tonne)				Construction Waste Quantity (million tonne)			
		2016	2017	2018	2019	2016	2017	2018	2019
Concrete	7.5%	93.89	162.00	166.56	142.32	7.04	12.15	12.49	10.67
Bricks	7.5%	15.36	17.11	20.59	28.35	1.15	1.28	1.54	2.13
Tiles and Ceramic	7.0%	0.64	0.84	0.84	0.73	0.05	0.06	0.06	0.05
Steel Reinforcement	6.0%	5.70	8.90	8.80	7.10	0.34	0.53	0.53	0.43
Cement	7.5%	1.50	2.40	4.60	6.50	0.11	0.18	0.35	0.49
Timber	9.0%	1.43	1.38	2.67	2.17	0.13	0.12	0.24	0.20
Glass	3.0%	0.12	0.11	0.18	0.31	0.004	0.003	0.005	0.009
Total (million tonne)						**8.83**	**14.33**	**15.21**	**13.97**

The quantity of paper, plastic and kitchen & garden waste data from 2016 to 2019 generated is tabulated as below:

Table 52: Other construction waste generation (year 2016 to 2019)

Description	2016	2017	2018	2019
Total No. of Employment	1,386,642	1,498,592	1,629,243	1,782,118
Amount of waste generated (tonne/year)	384,654.58	415,709.35	451,952.09	494,359.62

Description	2016	2017	2018	2019
Quantity of paper (million tonne)	0.03	0.04	0.04	0.04
Quantity of paper disposed (million tonne)	**0.01**	**0.01**	**0.01**	**0.01**
Quantity of plastic (million tonne)	0.05	0.05	0.06	0.07
Quantity of plastic disposed (million tonne)	**0.01**	**0.02**	**0.02**	**0.02**
Quantity of kitchen and garden (million tonne)	0.19	0.21	0.23	0.25
Quantity of kitchen and garden (million tonne) disposed	**0.19**	**0.21**	**0.23**	**0.25**

Note:

1. Waste generation rate is 0.76kg/cap/day.
2. Waste composition for paper is 8.5%; average wastage for paper is 27.5%.
3. Waste composition for plastic is 13.2%; average wastage for plastic is 28%.
4. Waste composition for kitchen and garden waste is 50.3%; average wastage for kitchen and garden waste is 100%.

The emission factors for construction waste were obtained from MyCREST. The emission factors only applicable to a few types of waste which are tabulated as below:

Table 53: EF ($tCO_2eq./t$) for construction waste

Waste Type	Wood	Glass	Metal	Paper	Plastic	Kitchen and Garden
EF ($tCO_2eq./t$)	0.792	0.026	0.02	0.58	0.034	0.213

For the GHG estimation, the emission factor for metal was applied for steel reinforcement, and emission factor for wood was applied to timber. The GHG emissions from waste treatment were calculated as below:

Table 54: GHG emissions from construction waste (year 2016 to 2019)

Waste Type	Construction Waste Quantity (million tonne)				EF ($tCO_2eq./t$)	GHG Emissions (million $tCO_2eq.$)			
	2016	2017	2018	2019		2016	2017	2018	2019
Steel Reinforcement	0.342	0.534	0.528	0.426	0.02	0.0068	0.0107	0.0106	0.0085
Timber	0.129	0.124	0.240	0.195	0.792	0.1019	0.0984	0.1903	0.1546
Glass	0.004	0.003	0.005	0.009	0.026	0.0001	0.0001	0.0001	0.0002
Paper	0.01	0.01	0.01	0.01	0.58	0.0052	0.0056	0.0061	0.0067
Plastic	0.01	0.02	0.02	0.02	0.034	0.0005	0.0005	0.0006	0.0006
Kitchen and Garden	0.19	0.21	0.23	0.25	0.213	0.0412	0.0445	0.0484	0.0530
Total GHG Emissions (million $tCO_2eq.$)						**0.156**	**0.160**	**0.256**	**0.224**

4.4.2 Transportation

4.4.2.1 Average Distance

The average distance from the construction site to landfill was estimated for all the states are tabulated as below:

Table 55: Average distance from construction site to landfill

State	Average Distance (km)
Johor	30.8
Kedah	15.1
Kelantan	10.9
Melaka	18.9
Negeri Sembilan	38.9
Pahang	9.9
Penang	44.1
Perak	14.5
Perlis	29.1
Sabah	33.1
Sarawak	16.5
Selangor	41.9
Terengganu	11.4
Average	**27.0**

4.4.2.2 Transport Capacity and Fuel Consumption

The typical capacity of the open truck to dispose of the construction waste from the construction site to landfill is 10 tonnes. For calculation purposes, the assumption was made using the maximum load of the truck capacity. The fuel consumption used for the 10-tonne capacity truck is 0.174 liter/km.

4.4.2.3 Density, Calorific Value, and Emission Factor

The default value applied in the calculation is explained in section 4.2.3.

The GHG emissions from transportation of waste from the construction site to landfill are calculated as shown in next page.

Diesel Production

Table 56: GHG emissions from transportation of waste from diesel production (year 2016 to 2019)

Construction Material	2016						2017					
	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)
Steel Reinforcement	0.000000277	0.000274	0.23991	0.00555651	0.00000391735	0.000109	0.00000043	0.000428	0.23991	0.00555651	0.00000391735	0.000170
Timber	0.000000104	0.000103	0.23991	0.00555651	0.00000391735	0.000041	0.00000010	0.000100	0.23991	0.00555651	0.00000391735	0.000040
Glass	0.000000003	0.000003	0.23991	0.00555651	0.00000391735	0.000001	0.00000000	0.000003	0.23991	0.00555651	0.00000391735	0.000001
Paper	0.000000007	0.000007	0.23991	0.00555651	0.00000391735	0.000003	0.00000001	0.000008	0.23991	0.00555651	0.00000391735	0.000003
Plastic	0.000000012	0.000011	0.23991	0.00555651	0.00000391735	0.000005	0.00000001	0.000012	0.23991	0.00555651	0.00000391735	0.000005
Kitchen and Garden	0.000000157	0.000155	0.23991	0.00555651	0.00000391735	0.000062	0.00000017	0.000168	0.23991	0.00555651	0.00000391735	0.000067
Total Emission (million tCO_2eq)						**0.00021982**						**0.00028496**

Construction Material	2018						2019					
	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)	Diesel Consumption (million ktoe)	Diesel Consumption (million tonne)	CO_2 Emission Factor $kgCO_2/kg$ diesel	CH_4 Emission Factor $kgCH_4/kg$ diesel	N_2O Emission Factor kgN_2O/kg diesel	GHG Emission from Diesel Production (million tCO_2eq)
Steel Reinforcement	0.000000428	0.000424	0.23991	0.00555651	0.00000391735	0.000168	0.00000035	0.000342	0.23991	0.00555651	0.00000391735	0.000136
Timber	0.000000195	0.000193	0.23991	0.00555651	0.00000391735	0.000076	0.00000016	0.000157	0.23991	0.00555651	0.00000391735	0.000062
Glass	0.000000004	0.000004	0.23991	0.00555651	0.00000391735	0.000002	0.00000001	0.000008	0.23991	0.00555651	0.00000391735	0.000003
Paper	0.000000009	0.000008	0.23991	0.00555651	0.00000391735	0.000003	0.00000001	0.000009	0.23991	0.00555651	0.00000391735	0.000004
Plastic	0.000000014	0.000013	0.23991	0.00555651	0.00000391735	0.000005	0.00000001	0.000015	0.23991	0.00555651	0.00000391735	0.000006
Kitchen and Garden	0.000000184	0.000182	0.23991	0.00555651	0.00000391735	0.000072	0.00000020	0.000199	0.23991	0.00555651	0.00000391735	0.000079
Total Emission (million tCO_2eq)						0.00032714						0.0002892

Fuel Combustion

Table 57: GHG emissions from transportation of waste (year 2016 to 2019)

Construction Waste	Average Distance Travelled (km) - Round Trip	Diesel Consumption (liter/km)	Max. Load Capacity (tonne)	$NCV_{i,y}$	$EFCO_{2,i,y}$	EF_{Diesel}	D_{Diesel}	CO_2 Emission Factor (tCO_2/km)	2016		2017		2018		2019	
				Weighted Average Net Calorific Value (GJ/t diesel)	Weighted Average CO_2 Emission Factor (tCO_2/GJ)	CO_2 Emission Coefficient (tCO_2/tdiesel)	Diesel Density (kg/l)		Material Quantity (million tonne)	CO_2 Emission (million tCO_2eq)	Material Quantity (million tonne)	CO_2 Emission (million tCO_2eq)	Material Quantity (million tonne)	CO_2 Emission (million tCO_2eq)	Material Quantity (million tonne)	CO_2 Emission (million tCO_2eq)
Steel Reinforcement	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.34	0.000874	0.53	0.001365	0.53	0.001350	0.43	0.001089
Timber	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.13	0.000329	0.12	0.000317	0.24	0.000614	0.20	0.000499
Glass	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.00	0.000009	0.00	0.000009	0.01	0.000014	0.01	0.000024
Paper	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.01	0.000023	0.01	0.000025	0.01	0.000027	0.01	0.000030
Plastic	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.01	0.000036	0.02	0.000039	0.02	0.000043	0.02	0.000047
Kitchen and Garden	54.00	0.174	10	43	0.0741	3.1863	0.8538	0.0004734	0.19	0.000495	0.21	0.000534	0.23	0.000581	0.25	0.000636
Total Emission from CO_2 (million tCO_2eq)										**0.0018**		**0.0023**		**0.0026**		**0.0023**

The GHG emissions from CH_4 and N_2O for transportation of waste from the construction site to landfill are calculated as below:

Table 58: GHG emissions from CH_4 and N_2O for transportation (year 2016 to 2019)

Year 2016

Construction Material	Fuel Consumption (liter) per truck	2016						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	8.352	0.342	0.034	0.286	0.00000025	0.00001047	0.00000114	0.00001082
Timber	8.352	0.129	0.013	0.107	0.00000009	0.00000394	0.00000043	0.00000407
Glass	8.352	0.004	0.000	0.003	0.00000000	0.00000011	0.00000001	0.00000012
Paper	8.352	0.009	0.001	0.008	0.00000001	0.00000028	0.00000003	0.00000028
Plastic	8.352	0.014	0.001	0.012	0.00000001	0.00000044	0.00000005	0.00000045
Kitchen and Garden	8.352	0.193	0.019	0.162	0.00000014	0.00000592	0.00000065	0.00000612
Total Emission from CH_4 and N_2O (million tCO_2eq)							**0.00000231**	**0.00002186**

Year 2017

Construction Material	Fuel Consumption (liter) per truck	2017						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	8.352	0.534	0.053	0.446	0.00000038	0.00001634	0.00000178	0.00001689
Timber	8.352	0.124	0.012	0.104	0.00000009	0.00000380	0.00000042	0.00000393
Glass	8.352	0.003	0.000	0.003	0.00000000	0.00000010	0.00000001	0.00000011
Paper	8.352	0.010	0.001	0.008	0.00000001	0.00000030	0.00000003	0.00000031
Plastic	8.352	0.015	0.002	0.013	0.00000001	0.00000047	0.00000005	0.00000049
Kitchen and Garden	8.352	0.209	0.021	0.175	0.00000015	0.00000640	0.00000070	0.00000661
Total Emission from CH_4 and N_2O (million tCO_2eq)							**0.00000299**	**0.00002834**

Year 2018

Construction Material	Fuel Consumption (liter) per truck	2018						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	8.352	0.528	0.053	0.441	0.00000038	0.00001616	0.00000176	0.00001670
Timber	8.352	0.240	0.024	0.201	0.00000017	0.00000735	0.00000080	0.00000760
Glass	8.352	0.005	0.001	0.005	0.00000000	0.00000017	0.00000002	0.00000017
Paper	8.352	0.011	0.001	0.009	0.00000001	0.00000032	0.00000004	0.00000033
Plastic	8.352	0.017	0.002	0.014	0.00000001	0.00000051	0.00000006	0.00000053
Kitchen and Garden	8.352	0.227	0.023	0.190	0.00000016	0.00000696	0.00000076	0.00000719
Total Emission from CH_4 and N_2O (million tCO_2eq)							**0.000003437**	**0.000032530**

Year 2019

Construction Material	Fuel Consumption (liter) per truck	2019						
		Material Quantity (million tonne)	No. of Truck (million)	Diesel Consumption (million litre)	Diesel Consumption (million ktoe)	Diesel Consumption (TJ)	CH_4 Emission (million tCO_2eq)	N_2O Emission (million tCO_2eq)
Steel Reinforcement	8.352	0.426	0.043	0.356	0.00000031	0.00001304	0.00000142	0.00001348
Timber	8.352	0.195	0.020	0.163	0.00000014	0.00000597	0.00000065	0.00000617
Glass	8.352	0.009	0.001	0.008	0.00000001	0.00000029	0.00000003	0.00000030
Paper	8.352	0.012	0.001	0.010	0.00000001	0.00000035	0.00000004	0.00000037
Plastic	8.352	0.018	0.002	0.015	0.00000001	0.00000056	0.00000006	0.00000058
Kitchen and Garden	8.352	0.249	0.025	0.208	0.00000018	0.00000761	0.00000083	0.00000787
Total Emission from CH_4 and N_2O (million tCO_2eq)							**0.000003038**	**0.000028756**

Note:
1. 1 tonne of diesel is equivalent to 1.010 toe.
2. The conversion factor for diesel from ktoe to TJ is 42.496 TJ/ktoe obtained from the NEB report.
3. The emission factor for CH_4 and N_2O is 3.9 Kg/TJ[55].
4. GWP for CH_4 is 28 $tCO_2eq./tCH_4$, and N_2O is 265 $tCO_2eq./tN_2O$ obtained from the IPCC Technical Assessment Report.

[55] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

The summary of the GHG emissions from waste is tabulated as below:

Table 59: GHG emissions from waste (year 2016 to 2019)

Year	Waste (million $tCO_2eq.$)		Total GHG Emissions from Waste (million $tCO_2eq.$)
	Waste Treatment	Transportation	
2016	0.16	0.0020	0.16
2017	0.16	0.0026	0.16
2018	0.26	0.0030	0.26
2019	0.22	0.0026	0.23

Referring to Figure 31, the average GHG emission from waste treatment for the year 2017 - 2019 contributed 99% from total GHG emission from waste treatment while transportation of waste from the construction site to landfill is only contributed 1%.

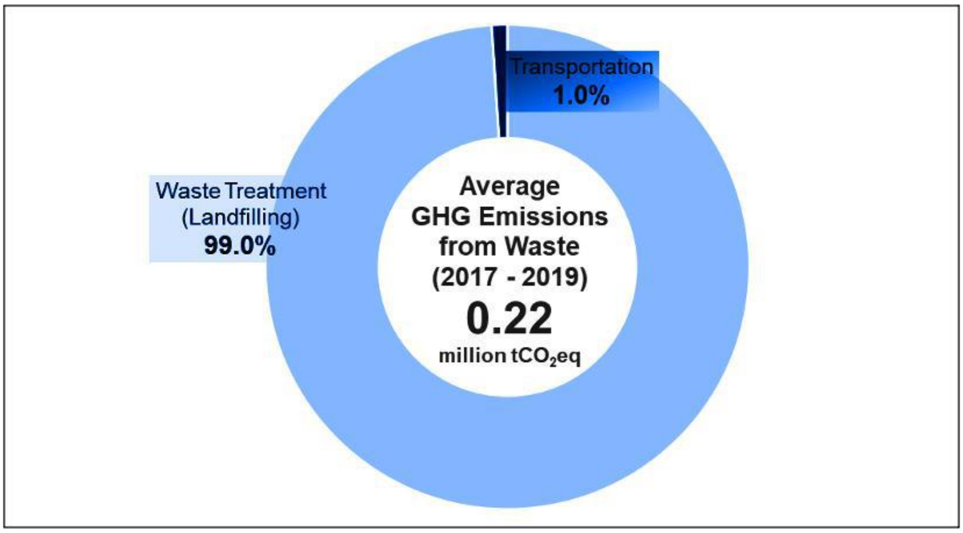

Figure 31: Average distribution of GHG emissions from waste for the year 2017 - 2019

4.4.3 Total GHG Emissions from Construction Site

The total GHG emissions from the construction site are tabulated as below:

Table 60: Total GHG emissions from construction site (year 2016 to 2019)

Year	GHG Emission (million $tCO_2eq.$)			Grand Total GHG Emissions from Construction Site (million $tCO_2eq.$)
	Fuel Consumption	Electricity Consumption	Waste	
2016	4.48	0.28	0.16	**4.92**
2017	4.79	0.29	0.16	**5.24**
2018	4.94	0.33	0.26	**5.53**
2019	5.03	0.33	0.23	**5.59**

Referring to Figure 32, the highest average GHG emission from the construction sites for the year 2017 - 2019 is contributed by fuel consumption (90%), followed by electricity consumption (6%) and lastly is waste (4%). As shown in the breakdown graph of fuel consumption in Figure , bitumen was the main contributor (42%), followed by diesel (35%), lubricant (12%) and liquefied petroleum gases (LPG) (11%). Bitumen mainly used in road construction, roofing and waterproofing; lubricant is used to reduce the friction between moving parts or surfaces and to enhance the efficiency of the machines used in the construction industry; while LPG is used to replace electricity and diesel such as for bitumen boilers, drying out structural elements, curing concrete, etc.

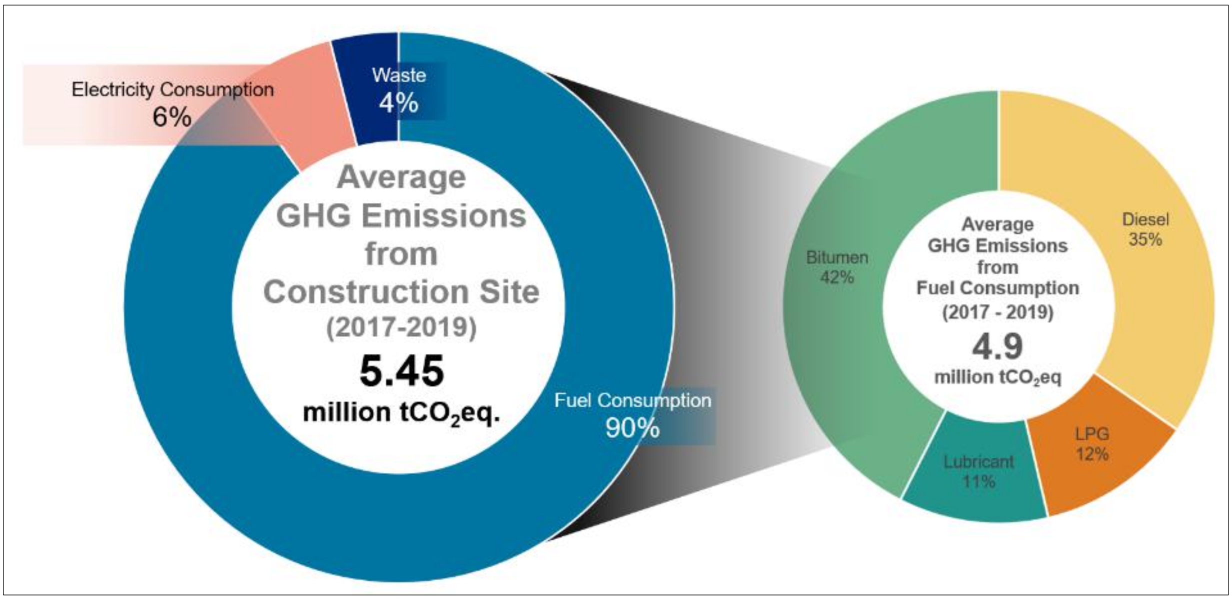

Figure 32: Average distribution of GHG emissions from construction sites (year 2017 to 2019)

4.5 Total GHG Emissions (Cradle-to-Site)

The total GHG emissions from cradle-to-site are tabulated as below:

Table 61: Total GHG emissions from cradle-to-site (year 2016 to 2019)

Year	GHG Emission (million $tCO_2eq.$)			Total GHG Emissions (million $tCO_2eq.$)
	Construction Material	Transportation	Construction Site	
2016	45.6	1.2	4.9	51.8
2017	67.9	2.1	5.2	75.3
2018	71.8	2.3	5.5	79.6
2019	66.8	2.3	5.6	74.6
Average (2017 – 2019)	68.8	2.2	5.5	76.5
Average Distribution (2017 – 2019)	**90%**	**3%**	**7%**	

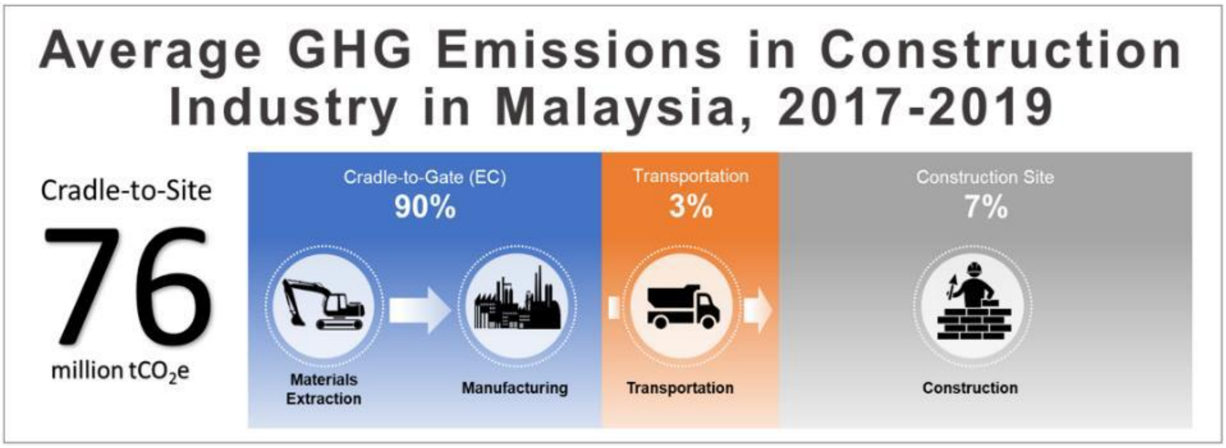

Figure 33: Average of GHG emissions (million tCO_2eq.) from construction industry for the year 2017 – 2019

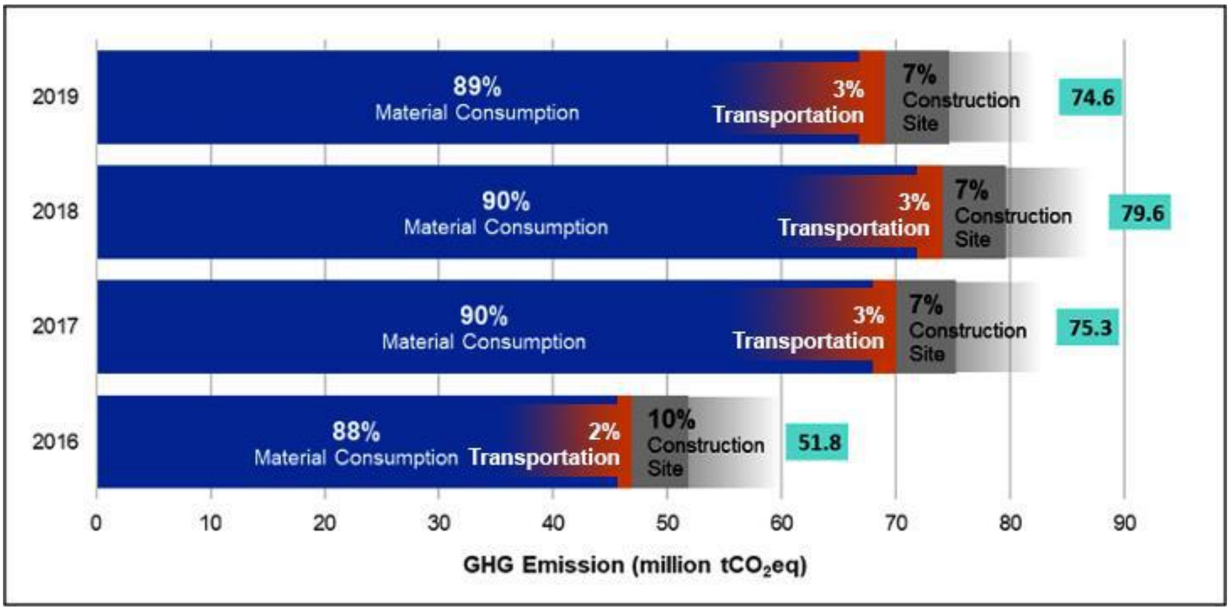

Figure 34: Summary of GHG emissions (million tCO_2eq.) from construction industry from the year 2016 to 2019

The GHG emissions from cradle-to-site were compared to the national GHG emissions, 317.63 million tCO_2eq. in the year 2014 as reported in NC3/BUR2 to the UNFCCC and tabulated in Table 62.

Table 62: Comparison of GHG emissions from construction materials used in construction industry (EC cradle-to-gate) and national GHG emissions

Year	GHG Emissions from Construction Materials Used (Cradle-to-Gate) (million tCO_2eq.)	% compared to the National GHG Emissions 2014 (NC3/BUR2)
2016	51.8	16%
2017	75.3	24%
2018	79.6	25%
2019	74.6	23%
Average 2017 - 2019	76.5	24%

The average GHG emissions from cradle-to-site from 2017 – 2019 were calculated to be **76 million tCO_2eq.** This amount is approximately **24% of the total national GHG emissions** in the year 2014 (latest available report) as reported in NC3/BUR2 to the UNFCCC (Table 62), which shows the significant contribution of GHG emissions from construction sector (cradle-to-site).

4.6 Projection of GHG Emissions in Malaysia's Construction Industry (Year 2020 to 2050)

The GHG emissions projection from the year 2020 to the year 2050 contributed by the construction industry (cradle-to-site) in Malaysia was carried out under this Study. The material consumptions, fuel consumptions, electricity consumptions, and waste projections up to 2050 were estimated using the econometric approach. The economic indicators used in a projection such as GDP were taken from the DOSM, EPU and World Bank. The historical correlation between consumption of construction materials and energy demand as well as macroeconomic and activity indicators were derived by regression analysis.

As shown in Chapter 3.5 of this report, macroeconomic data, which is GDP, was the best variable as it has a strong relationship with the materials and energy demand trend. These macroeconomic indicators were mainly used to generate the model equations. The projections for material consumption, fuel consumption, electricity consumption, and waste are described below. Based on Table 63, about 75.9 to 134.7 million tCO_2eq. projected GHG emissions will be released to the atmosphere.

Table 63: Projected GHG emissions for the construction industry in Malaysia for the year 2020-2050

Year	Material Consumption	Transportation	Construction Site	Grand Total (million tCO_2eq.)
2020	68.6	2.3	5.7	76.6
2025	78.7	2.7	6.6	87.9
2030	89.2	3.0	7.5	99.7
2035	99.8	3.4	8.3	111.5
2040	110.6	3.7	9.3	123.6
2045	121.7	4.1	10.2	135.9
2050	131.6	4.4	11.0	147.0

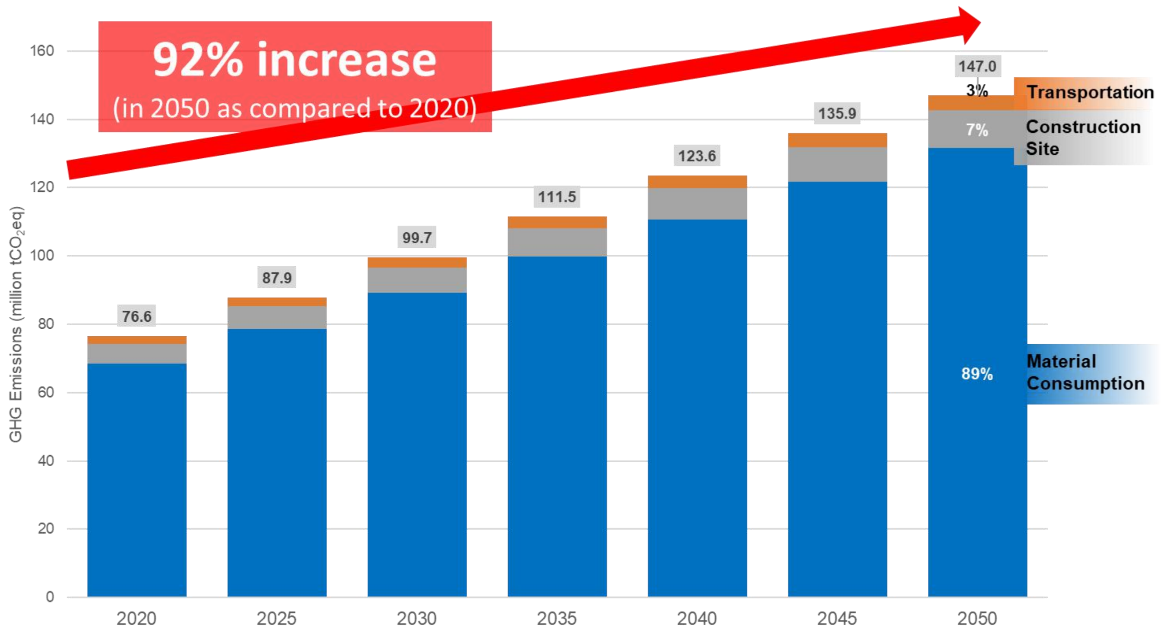

Figure 35: Projected GHG emissions for construction industry in Malaysia for year 2020 to 2050

It was projected that the total GHG emissions of **147 million tCO_2eq.** (**92% increase** as compared to 2020) will be emitted from the construction industry (cradle-to-site only) by the **year 2050** (Figure 35) if no mitigation efforts are taken[56].

4.7 GHG Emissions and Reduction Target Assessment

In order to mitigate climate change and reduce GHG emissions in Malaysia, one of the outcomes of the strategic thrust of CITP 2016 – 2020 is to support the nation's goal to reduce the industry's GHG emissions by **4 million tCO_2eq.**

As shown in Figure above, the **embodied carbon (EC)** in construction material contributes to **90%** of the **total GHG emissions** (cradle-to-site). Thus, considering the impact of proposed mitigation strategies, it was proposed that the government to focus on GHG mitigation efforts related to developing and adopting low carbon construction material.

If low carbon construction materials are introduced in the initial building design of the construction projects, the total GHG emissions of the whole constructed facility can be efficiently controlled and mitigated. A practical mechanism for reducing GHG emissions is through the adoption of low carbon construction material labelling, which involves the measurement of the EC from the extraction, production and final product (Cradle-to-Gate).

Based on the average GHG emissions calculation from the year 2017 - 2019, the five (5) construction material listed below are the major GHG contributors, contributed approximate **92% of the total EC emissions**:

- Ready mixed concrete;
- Steel reinforcement;
- Bricks;
- Cement; and
- Steel and metal.

[56] Detail Calculation for the GHG emissions Projection (2020 – 2050)

Different scenarios for the target reduction were analysed and it was found that the reduction target under the CITP of 4 million tCO_2eq. could be achieved by reducing at least **6.4% of the total GHG emissions** from the five (5) construction materials listed above:

Table 64: Proposed reduction target for five (5) major GHG contributors' construction material

Construction Material	Target Reduction (%)		
	10%	8%	6.4%
Ready Mixed Concrete	3.28	2.62	2.10
Steel Reinforcement	1.57	1.26	1.01
Bricks	0.58	0.47	0.37
Cement	0.46	0.37	0.30
Steel and Metal	0.42	0.33	0.27
Total (million tCO_2eq.)	**6.31**	**5.05**	**4.04**

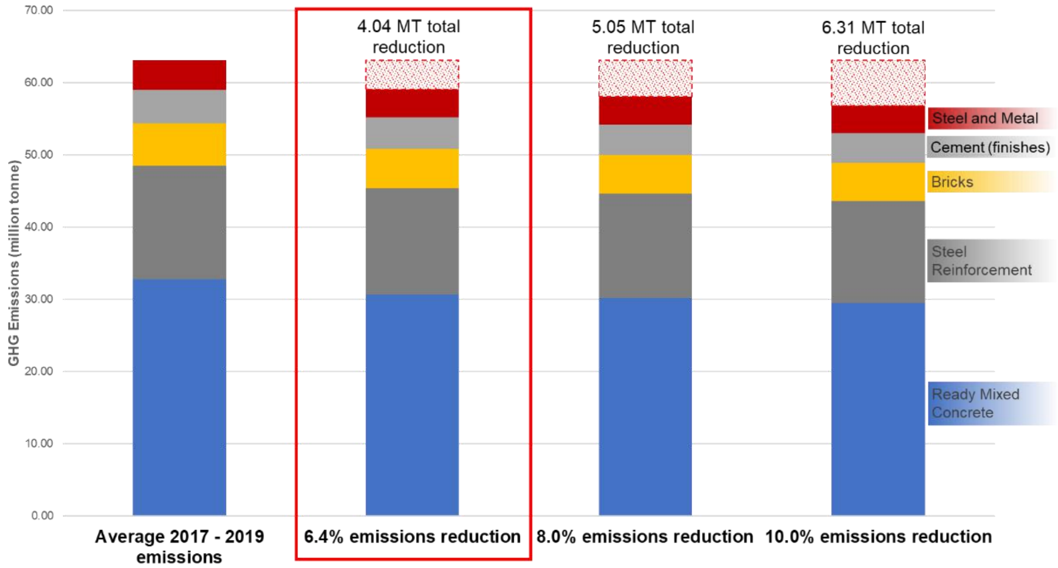

Figure 36: Proposed reduction target for five (5) major GHG contributors' construction material

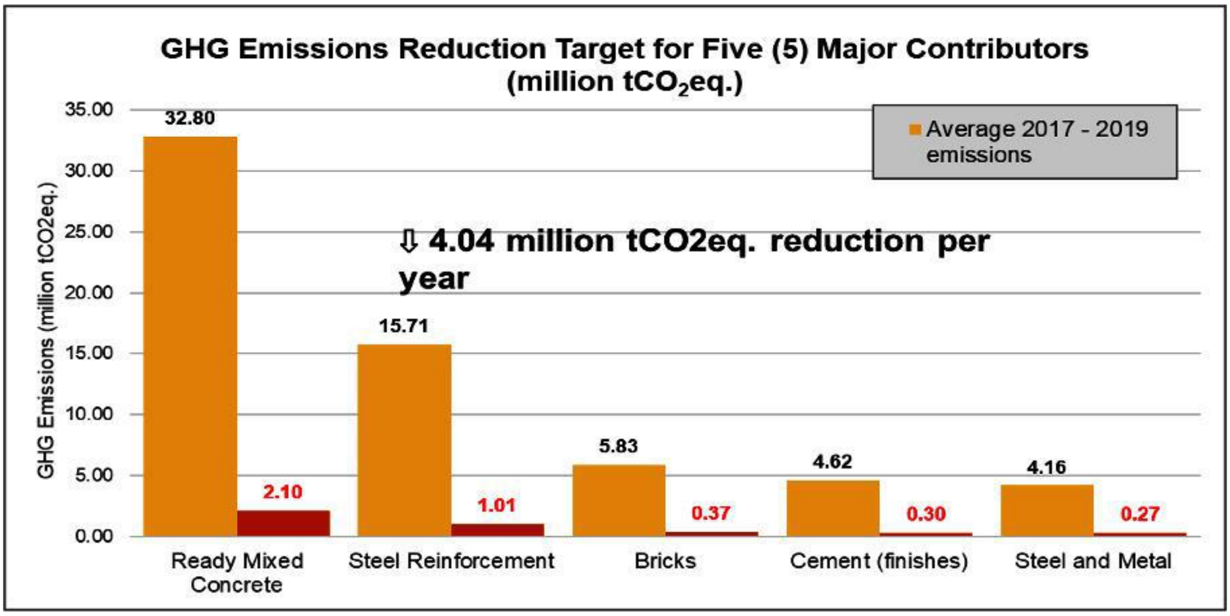

Figure 37: GHG emission reduction target for five (5) major contributors (million $tCO_2eq.$)

A practical mechanism towards reducing GHG emissions is through the development and adoption of a carbon rating and labelling scheme for the material with high EC. The benchmarks of construction material proposed for the top five (5) major contributor is based on the review of local and international databases[57] available. The detailed description of the proposed benchmarks is presented in Section 5.3.2.4.

[57] http://www.cic.hk/files/page/148/CICR06-14-A%20Comprehensive%20Hong%20Kong%20Based%20Carbon%20Labelling%20Scheme_RS_023.pdf

5.0 INCENTIVE AND DISINCENTIVE MECHANISM

In response to the pledge made under the Paris Agreement in the year 2016, Malaysia is committed to reducing its GHG emission intensity per GDP by 45% by the year 2030 compared to the year 2005. This is subjected to technology transfer and financial support from developed countries.

In order to achieve Malaysia's commitments to the Paris Agreement, drivers are needed to encourage the construction sector to shift towards low GHG emissions practices.

In July 2009, Malaysia has launched a National Green Policy which stated that Green Technology (GT) shall be one of the drivers to accelerate the national economy and promote sustainable development. The GT is defined as the development and application of products, equipment and systems used to conserve the natural environment and resources, which minimises and reduces the negative impact of human activities. Among the criteria of the GT, one of them is the GT must have zero or low GHG emissions.

The National Green Policy had four (4) major emphases in which one of them is on the building. The adoption of new technologies has been promoted by the government alongside the introduction of various incentive mechnisms such as green technology tax incentives (i.e. Investment Tax Allowance (ITA) and Income Tax Exemption (ITE)) and GT Financing Scheme. Developers, project owners and service providers for the green projects that able to meet the criteria of GT are eligible for the application. The incentives offer an exemption on income tax and capital expenditure tax allowance for the qualified investments and purchases related to GT. While the GT Financing Scheme promotes green investments by providing easier access to financing and lower financing cost. The main target of these schemes is to encourage the project owners/ developers/ companies to venture into the GT project which ultimately can contribute to the overall GHG emissions reduction.

Despite all the incentives available, there is a gap in bridging the construction sector and usage of GT in construction projects. There appear to be no strong incentive mechanisms that can greatly move the construction sector towards a greener and more sustainable construction practices. Therefore, it is important to establish a baseline of incentives and disincentives mechanism that specifically targets the construction sector.

5.1 Compendium on Incentive and Disincentive on Construction Industry

Incentives and disincentives are common tools to influence the behaviour of individuals and organisations. The types of incentives often differ according to the target group and objective intended. In order to reduce GHG emissions from the construction industry, specific mechnism should be devised to specifically target each construction activity. Construction activity can be divided into a few stages such as material extraction, material manufacturing, material transportation to site and construction operation.

There are a few incentive and disincentive mechanisms implemented globally aiming to reduce GHG emissions from the construction industry. This section assesses selected mechanisms that have relevance to the construction industry in Malaysia and are elaborated below:

Table 65: Compendium of incentives and disincentives

INCENTIVES	DISINCENTIVES
Tax incentives for GHG reporting	Carbon tax
Low carbon funding	Mandatory GHG inventory
Low carbon materials incentive	Cap-and-trade system

Each of the mechanisms assessed in terms of the implementation, feasibility and other key parameters.

5.1.1 Incentives

5.1.1.1 Tax Incentives for Conducting a GHG Reporting

GHG reporting is an inventory for any process or activity that releases a GHG from an entity within the defined reporting boundary. A GHG reporting allows one to identify the main contributors of GHG emissions within the reporting boundary. Monitoring plans and GHG reduction strategies can be created efficiently and effectively from the information gathered for the GHG reporting.

The process of GHG reporting requires extra efforts, time and cost (e.g. extra overhead, hiring consultant, etc.) on top of the normal operational expenditure which may cause a burden to the reporter. Most of the organisations do not see the need and not mandatory to have the GHG reporting unless it is required by their client or customer. Thus, a financial incentive that helps subsidise the costs of GHG reporting can encourage greater participation in voluntary GHG reporting. Below are two (2) examples of tax incentives for conducting GHG reporting.

5.1.1.1.1. CarbonSmart

CarbonSmart is a government funded program organised by the Hong Kong Productivity Council (HKPC) in collaboration with the Federation of Hong Kong Industries, the Hong Kong General Chamber of Commerce and the Business Environment Council. The objective of the program is to encourage industry-wide participation in carbon audit and GHG reductions. The key initiative of the program is to provide subsidies towards conducting carbon audit to Hong Kong companies who participate in the development of environmental industries to make Hong Kong a low carbon city. The total budget of the program is $6 million. An organisation or building can be subsidised up to 50% of the cost for preparing GHG reporting or a maximum of $30,000.

5.1.1.1.2. MYCarbon

In the year 2013, the then Ministry of Natural Resources and Environment (now known as KASA) had launched a national corporate GHG reporting program in Malaysia, MYCarbon with the support from United Nation Development Programme (UNDP). The program had developed a reporting standard to guide the organisations in Malaysia to prepare their corporate GHG reporting. Trainings were provided to the organisations who are interested to join the program. The participated organisations were from different sectors such as finance, telecommunication, power, manufacturing and etc. The program is idle since the year 2015.

5.1.1.2 Low Carbon Fund

A low carbon fund is a fund allocated by the government to reward organisations, companies or developers that venture in low carbon initiatives including services, assets or projects. The technology or materials are assessed by a regulatory body and verified using s certificate or green label. The fund is also used as a boost for companies to shift towards low carbon initiatives such as eco-friendly machinery and a low carbon production line. Examples of funds established by the Building and Construction Authority (BCA) Singapore are elaborated below.

5.1.1.2.1 Sustainable Construction Capability Development Fund (SC Fund)

As part of BCA Singapore initiatives to drive sustainable construction, a fund has been set up to develop capabilities of the industry to adopt sustainable construction methods and materials. The S$15 million funds are allocated; effective from April 2010 until it was exhausted. The key areas of sustainable construction include the encouraging greater adoption of recycled materials into construction practice, waste management and recovery, and development of eco-friendly products.

5.1.1.2.2 Green Mark Incentive Scheme (GMIS)

The GMIS by the BCA Singapore aims to encourage developers, building owners and project consultants to adopt the environmentally-friendly design, technologies and practices in their building projects to achieve a more sustainable built environment. Cash incentives from a fund will be awarded to the developer, building owner or consultant for new projects which meet at least a BCA's Green Mark Gold rating or higher. The scheme is categorised into four (4) categories:

a) Green Mark Incentive Scheme for New Buildings (GMIS-NB)
   - *Cash incentives for new buildings who achieve at least a BCA Green Mark Gold rating in the design and construction*

b) Green Mark Incentive Scheme – Design Prototype (GMIS-DP)
   - *Provides funding for the engagement of Environmentally Sustainable Design (ESD) consultants to conduct collaborative design workshops and assist in simulation studies early in the project*

c) Green Mark Gross Floor Area Incentive Scheme (GM-GFA)
   - *Extra fund by URA for those who attained Gold and Platinum awards (encourage the private sector to strive higher green mark rating)*

c) Green Mark Incentive Scheme for Existing Buildings (GMIS-EB)
   - *Fund to encourage adopting energy-efficient retrofitting design, technologies and practices in their existing building to achieve a significant improvement in the building energy efficiency*

5.1.1.3 Low Carbon Materials Incentive

The construction sector is the largest global consumer of materials while the building sector is the largest single energy user worldwide[58]. According to IPCC 2014, GHG emissions from the building are approximately 19% of the global emissions. Consequently, policymakers have structured various regulations and policies in order to minimise GHG emissions by buildings. However, the majority of the regulations were only focused on the GHG emissions associated with energy use activities such as heating, cooling and lighting. Less focus is given towards the initial process of construction such as materials extraction, materials transportation and the initial phase of construction.

There are many alternative materials with low EC that can potentially be adopted by the construction industry in Malaysia. The by-products of power plant operations can be recycled and convert into additives to the cement. Some examples of this include fly ash brick, blended cement with the addition of ash and metal residual slags. The quality of the cement is proven to be the identical as the conventional cement used in construction. Figure shows some other alternatives low carbon materials for construction.

Figure 38: Alternative low carbon construction materials

One of the incentives for low carbon materials is to reward the contractor, developer or building owner who incorporate low carbon materials in their building. The reward can be in the form of tax reduction or exemption. Without the tax reward, conventional materials that have high EC but low in expenditure costs are often favoured by main players. There are two (2) examples of tax incentives implemented in Malaysia as elaborated below. However, the incentive mechanisms are not attractive enough to gain huge participation interest from the industry and construction players nowadays

[58] Krausmann et al., 2009; De la Rue du Can & Price, 2008

5.1.1.3.1 MyHIJAU Mark

MyHIJAU Mark is a government program designed to promote the purchasing of goods and services that are environmentally friendly. Through the program, products, systems or services certified by other eco-related labels will be endorsed under one uniform label namely MyHIJAU Mark. The certified green products and services are systematically organised and categorised with detailed information for consumer reference. Products and services that carry the MyHIJAU Mark logo are entitled to ITA and ITE. The products and services are also eligible to participate in the government green procurement.

5.1.1.3.2 Industrialised Building System

Industrialised Building System (IBS) is defined as a construction process that uses the adoption of prefabrication of components in building construction and projects. The components are manufactured in a controlled environment, on or off-site and then transported, positioned and assembled into a structure with minimal additional site work. IBS has been proven to reduce the construction time at the site, reduce the materials wastage and reduce environmental impact due to transportation of construction materials to the site. Therefore, shifting towards the IBS system will reduce GHG emissions by the construction industry compared to conventional construction practice.

In order to encourage the adoption of IBS in the construction projects in Malaysia, the IBS Tax Incentive is introduced. There are four (4) tax incentives available for the IBS business[59].

a) Income Tax Exemption
   - *Tax exemption given to the new IBS manufacturers or those with pioneer status for setting up a new factory, yard or IBS plant.*

b) Investment Tax Allowance
   - *Tax allowance given to new IBS manufacturers with a 60% or 100% tax allowance on capital expenditures for 5 years.*

c) Reinvestment Allowance
   - *60% allowance on qualifying capital expenditure for exemption for fifteen (15) consecutive years.*

d) Import Duty Exemption
   - *Import duty exemption given for raw materials, components, machinery and equipment.*

5.1.2 Disincentives

5.1.2.1 Carbon Tax

A carbon tax is where the government imposes a tax on any company that emits GHG above the set limit. The tax system can be modified gradually either by increasing the cost tax or decreasing the limit of the tax over time. Generally, the tax system is implemented on the overall GHG emissions over any sector eligible, including the

[59] http://www.cidb.gov.my/images/content/pdf/bisnes/prospect20182019/CIR-2018-2019-Chapter-5.pdf

construction sector. The carbon tax is carrying out in many countries such as Singapore, Finland, Denmark and etc. as elaborated below.

5.1.2.1.1 Singapore

National Environment Agency (NEA) of Singapore introduced the Carbon Pricing Act at the end of 2018 and executed the carbon tax in the year 2019. It covers the major industrial direct emitters which comprise 80% of Singapore's total GHG emissions. The facilities that emit 25,000 tCO_2eq. and above annually are levied for S$5/$tCO_2eq$. for the year 2019 until 2023; the tax rate will be reviewed, plans to increase to S$10 to S$15/tCO_2eq. by the year 2030.

The taxable facilities include power generators, oil refineries, petrochemicals, semi-conductor manufacturing, electronics, biomedical manufacturing, waste and water management industries. The taxable facilities are required to purchase carbon credits from NEA upon receiving the Notice of Assessment. The revenue from the received tax will use as a fund/ grant to support industries in energy efficiency efforts which eventually will minimise GHG emissions.

Apart from the carbon tax, the taxable facilities are required to submit a monitoring plan which identifies and describes the emission sources and stream, emissions quantification methods, alternative methods, quality management procedures and uncertainty. The facilities are also required to engage an accredited third-party verifier to verify the emissions report.

5.1.2.1.2 Finland

Finland was the first country to introduce a carbon tax as an instrument for climate change mitigation. The scheme was enacted since January 1990 and it is a tax based on the carbon content of the fossil fuels with a charge of €1.12/tCO_2eq. (now €70/tCO_2)[60]. When the carbon tax was in place in Finland in 1990, there were a few exemptions for specific fuels and sectors. For example, the wood industry was exempted due to the export-oriented industry. Also, the fuels used in the industrial production for manufacturing goods were also exempted. However, the carbon tax scheme slowly evolved and the rates and coverage have gradually expanded.

5.1.2.1.3 Denmark

The Danish carbon tax system started in 1991 covering all consumption of fossil fuels with a partial exemption for sectors covered by European Union (EU)-Trading schemes, energy-intensive processes, exported goods and many transport-related activities. The main goal was to reduce GHG emissions from 61.1 to 48.9 million tCO_2eq. before 2005 (equivalent to 20% reduction within 15 years). Thus, this proves that the tax system is able to reduce GHG emissions in long term period.

5.1.2.2 Mandatory GHG Reporting

The big data obtained from the mandatory reporting programs can provide a better overview of GHG emissions in the region/country which can enhance policymakers'

[60] http://blogs.ubc.ca/rosonluo/files/2013/02/30porter-graphic-popup.gif

understanding of specific emissions sources within each sector and create effective policies to reduce emissions.

Figure 39 shows the countries that participate in the mandatory GHG reporting programs.

Source: WRI

Figure 39: Countries participate in the mandatory GHG reporting program

In addition, the mandatory reporting supports emission-trading schemes by providing reporters with a uniform methodology to calculate, report, monitor and verify emissions from all sectors. This is essential to build trust for the carbon market as it encourages data to be uniform, reliable and comparable amongst the participants.

5.1.2.2.1 Singapore

NEA has implemented mandatory annual GHG reporting since 2013. Any facilities with annual GHG emissions of 20,000 tCO_2eq. and above from their Scope 1 emissions are required to submit their report via Emissions Report User-Interface (UI) provided by NEA in the Emissions Data Monitoring and Analysis (EDMA) system by the 30th of June on the following year. Through this mandatory GHG reporting program, NEA is able to study and establish the baseline to implement the carbon tax.

5.1.2.3 Cap-and-Trade System

The cap-and-trade system is a government regulatory program designed to limit or cap the total level of GHG emissions from the industrial sectors. The main objective of the system is the same as the carbon tax, which is to reduce the environmental damage without causing any negative economic impact to the industry. The Government will set a limit on the issuance of annual permits that allow companies to emit a certain amount of GHG. The limit will become the "cap" on the emissions. Companies that reduce their emissions can sell or "trade" the unused permits to other companies that reach or go above the limit permitted. Companies also have the option to store spare allowances received through the reduction of their emissions. These spare allowances can be then used later to cover the company future's emissions. Few examples are elaborated below.

5.1.2.3.1 EU Emissions Trading System (EU ETS)

The EU ETS is the largest and the first GHG emissions trading scheme in the world launched in the year 2005. It is a major pillar of EU climate change energy policy. According to the European Commission, GHG emissions from big emitters covered by EU ETS have decreased on average by 17,000 tonnes per installation during the year 2005 until 2010. Overall, the result from the trading scheme shows an immediate and significant GHG emissions reduction at minimal cost while having GPD growth. The EU ETS has also shown an escalation of various low carbon solutions to cater to the demand from the industries.[61]

5.1.2.3.2 South Korea Cap-and-Trade

The program was launched in 2015 and became the second-biggest carbon trading scheme after the EU ETS. South Korea aiming to cut GHG emissions by the year 2020. The cap and trade scheme include 525 of the country's largest polluters across various sectors. The total allowable emissions for the year 2015 to 2017 for all the polluters are 1.67 million tCO_2eq.

5.1.2.3.3 California Cap-and-Trade

The program launched in the year 2013 is one of the major policies in the State to lower GHG emissions. The cap-and-trade rule applies to large power plants, industrial plants and fuel distributors. Facilities that emit more than 25,000 tCO_2eq. yearly are subject to the regulation. Around 450 businesses are required to commit to the program which is equivalent to 85% of the total GHG emissions in California.

5.1.2.4 Mandatory Low Carbon Materials

The construction sector often neglects the use of low carbon materials in their projects due to no regulatory or instruction given. Implementation of mandatory low carbon materials in the construction sector will force one to adhere to the regulation and thus greatly reduce the level of EC in the construction sector.

5.1.2.4.1 Buy Clean California Act (AB 262)[62]

Buy Clean California act or the AB 262 is a law enforced in 2017 to encourage GHG emission reductions associated with state infrastructure projects. AB 262 requires state agencies to consider EC from the production of construction materials, such as rebar, during contracting for state projects. The Department of General Service (DGS) established a GHG emissions performance standard to be used in all state infrastructure projects. The state agencies' projects will need to include the GHG standard in bid specifications that are the same or below the standard set by DGS. The awarded bids then need to demonstrate the proof of materials to meets the standard.

[61] Lucas Merrill Brown, Alex Hanafi, & Annie Petsonk, 2012; UNESCAP, 2012

[62] http://us.wsp-pb.com/blogs/green-scene/greenhouse-gas-management/buy-clean-california-act-creates-incentive-to-cuts-carbon-emissions-by-requiring-epds/

5.2 Feasibility Report on Incentive and Disincentive on Construction Materials

Incentives and disincentives are essentially a way to encourage different parties to perform under a required set of objectives, in this case being the reduction of GHG emissions from the construction industry. The difference of each mechanism is usually depending on the micro objective needed to be achieved from the parties. Thus, these mechanisms should be discussed specifically. Several perspectives should be considered when assessing the feasibility of these available GHG reduction mechanisms.

5.2.1 Economic Perspective

Incentive and disincentive mechanisms have economic and financial consequences. The conventional construction practice has been in place for many decades. The changes in the materials and equipment will result in more expenses. Incentive mechanisms should be able to balance out the extra expenses incur.

5.2.2 Relational Perspective

Collaborative working has become popular among organisations. People build mutual understanding and may have built business commitment with each other. Hence, the impact of incentive or disincentive sometimes get ignored due to the networking and work relational factors. Thus, it is important to look at the relationships in business whenever incentives or disincentives are put into effect.

5.2.3 Psychological Perspective

The psychology of how people and organisations can be motivated to improve performance in a wide area that need to be considered when implementing the mechanism. Disincentives such as penalties for bad performance, will sometimes result in demotivation to adhere to the GHG emissions reduction goals. Thus, balancing between incentive and disincentive is crucial to ensure the industrial and construction players are willing to participate in the GHG reduction goals in the long run.

Table 66: Perception on the incentives and disincentives mechanisms

		Economic Perspective	Relational Perspective	Psychological Perspective
INCENTIVES	Tax Incentives for Conducting a GHG Reporting	• GHG reporting and report verification to incur extra costs to the organisation • Incentives can compensate for the extra cost incurred	• Lack of skills and knowledges on GHG reporting within the organisation • Required accredited third-party verifier to verify the report • Training and guidance on GHG reporting is needed to encourage the participation from the organisations	• No motivation to conduct GHG reporting • Not aware the importance of GHG reporting • Non-mandatory reporting will lead to negligible action by the organisations
	Low Carbon Fund	• Funds can be allocated by government or joint fund provided by investors • Many investors will result in a huge amount of funds, thus the funding mechanism can widely cover various sectors	• Government should emphasise on the marketing and communication of the low carbon fund • Encourage more research and development (R&D) on low carbon materials and operation • More job opportunities created	• More participation from small businesses can be achieved • Able to attract more investors to contribute to invest and eventually increase the low carbon fund
	Low Carbon Materials Incentive	• Low carbon materials are perceived as high-cost materials • The incentive given to the construction players to switch to low carbon materials must at least the same as the cost gap between conventional and low carbon material	• Lack of knowledge on the alternative low carbon materials • Difficult to obtain low carbon materials from local sources • Quality assurance and certification of the low carbon materials are needed. SIRIM and MGTC should be the "bridge" to connect the low carbon materials supplier to the contractors and developers	• Clients, architects or engineers preference for conventional construction materials as no quality assurance is given to the low carbon materials • Not a regulatory requirement to use low carbon materials in a project

		Economic Perspective	Relational Perspective	Psychological Perspective
DISINCENTIVES	Carbon Tax	• Proven effective way to curb climate change. • The tax can be increased gradually, hence can raise income for the government to support other low carbon reductions mechanisms in the long run	• Mandatory GHG reporting has to be implemented before hand • Potential production loss in order to meet the GHG emissions limit • Possible to affect the supply chain of products. For example, the tiles manufacturer might reduce the production in order to overly emit the GHG.	• The tax may hinder the development progress of a country especially the developing countries The tax should be alongside the mandatory GHG reporting. Mandatory GHG reporting in advance to study the baseline and gradually introduce the tax so that industries have sufficient time to get ready for the implementation of tax
	Mandatory GHG Reporting	• Extra cost to conduct GHG reporting caused by extra overhead or/and hire a consultant	• Create more job opportunities such as environmental executive or consultant for GHG reporting	• Create an extra task for the organisation to obtain all relevant data
	Cap-and-Trade System	• Uncertainty of the GHG emissions limit and penalty rates	• The cap-and-trade system should be implemented alongside with mandatory GHG reporting • A reporting guideline that suits all sectors need to be established to avoid misinterpretation of the GHG emissions	• Perceived as one is allowed to emits GHG by sourcing carbon credits from other parties and not solving the real GHG emission issue • The flexibility of this system also encourages one to take efforts to reduce their emissions and trade their carbon credits (alternative revenue)
	Mandatory Low Carbon Materials	• Extra cost incurred to change the equipment and use low carbon materials • Should be balanced with the usage incentive	• Some contractors are bound to suppliers due to business agreements. Hence, the mutual agreement will be interrupted • Quality assurance and certification of the low carbon materials need to be implemented before hand • Balance of supply and demand	• The quality of the low carbon materials is questioned • Government to take the lead to mandatory the use of low carbon materials in their project as show cases.

5.3 Consideration of Incentive and Disincentive Mechanisms for Malaysian Construction Industry

Based on the above assessment of possible incentive and disincentive mechanisms, as well as the inputs and feedbacks from the FGD conducted on the 7th of January 2020, 18th of June 2020 and the benchmarking visit to Singapore between the 12th to 15th of January 2020, the following mechanisms are proposed to be considered for adoption in the Malaysian construction industry.

The mechanisms/policies are discussed in terms of possible implementation, incentives support and disincentives measures. The recommended implementation is based on the priority and timeframe which is listed as below:

- Short term : 1 – 2 years
- Medium term : 2 – 5 years
- Long term : > 5 years

Table 67: Proposed incentive and disincentive mechanisms

No	Recommended Incentive/Disincentive Mechanism	Potential Impact on GHG	Implementation Priority
GHG Reporting			
1.	c) <u>Voluntary GHG reporting</u> • Revive MYCarbon program – reporting framework	• Encourage stakeholders to track, monitor and reduce GHG emission	Short Term
	d) <u>Mandatory GHG reporting</u> • To extend the reporting requirement to the manufacturers who emit above a cap value of GHG emissions • Complementary with tax incentives	• Encourage stakeholders to track, monitor and reduce GHG emission	Medium Term
Low Carbon Construction Materials			
2.	d) <u>Market development</u> • Research and Development (R&D) research fund • Enhance acceptance of usage – e.g. material standards/ specifications/ certification • Include in Government Green Procurement requirement	• To establish market demand for low carbon materials in the construction industry • Wider acceptance and adoption of low carbon material, leading to direct	Short to Medium Term

No	Recommended Incentive/Disincentive Mechanism	Potential Impact on GHG	Implementation Priority
		emission reduction.	
	e) <u>Enhancing material usage</u> • Carbon labelling/ rating for material • Tax incentives for recycling of construction waste and usage of low carbon material	• Carbon labelling rating as a tool to benchmark the GHG intensity of material use – encourage adoption of low carbon construction material	Short to Medium Term
	f) <u>Mandatory material usage</u> • Progressive target for manufacturers • Progressive target for projects (e.g.% material must be low carbon)	• Manufacturer to lower the GHG intensity of their products through various innovations progressively	Medium to Long Term
	Carbon Tax / Cap-and-trade System		
3.	b) <u>Create carbon mechanism</u> • Government to decide on whether to impose a carbon tax or introduce a cap-and-trade system	• Drives industries towards low carbon development to stay competitive • Carbon trading encourage more investment in the low carbon material selection	Medium to Long Term

5.3.1 GHG Reporting

GHG reporting has been widely implemented globally especially in developed countries. Through undertaking the GHG reporting, emissions can be identified and specific action plans can be devised by policy-makers with a strong basis and baseline emissions value. The reporting is completed through a voluntary or mandatory reporting approach. Guidelines and frameworks are provided by the government to ensure a uniform reporting format across the nation. The coverage of the reporting can be included in various types of business sectors such as manufacturing factory, office building, commercial building and power generation plant. Uniform reporting can offer comparable values and parameters which will play as a crucial role for future policy undertake such as cap-and-trade system and carbon tax.

Several feedbacks have received from the industrial players regarding to the GHG reporting which including the lack of expertise, support and guidelines to conduct the GHG reporting. The players are also reluctant to invest for the reporting purpose because of no obligation or Act for the GHG reporting. Therefore, a government agency such as the Ministry of Environment and Water (KASA) (also known as Ministry of Energy, Science, Technology, Environment and Climate Change, MESTECC) should spearhead the GHG reporting program for the industrial players. By carrying out the discussion with the Climate Change team of KASA, the Ministry is currently conducting a scoping study on the development of climate change legislative framework which including the study on the GHG reporting mechanism for the private sectors.

One of the critical aspects to address regarding to GHG reporting is the selection of the business sector to conduct the reporting. A threshold value of GHG emissions needs to be determined before imposing the mandatory GHG reporting on the emitters. To kickstart the GHG reporting policy, large GHG emitters should be determined to report on their emissions by reviving the MYCarbon program in order to identify the threshold of the emissions. In fact, re-establishing the program can save lot of resources and time by implement it as a "voluntary" basis. The program shall expand its coverage to cover the GHG reporting for products (especially production of construction materials) and project (especially construction activities).

GHG reporting required specific skills and knowledges. An extra cost is needed to develop the "in-house" capability to conduct the GHG reporting. Undoubtedly, engaging third-party experts to conduct the reporting and verification will incur additional expenses for the companies, hence, it is recommended to start the GHG reporting policy using the voluntary approach. The government should encourage the large emission emitters to voluntarily conduct GHG reporting and to allocate funds to subsidise a portion of the GHG reporting cost in order to maintain the reporting effort in the long run. This can progressively gain the interest of many companies to report on GHG emissions in the future.

As the GHG reporting policy matured, it can be expanded to cover more business sectors including construction sectors. For an instance all construction projects have to provide an inventory of the materials, transportation distance, fuels and electricity used though out the entire project period. Subsequently, overall GHG emissions can be compiled as a report using the guideline provided by the government. The reports can be used as a reference to determine the overall GHG emission from the entire construction sector in Malaysia.

Ultimately, the GHG reporting can be gazetted mandatory as done in many developed countries to provide continuous monitoring of the GHG emissions from construction industry which compliance with the feedback from the industrial players regarding the need for GHG reporting currently. With the mandatory Act implemented together with the support from government through the incentive mechanism, GHG reporting can be successfully implemented in Malaysia.

Summary: GHG Reporting

Key agency: **KASA**

Figure 40: Proposed workflow to develop a GHG reporting policy

5.3.2 Low Carbon Construction Materials

EC can account between 2% to 80% of whole-life GHG emissions of a whole life cycle of a building[63]. GHG emissions from the EC of the construction materials have a significant contribution through-out the construction project period. Therefore, a key mitigation strategy to reduce the overall GHG emission is shifting towards the lower EC materials in the construction industry.

Similar to other developing countries, the construction industry in Malaysia is facing the same problem on the supply and demand of the low carbon construction materials in construction projects which is due to the barriers in developing the market of alternative materials. Meanwhile, the lack of demand for such materials in view of the low level of awareness and acceptance of the low carbon alternative material in the current market.

5.3.2.1 Market Development

The first key strategy for the adoption of low carbon construction materials is to develop a market demand for the materials. This can be achieved through a fund to support the low carbon effort by the construction industry. As an example, the development of "green bricks" using the reservoir sediment which have been demonstrated and proved to behave similarly to the clay bricks. Another example of R&D is the selection of cement with low clinker content based on the use of supplementary cementitious materials (e.g., alternative scheduled waste), innovative materials, material compositions or processes that reduce the EC content (e.g., mechanical treatment, lower temperature requirements, utilisation of recycled materials such as biomass, refuse derived fuel (RDF) from municipal waste) and so forth.

The process of reducing EC in construction materials required changes in the whole life-cycle process of the material. High-efficiency equipment and machinery are needed to improve the quality of the materials. Therefore, the fund can be utilised to develop new low carbon construction materials. The fund can be part of the government budget or joint fund contributed by investors. The framework of the fund needs to be refined further and can potentially encourage more R&D as well as market development for low carbon materials selection

[63] Operational vs. embodied emissions in buildings—A review of current trends (https://doi.org/10.1016/j.enbuild.2013.07.026)

Through the stakeholder's consultation workshop, the industrial players who embarked on the development of the alternative material mentioned that the key influencing factor of the selection of conventional materials over the low carbon materials on account of the credibility on the alternative materials. This is mainly due to a lack of good-quality data and information on the new materials which can be used as a reliable reference for the practicing engineers especially when the alternative materials are being selected like the recycled materials. For an instance, the usage of coal bottom ash is not allowed in Malaysia due its classification as scheduled waste. Unlike other developed countries, bottom ash is proven safe to be used in construction projects. In order to tackle this matter, it is recommended that the government to set up a special task force involving key players such as the Department of Environment (DOE), JKR, CIDB and industrial players to discuss potential issues regarding to the development of alternative construction materials. Guidelines and specifications should be outlined in detail to encourage future development of new low carbon materials in the market.

It is also advisable to include case studies on the usage of the low carbon materials in the construction projects as a practical vision for the construction players to foresee and implement. This could be done by the government to lead by example through the Government Green Procurement (GGP). GGP is referring to the acquisition of products, services and work in the public sector with consideration on protecting the environment, reducing pollution and minimising waste and emissions. GGP is expecting to increase the demand for green products and services since the national Long-Term Action Plan is targeting 100% green procurement by 2030 for the public entities[64]. According to EPU (also known as Ministry of Economic Affairs, MEA), the coverage of materials under the GGP will be expanded and likely to cover more low carbon construction materials in the near future. Therefore, a growing market of low carbon construction materials can be developed and thus raise the awareness of private sectors to select a lower EC construction material.

Another aspect that can be prioritised is to strengthen the market of industrialised building system (IBS) which is growing gradually in Malaysia's construction industry. Even though IBS is proven to speed up the construction process and reduce the overall cost of construction, the usage of IBS is still limited. The advantages of IBS in curbing carbon emission through the reduction of energy used on site, reduction of timber as temporary formwork and reduction of construction waste on site should be utilised to achieve the overall carbon emission reduction in construction industry. IBS score system introduced by CIDB should be revised and regulated to ensure the IBS usage is optimised in government and private projects. The IBS tax incentive also should be improved to attract more participation.

[64] The National SCP Blueprint, 2016-2030

Summary: Low Carbon Construction Materials – Market Development

Key agency: **EPU, MOF, KASA, MITI, CIDB, JKR, DOE, KeTSA, ST, DOE**

Figure 41: Proposed workflow to develop market for a low carbon construction materials

Note:
MITI - Ministry of International Trade and Industry
KeTSA - Ministry of Water, Land and Natural Resources
ST – Suruhanjaya Tenaga

5.3.2.2 Enhancing Materials Usage

Under careful observation and investigation, we can realise that various products labels in the market are certifying green, sustainable and environmentally friendly. As a result, consumers may become confused with the different type of labels and tend to favour with one type of label that they are more familiar with. Under such circumstances, it will create a market diversion of the products and hinder the usage of other green products available in the market. By adopting the National Sustainable Consumption and Production (SCP) Blueprint, government has undertaking an initiative to enhance the MyHIJAU Mark by standardising all other "green label" under one distinctive mark. All products and services that have been certified by other labels will be given MyHIJAU Mark without the need to go through the redundant certification process. All products with the MyHIJAU Mark will be compiled in the MyHIJAU Directory which can be easily accessed through the official website. The certification and endorsement activity should be spearhead by KASA through MGTC and collaboration with SIRIM and Standards Malaysia.

Low carbon materials tend not to be considered as consumers' first choice during the planning and preparation of the bill of quantities of the project due to the perception of the high cost of the materials. Encouraging earlier engagement of supply chains and possible change of tender documents to include low carbon materials should be considered as a requirement for any new project. As a matter of fact, there are still a relatively small number of professions in the construction industry that hold important responsibility for material selection of a project namely architects, clients (developer) and engineers (civil/structural/mechanical/electrical). In order to achieve a reduction in GHG emissions from the construction, architect is required to incorporate the low EC materials during the designing stage. First and foremost, the choices of materials must be specified earlier and proposed to the client. Meanwhile, mechanical and electrical engineers should choose material with lower EC in the beginning of the material selection process. However, in the end, client is the one who make decision for the project. Therefore, knowledge related to the low carbon construction should not only be limited to the architect or engineers. The knowledge of low carbon construction should be incorporated in the syllabus of university to ensure earlier exposure and awareness to the future professionals.

Another initiative that could be undertake by the government is to enhance the alternative construction materials by developing capabilities of the industry to recycle construction and demolition waste for future construction project usage. This has been successfully demonstrated by Singapore where fund (SC Fund) was allocated to encourage sustainable construction practice, improving waste recovery and waste upcycling for non-structural purpose. This initiative should be led by CIDB and SWCorp where a proper guideline and generic template for construction site waste management plan could be developed. Proper waste management and waste recovery for reuse purposes should be outlined clearly to ensure the optimised usage of construction materials at the site. Ultimately, the level of GHG emissions can be reduced due to less volume of raw materials required.

Incentives mechanism should be introduced to gain more participation from the developer (users) and industry (manufacturers). Incentives shall be given to the developer, supplier or contractor who procured or manufactured low carbon materials. Incentive mechanism such as tax exemption to those who procured MyHIJAU Mark's materials can be implemented to increase the uptake of the alternative materials in construction industry.

Summary: Low Carbon Construction Materials – Enhancing Materials Usage

Key agency: **KASA, MITI, MGTC, MOF, SIRIM, Standard Malaysia, Academician**

Figure 42: Proposed workflow to enhance the usage of low carbon construction materials

5.3.2.3 Mandatory Materials Usage

The first step to move towards mandatory use of low carbon construction materials is by setting up a comprehensive carbon labelling for the materials. A label in the form of carbon footprints which includes the level of EC, raw material origin and energy required to manufacture, should be developed to allow a direct comparison between materials. The government should standardise the parameters that need to be shown by the manufacturer and give rating based on the level of environmentally friendly of the products. All the information should be compiled in one database and made ready for consumers. Example of such database is the Environmental Product Declaration (EPD). EPD is primarily to facilitate the consumers who are environmentally concern on the product use. It provides the environmental information on the life cycle of a product and enable a direct comparison between products that serve the same purpose.

Speaking of Hong Kong as an example, construction material carbon rating (labelling) system has been introduced and such a system could also be adopted for Malaysia as a basis for developing low carbon material incentives. The labelling system aims to develop a set of a carbon assessment framework for selected categories of construction materials. The carbon label also shows the total amount of GHG emissions of the materials from "cradle-to-site", covering the extraction of raw materials, manufacturing and transportation to the boundary of Hong Kong. Construction projects that utilise high carbon rating (low EC emissions) materials will get better rating for their projects and applicable to enjoy tax incentives.

Table 14 Proposed benchmark for stainless steel

Carbon Rating	Carbon Emission ($kgCO_{2e}/kg$)
A	≤ 1.61
B	1.61~2.19
C	2.19~3.65
D	3.65~4.25
E	≥4.23

Figure 43: Example of carbon rating system for construction material in Hong Kong[65]

The establishment of carbon labelling will enable the government to progressively limiting the level of EC in construction. The materials' manufacturers should be required to reduce the level of EC gradually. This regulation could potentially be the greatest driver in changing the construction industry practice. However, it must be carefully studied and involve consultation with the manufacturers and consumers. The processing changes to lower the EC level required high capital cost. Therefore, consultation with manufacturers and consumer is crucial to avoid market disruption. Unrealistic mandatory reduction targets will discourage the manufacturer's production. The local supply of materials will be reduced and consumers will choose to import the construction materials from overseas.

Summary: Low Carbon Construction Materials – Mandatory Materials Usage

Key agency: **KASA, MOF**

Figure 44: Proposed workflow to establish mandatory low carbon construction materials usage

Sustainable Carbon Rating and Labelling

As mentioned in Section above, a practical mechanism towards reducing GHG emissions is developed through the adoption of a carbon rating and labelling scheme

[65] Hong Kong Construction Industry Council (2018). A Comprehensive Hong Kong based Carbon Labelling Scheme Covering Carbon Intensive Construction Materials.

for the material with high EC. The benchmarks of construction material proposed are established based on the review of local and international databases[66] available.

Top five (5) major GHG contributors

The EC for the five (5) types of construction materials identified and applied is tabulated as below:

Table 68: EC for top five (5) GHG contributors applied in GHG calculation

Construction Material	EC ($tCO_2eq./t$)		
	ECO-CM Hong Kong (2013)[67]	ICE UK V3.0 (NOV 2019)	Malaysia SIRIM (2013 – 2018)
Ready Mixed Concrete		0.209	
Steel Reinforcement	1.900		
Bricks	0.265		
Cement			1.0257
Steel and Metal	1.988		

An example of the proposed benchmark for five (5) types of major contributor for Malaysia is tabulated as below:

Table 69: Proposed benchmark for five (5) major GHG contributors

Carbon Rating	EC (tCO_2eq/t)				
	Ready Mixed Concrete	Cement	Steel Reinforcement	Bricks	Steel & Metal
A	< 0.179	< 0.8557	< 0.99	< 0.229	< 1.078
B	0.179 ~ 0.199	0.8557 ~ 0.9657	0.99 ~ 1.39	0.229 ~ 0.249	1.078 ~ 1.478
C	0.199 ~ 0.219	0.9657 ~ 1.0857	1.39 ~ 2.41	0.249 ~ 0.279	1.478 ~ 2.498
D	0.219 ~ 0.239	1.0857 ~ 1.1957	2.41 ~ 2.81	0.279 ~ 0.299	2.498 ~ 2.898
E	> 0.239	> 1.1957	> 2.81	> 0.299	> 2.898

In terms of short-term goals and based on the average GHG emissions from the year 2017-2019 (76 million $tCO_2eq.$) and using the above benchmark as a guide, the government can assess against the 4 million $tCO_2eq.$ target set under the CITP. Currently, the EC rating of the material is roughly within rating C. Should the rating of all five (5) material to be **improved to rating B** i.e. a reduction in EC per ton of material used, it is estimated that a total reduction of **7.5 million $tCO_2eq.$** (*Table 70*) (beyond the 4 million $tCO_2eq.$ target) GHG emissions can potentially be achieved.

Consequently, the government can set a gradual action plan towards the stage compliance with the rating over a period. The priority can be given to the most significant contributor such as ready mixed concrete, steel reinforcement and cement.

[66] http://www.cic.hk/files/page/148/CICR06-14-A%20Comprehensive%20Hong%20Kong%20Based%20Carbon%20Labelling%20Scheme_RS_023.pdf
[67] http://cejcheng.people.ust.hk/ec/carbonInventoryLocalized.html.

Table 70: Estimated GHG reduction according to carbon rating B EC for top five (5) GHG contributors

Construction Material	EC (Carbon Rating C)	Carbon Rating B	% Reduction	Average Material Consumption 2017-2019 (million tonne)	GHG Emission 2017-2019 (million tCO_2eq)		GHG Reduction (million tCO_2eq)
					EC Rating C	Carbon Rating B	
Ready mixed concrete	0.209	0.199	-5%	156.96	32.80	31.24	1.57
Steel reinforcement	1.90	1.39	-27%	8.27	15.71	11.49	4.22
Bricks	0.265	0.249	-6%	22.02	5.83	5.48	0.35
Cement	1.0257	0.9657	-6%	4.50	4.62	4.35	0.27
Steel & metal	1.988	1.478	-26%	2.09	4.16	3.10	1.07
Average Reduction from Carbon Rating C to B			**-14%**				
Total GHG Emission (million tCO_2eq)					**63.13**	**55.65**	**7.48**

The **average percentage of reduction** for the proposed EC carbon rating C to be improved to B for the five (5) materials is **14%**.

A quick assessment of the feasibility of such a reduction of EC intensity is carried out. During the benchmarking visit to City Development Limited (CDL), Singapore on 13th January 2020, CDL informed that by 2030, they have committed to using sustainable materials to reduce **EC of materials by 24%.** This indicates the average of 16% can be a reasonable target if compared to CDL's target.

On the other hand, World Green Building Council (WGBC) has targeted by 2030, all new buildings, infrastructure and renovations will have at least **40% less EC** with significant upfront GHG reductions, and all new buildings must be net-zero operational GHG.

Among the five (5) construction materials stated above, more attention was given to cement and concrete, where internationally effort has been placed on:

(1) reduce the EC of cement and concrete through a partial use of waste/by-product cementitious materials and (2) find alternative low-carbon materials for cement and concrete. The possibility of reducing the EC of concrete structures by substituting Portland cement fully or partially with supplementary cementitious materials (SCMs), including fly ash, ground granulated blast furnace slag (GGBFS), and amorphous silica (silica fume).

As an example, Table 71 presented the effect of different percentages of fly ash, as a representative SCM, substitution for Portland cement on the EC of different grades of concrete as reported by the ICE GHG inventory.

Table 71: Effect of fly ash replacement for Portland cement on EC of concrete[68]

Concrete Grade	Embodied Carbon ($tCO_2eq./t$)				
	Cement Replacement with Fly Ash (%)				
	0%	15%	% Reduction	30%	% Reduction
RC 20/25 (20/25 Mpa)	0.132	0.122	-8%	0.108	-18%
RC 25/30 (25/30 Mpa)	0.140	0.130	-7%	0.155	-18%
RC 28/35 (28/35 Mpa)	0.148	0.138	-7%	0.124	-16%
RC 32/40 (32/40 Mpa)	0.163	0.152	-7%	0.136	-17%
RC 40/50 (40/50 Mpa)	0.188	0.174	-7%	0.155	-18%
Average			**-7%**		**-17%**

Partial replacement of Portland cement with fly ash can result in a considerable reduction in the EC of concrete, with reductions as high as 7% achievable at 15% replacement and 17% achievable at 30% replacement. It is estimated that a total reduction of 5% of EC reduction for the proposed benchmark for the EC rating of cement from rating C (1.0257 $tCO_2eq./t$) to be improved to rating B (0.9757$tCO_2eq./t$). This is achievable if partial replacement of Portland cement with 15% fly ash.

In Malaysia, usage of fly ash in cement industries is already a common practice and it is necessary to conduct a technical feasibility assessment on the potential reduction that can be achieved within the cement manufacturer within Malaysia.

Minor GHG contributors

Other than the benchmarks proposed for the top five (5) major GHG contributors, the benchmarks for other minor GHG contributors also analysed and tabulated as below:

Table 72: EC for other minor contributors applied in GHG calculation

Construction Material	EC ($tCO_2eq./t$)		EC ($tCO_2eq./m^2$)
	ECO-CM Hong Kong (2013)[69]	ICE UK V3.0 (Nov 2019)	Foshan, China
Sand		0.0051	
Aggregates		0.00493	
Plywood	1.932		
Timber		0.306	
Glass	1.095		
Paint		2.91	
Roofing Tiles/Sheet		3.045	
Sanitary Ware		1.61	
Ceramic Tiles			0.0164

68 https://www.mdpi.com/2075-5309/7/1/5/pdf
69 http://cejcheng.people.ust.hk/ec/carbonInventoryLocalized.html.

The example of the proposed benchmark for minor GHG contributors for Malaysia is tabulated as below:

Table 73: Proposed benchmark for minor GHG contributors

Carbon Rating	EC (tCO_2eq/t)								EC (tCO_2eq/m^2)
	Sand	Aggregates	Plywood	Timber	Glass	Paint	Roofing Tiles/Sheet	Sanitary Ware	Ceramic Tiles
A	< 0.0046	< 0.0043	< 1.772	< 0.176	< 0.93	< 2.00	< 1.79	< 0.70	< 0.0073
B	0.0046 ~ 0.0049	0.0043 ~ 0.0047	1.772 ~ 1.882	0.176 ~ 0.266	0.93 ~ 1.04	2.00 ~ 2.40	1.79 ~ 2.19	0.70 ~ 1.10	0.0073 ~ 0.0113
C	0.0049 ~ 0.0053	0.0047 ~ 0.0050	1.882 ~ 1.992	0.266 ~ 0.346	1.04 ~ 1.16	2.40 ~ 3.42	2.19 ~ 3.21	1.10 ~ 2.12	0.0113 ~ 0.0215
D	0.0055 ~ 0.0056	0.0050 ~ 0.0054	1.992 ~ 2.102	0.346 ~ 0.436	1.16 ~ 1.27	3.42 ~ 3.82	3.21 ~ 3.61	2.12 ~ 2.52	0.0215 ~ 0.0255
E	> 0.0056	> 0.0054	> 2.102	> 0.436	> 1.27	> 3.82	> 3.61	> 2.52	> 0.0255

Currently, the EC rating of the material is roughly within rating C. Should the rating of all minor material is **improved to rating B** i.e. a reduction in EC per ton of material used, it is estimated that a total reduction of **0.5 million tCO_2eq.** (*Table 74*).

Table 74: Estimated GHG reduction according to carbon rating B EC for minor GHG contributors

Construction Material	EC (Carbon Rating C)	Carbon Rating B	% Reduction	Average Material Consumption 2017-2019 (million tonne)	GHG Emission 2017-2019 (million tCO_2eq)		GHG Reduction (million tCO_2eq)
					EC Rating C	Carbon Rating B	
Sand	0.0051	0.0049	-4%	25.10	0.13	0.12	0.01
Aggregates	0.0049	0.0047	-5%	35.00	0.17	0.16	0.01
Plywood	1.932	1.882	-3%	1.45	2.80	2.72	0.07
Timber	0.306	0.266	-13%	2.07	0.63	0.55	0.08
Glass	1.095	1.04	-5%	0.20	0.22	0.21	0.01
Paint	2.91	2.4	-18%	0.08	0.22	0.18	0.04
Roofing Tiles/Sheet	3.045	2.19	-28%	0.30	0.90	0.65	0.25
Sanitary Ware	1.61	1.1	-32%	0.05	0.09	0.06	0.03
Ceramic Tiles	0.0164	0.0113	-31%	0.51	0.01	0.01	0.00
Average Reduction from Carbon Rating C to B			**-15%**				
				Total GHG Emission (million tCO_2eq)	**5.17**	**4.67**	**0.50**

The **average percentage of reduction** for the proposed EC carbon rating C to be improved to B for the five (5) materials is **15%.**

5.3.2.4 Proposal on Low Carbon Construction Materials

Construction materials are responsible for a large amount of GHG emissions into the atmosphere. Based on the Study findings, 90% of the total carbon emission of the construction industry (cradle-to-site) emitted from the materials extraction and manufacturing. Therefore, it is crucial to shift to a lower EC construction material in order to achieve an overall GHG emissions reduction from the construction industry.

This section outlines the potential alternative construction materials with lower EC compared with the conventional construction materials used.

5.3.2.4.1 Blended cement

Cement is the main ingredient in concrete which is known as the most consumed construction materials. Concrete is used in the form of foundations and structures of a building and infrastructure. Usage of cement and concrete in construction is avoidable, thus finding a solution to reduce the emission associate with the materials is crucial. Ordinary Portland Cement is the most common type of cement used in many countries including Malaysia. GHG emissions associated with Portland cement manufacturing mainly come from decarbonation of limestone, kiln fuel combustion, vehicles and machinery at a manufacturing plant and electrical power generation. Thus, changes are needed at each of the manufacturing processes in order to reduce the EC level.

One of the methods to reduce EC is by increasing the clinker substitution with Supplementary Cementitious Materials (SCMs) in traditional Portland cement. Portland cement consists of at least 90% lime-based clinker. Clinker is a nodular material produced during the production of cement in the kilning stage. Clinker is used as binder in the cement products. It is produced by heating limestone and clay to the point of liquefication at about 1400°C – 1500°C in the rotary kiln. The high-temperature process is associated with high GHG emissions. Thus, substitute the clinker produced during the kiln combustion process will greatly reduce the overall GHG emission.

Type of SCMs that can be used is such as fly ash of combustion ashes from the coal industry and blast furnace slag from the steel industry. The by-products from the coal and steel industry through the combustion process can be used as clinkers in the Portland cement. Utilising the recycled by-product will greatly reduce the heating process in cement manufacturing and thus reduce overall EC.

Currently, there has been an effort made by local companies to develop low carbon cement-based materials. TNBR for example has developed protection slab using coal bottom ash mixed with cement. The strength of the concrete-mixed cement slab is comparable with the conventional existing type of protection slab used by TNB. The material also has been proven complies to all DOE Regulatory requirements. This shows that the abundant by-products have high potential to be used as supplementary clinker for cement. The advantages and disadvantages of using blended cement for replacement are tabulated in *Table 75.*

Table 75: Advantages and disadvantages using blended cement for replacement

ADVANTAGES	DISADVANTAGES
• Fly ash and slags are abundant – efficiently use the by-products and create a circular economy • Reduce emissions from cement production	• Cement manufacturers need to invest in equipment and logistics for the fly ash and slag due to power plants usually located in remote areas • Need approval from DoE due to fly ash is classified as Scheduled Waste • Limited reliable data and track records

5.3.2.4.2 Innovative Concretes

Concrete is a mixture of Portland cement, water and aggregate with adequate proportion and used extensively in buildings, bridges and public infrastructures as a primary construction material. It is relatively cheap, low maintenance, can withstand the vertical load and easy to mould, thus made it to be the most consumed materials globally.

From the environmental perspective, concrete contributes largely to the overall GHG emissions in the construction industry. The volume of concrete used in a construction project is the largest and thus contribute high overall GHG emissions. Therefore, to reduce the overall EC of concrete, one must need to demonstrate the sustainability of each of the components of concrete – cement, water and aggregate.

The industrial process and construction industry produced a huge amount of waste materials and by-products. Reutilising the waste and by-products can be effectively reducing the dependencies of raw materials. The extraction process can be reduced and thus prevent the depletion of raw materials to produce concrete. Research studies on concrete from recycled materials are developed all over the world. Possible combinations of materials to make low EC concrete are tested and explored including the effective use of waste and by-products as additive.

As discussed previously, by-products from the industrial process like fly ash and slag have been successfully used as SCMs in the cement to reduce the dependency of clinker which requires high intense energy. The substitution of clinker has contributed a lot to reducing the overall EC of cement.

Meanwhile, the usage of waste in concrete can be categorised into industrial waste, demolition waste and agriculture waste.

Industrial Waste

One example of industrial waste that can be used in concrete is crumbed rubber. Crumbed Rubber Concrete (CRC) is a new type of material that currently being developed for construction purposes. Sand used in concrete mixture is replaced with rubber particles sources from rubber tyre waste. The material can be produced by first grinding the unused rubber tyre into small particles with a similar consistency to sand. Grinded rubber can replace a certain percentage of sand in concrete. Usage of ‘crumbed’ rubber in a concrete mixture will greatly reduce the environmental impact. Also, economic saving can be achieved while reducing the demand for natural sand.

Despite the possibility of CRC in the construction industry, the properties and performance of CRC still need to be improved. In general, the strength of CRC is depending on the percentage of rubber used and the size of rubber crumbs. The rubber crumb also needs to be pre-treated with chemicals to improve the cohesion with concrete particles[70]. The initial study on CRC shows that the material can potentially be used for footings and slabs since they are not depending much on concrete strength. The advantages and disadvantages using industrial waste for replacement is tabulated as below:

Table 76: Advantages and disadvantages of using industrial waste for replacement

ADVANTAGES	DISADVANTAGES
More resistant to tensile stress – slightly flexible and can withstand impact effectively	Lower compressive strength
Reduce the usage of natural sand	Strength of concrete depending on the percentage of rubber, size and shape of the rubber
Create value for end-of-life rubber tyre	Rubber crumb needs to be chemically pre-treated to enhance cohesiveness

Demolition Waste

Wastes created from a structure demolition can be reused for new concrete mixtures. The wastes are transformed into small pieces to produce new material called recycled concrete aggregates (RCA). The quality of RCA is relatively dependent on the type of demolished structure. Any contamination of the demolition waste such as gypsum board, reinforced steel, plaster, asphalt, wood and soil must be removed before crushed into specific size and quality. The usage of RCA will significantly reduce the GHG emissions associated with the aggregate extraction process for the concrete mixture.

Figure 45: Example of RCA[71]

[70] Crumbed Rubber Concrete: A Promising Material for Sustainable Construction, 2018, Prof J. Mills et al. https://www.scientia.global/wp-content/uploads/Mills-Zhuge-Skinner-Ma-Gravina/Mills-Zhuge-Skinner-Ma-Gravina.pdf
[71] https://civilalliedgyan.blogspot.com/2020/03/recycled-concrete-aggregates-its-uses.html

Nevertheless, RCA does not exhibit the same characteristic as the original aggregates. This is due to the inseparable mortar and cement component on the surface of RCA. It leads to the reduction of quality where the porosity is high and the density of materials is low. It is suggested that RCA is used for non-structural purposes. Take Singapore as an example, RCA is used in eco-concrete (RCA mixed concrete) for constructing non load-bearing walls, small drains, kerbs, footpath and non-suspended slabs. Despite of the suggestion, some research studies able to demonstrate an improvement of RCA quality by conducting specific pre-treatments procedures such as RCA coating, impurities removal and oven curing. The advantages and disadvantages of using demolition waste for replacement are tabulated as below:

Table 77: Advantages and disadvantages of using demolition waste for replacement

ADVANTAGES	DISADVANTAGES
👍 Source of waste is abundant 👍 Reduce dependency on natural aggregates	👎 Poor quality – high porosity and low density 👎 Extra pre-treatment needed to improve aggregates quality

Agricultural Waste

The use of agricultural waste as a composite in concrete is currently studied by researchers all around the world. The abundance of agriculture wastes determines the possibility of creating a new type of concrete with low GHG emissions. Agricultural waste can be partially used as a replacement of aggregates in a concrete mixture which can reduce the dependence on common materials such as gravels and sand.

For example, the replacement of cement by considering using sugarcane bagasse, rice husk, wheat straw, bamboo leaf and empty fruit bunch of palm oil plants. The materials are burnt in a furnace at high temperatures to transform them into ashes. The ash then can be used to substitute cement in concrete. Meanwhile, a possible substitute for aggregate is using wheat, corn and olive crops.

Although the agricultural wastes mentioned can be used to produce ‘recycled concrete’, the performance and strength of the concrete are still debatable. Most of the mixture will increase the water demand and thus reducing the workability of the concrete. The advantages and disadvantages of using agriculture waste for replacement are tabulated as below:

Table 78: Advantages and disadvantages of using agriculture waste for replacement

ADVANTAGES	DISADVANTAGES
👍 Source of waste is abundance 👍 Reducing dependency on conventional composite materials	👎 Poor quality – high water absorption 👎 Lack of large-scale project utilizing such materials

5.3.2.4.3 Alternative Bricks

Brick has been recognised as one of the most favoured construction materials around the world. Conventional clay bricks are the common type of bricks where the manufacturing process required the clay to be fired at high temperatures. The fossil fuel energy required to burn the clay bricks has resulted in high GHG emissions. In response to reducing the EC of clay bricks, a new type of bricks has been introduced where no energy-intensive is needed. The bricks do not contain clay but utilise the fly ash from the electricity generation power plant as the binder.

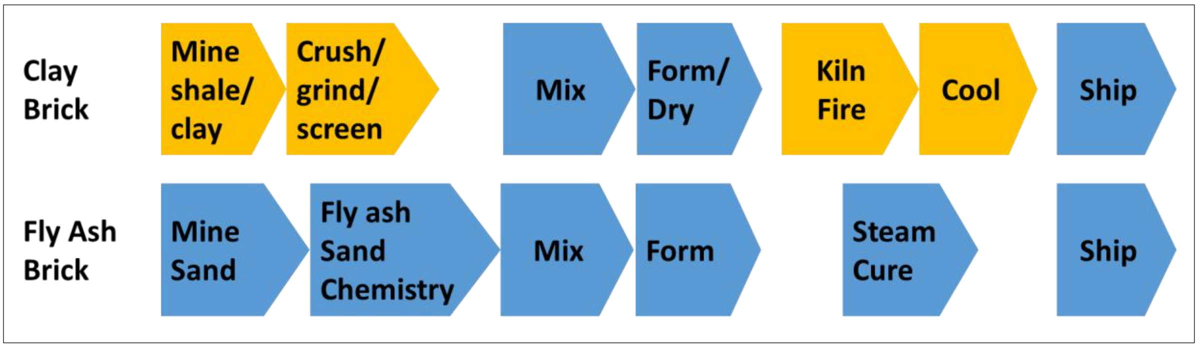

Figure 46: Comparison between clay brick and fly ash brick manufacturing[72]

Figure 46 shows the comparison of the manufacturing process between fly ash brick and clay brick. The kiln firing process, where most GHG emissions happened is replaced with a steam curing process where the process can be done at a low temperature. The fly ash brick utilised the recycled by-product materials (fly ash) with no kiln and cement required. Fly ash and sand are mixed and undergo compaction into moulds of desired shape and size. The bricks then cured in the curing chamber and ready to be used. No firing process required during the manufacturing fly ash brick significantly reduce the GHG emission, approximately 85% less energy is used compared with the conventional clay brick. Apart from that, fly ash bricks have been tested and proven to have the same performance as the conventional clay bricks. The advantages and disadvantages of using alternative bricks for a replacement are tabulated as below:

Table 79: Advantages and disadvantages of using alternative bricks for replacement

ADVANTAGES	DISADVANTAGES
The technology can be made decentralized production in the tiny scale industry Utilize industrial waste hence create a circular economy Energy-efficient and environmentally friendly	The binding process is slow at ambient temperature hence required a curing chamber to accelerate the low-temperature process Need approval from DOE due to fly ash is classified as Scheduled Waste

[72] Reducing Embodied Energy in Masonry Construction, 2012, Peter J. Arsenault, FAIA, NCARB, LEED-AP

Figure 47: Example of fly ash bricks[73]

5.3.2.4.4 Timber

Timber is a type of wood suitable for building or carpentry purposes. The usage of timber for a big building project is uncommon in Malaysia. Timber is usually used for small-scale buildings such as houses in the village area.

Contrary to other developed countries, timber is widely used in buildings. The emerging usage of timber in nowadays' construction is mostly driven by the climate change issue. Timber has a lower overall EC compared to concrete. Even though the strength of timber is not comparable to concrete, proper treatment and combination with appropriate materials can still enhance its properties.

An example of a project that used timber as the main structural component is a 8-storey apartment in London. The special feature of the building is the cross-laminated timber (CLT) panels used as load-bearing walls and floor 'slabs'. CLT is prefabricated timber boards that are stacked at right angles and glued together over their layer surfaces in 3, 5, 7 or more board layers (as seen in Figure 48). The panels are used for large wall, floor and roof elements, and are manufactured with precision cut-outs for doors, windows and building services.

Wall panel anchored to floor panel.

Typical internal wall arrangement.

Figure 48: Structure of the 8-storey apartment using timber[74]

[73] https://en.wikipedia.org/wiki/Fly_ash_brick#/media/File:Fly_Ash_Bricks.jpg
[74] https://eoinc.weebly.com/uploads/3/0/5/1/3051016/murray_grove_case_study.pdf

Another example of high-rise building using timber is a newly built 18-storeys student facility in Canada's University of British Columbia (Figure 49). The building is largely made up of CLT. The building was completed in 2016 and regarded as the tallest wooden building (53 metres) in 2016 before the completion of the Mjösa Tower (85.4 metres) in Brumunddal, Norway in 2019. There is a newly announced "Plyscraper City" in Tokyo which comprises 70-storey (350 metres) of wooden buildings[75] in the plan.

Figure 49: *18-storey student housing facility in Canada's University of British Columbia made of CLT* [76]

Figure 50: "Plyscrapper City" 2041 plan – a hybrid structure made from 90% wooden materials in Tokyo, Japan

It is proven that timber can potentially replace steel, cement and ceramic tiles in construction. Timber is relatively less energy-intensive during the manufacturing process. Also, the usage of prefabricated construction materials such as CLT will greatly reduce GHG emissions and materials waste during the construction stage. A

[75] https://www.theguardian.com/cities/2018/feb/16/plyscraper-city-tokyo-tower-wood-w350
[76] https://www.fastcompany.com/90504726/in-defense-of-big-pharma-the-innovation-engine-we-love-to-hate

5% reduction in GHG emissions (CO_2) is reported can be achieved using timber compared to steel and concrete[77].

However, using timber as the main component of building in the tropical climate of Malaysia can be challenging. The moisture from condensed water due to the humidity of air and frequent raining will cause timber to decay. Therefore, an extra protective coating layer might be required to reduce the impact of moisture. The advantages and disadvantages of using timber for replacement are tabulated below:

Table 80: Advantages and disadvantages of using timber for replacement

ADVANTAGES	DISADVANTAGES
Can replace structural concrete, masonry or steel Can reduce noise and dust associated with traditional construction Reduce time at onsite due to the fabrication of materials	Inflexibility due to design needs to be determined ahead of fabrication Any variations on site are very difficult and expensive to resolve Requires external cladding and usually need to add insulation Material cost is higher. The cost for the CLT floor slab can be double than of a pre-stress concrete slab

5.3.2.4.5 Rammed Earth Walls

Rammed earth is an ancient technique of forming solid walls using the high pressure to compact damp subsoil such as sand, gravel, stabilizer and clay into place between temporary formwork panels. This construction technique is slowly modernised and integrated into urban building to provide aesthetic value and architectural design. Example of ancient buildings is the Chuxi Tulou, Fujian (Figure 51).

Figure 51: Chuxi Tulou Cluster in Fujian province constructed using rammed earth[78]

There are two (2) types of rammed earth: non-stabilized and stabilized. The key difference between the two (2) types is the use of cement or lime additives to stabilize

[77] Environmental Impacts of Traditional and Innovative Forest-based Bioproducts (Environmental Footprints and Eco-design of Products and Processes) 2016

[78] https://www.chinatouradvisors.com/Attractions/Yongding-Chuxi-Tulou-Cluster-106.html

the soils. Non-stabilized rammed earth has lower EC than concrete due to the only source of carbon emission is during the compaction process. However, non-stabilized rammed earth is generally not suitable for structural applications due to a lack of binders between the soil. Hence, a stabilized rammed earth is a better option for building as shown in *Figure 52.*

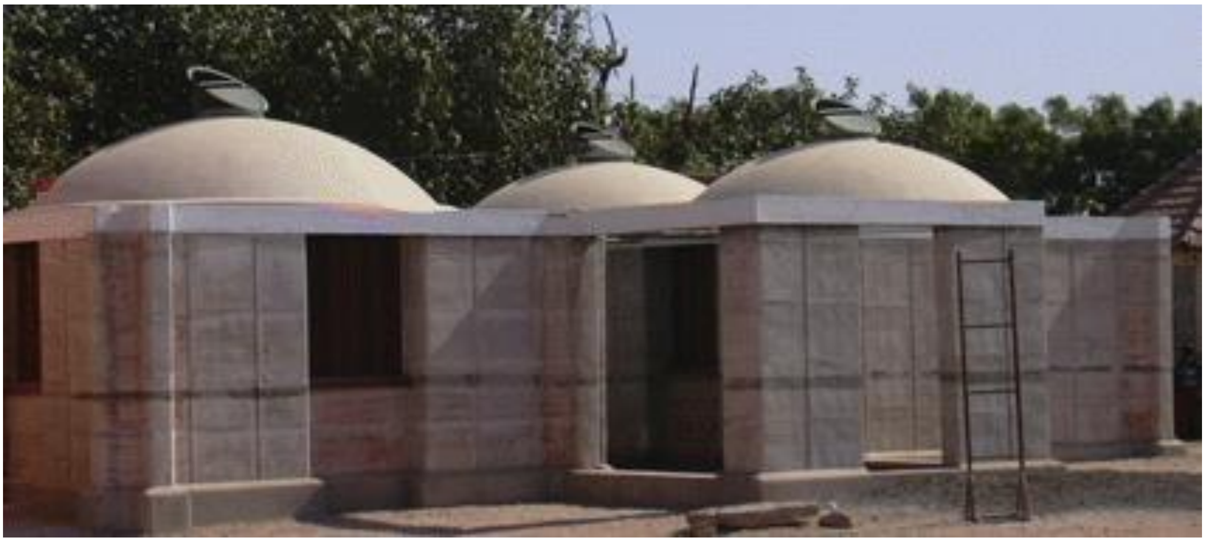

Figure 52: Load-bearing stabilized rammed earth building[79]

Rammed earth is not a common practice in the Malaysian construction industry. A rare application of rammed earth in construction in Malaysia is observed at Belum Rainforest Resort. Non - load bearing rammed earth walls were built at Deluxe Suite, Belum Rainforest Resort to act as barrier and as aesthetic value (Figure).

Figure 53: Rammed earth wall at Belum Rainforest Resort, Perak[80]

Lack of usage of rammed earth wall may due to relatively high humidity and moderate external temperature which may cause the extend the construction period. The type of suitable soil is also crucial to ensure a strong and high-density earth wall can be

[79] International Journal of Low-Carbon Technologies, Volume 4, Issue 3, September 2009, Pages 175–181,
[80] *http://keehuachee.blogspot.com/2015/06/part-2-belum-rainforest-resort-checking.html*

achieved. The advantages and disadvantages of using blended rammed earth walls for replacement are tabulated as below:

Table 81: Advantages and disadvantages of using rammed earth walls for replacement

ADVANTAGES	DISADVANTAGES
👍 Fly ash and slags are abundant – efficiently use the by-products and create a circular economy 👍 Exotic appearance – a traditional form of construction 👍 Low embodied carbon	👎 Poor thermal resistance, hence extra insulation is required 👎 High-level construction detailing and quality control 👎 Still required the addition of cement as a stabilizer. Higher the percentage of cement, higher the overall EC

5.3.2.4.6 Bamboo

Bamboo is a natural composite material with high compressive strength, lightweight and easily be founded in a mass quantity. Usage of bamboo is popular in the rural area where an abundance of bamboo can be found. It can be used as support for concrete and made into parts of building such as foundations, scaffolding, structural walls, columns, floor and woven doors and windows.

Figure 54: (right) Traditional bamboo house[81] (Left) Example of bamboo scaffolding[82]

In general, the EC of bamboo is lower than OPC and ceramic tiles due to the simple process of obtaining bamboo. No complex processes are needed hence low carbon emitted. An example of a bamboo structure in Malaysia is the Bamboo Playhouse at the Perdana Botanical Garden. The playhouse was built using bamboo as the supporting structure for the roof. It was built to accommodate the leisure activity for the public at the botanical garden.

[81] Flander, K. D., and R. Rovers. 2009. "One Laminated Bamboo-Frame House per Hectare per Year." Construction and Building Materials 23 (1): 210–218. doi:10.1016/j.conbuildmat.2008.01.004
[82] http://i.imgur.com/LgLugl6.jpg

Figure 55: The Bamboo Playhouse at Perdana Botanical Garden[83]

EC of bamboo is extremely low and undoubtedly reduce GHG emissions from the construction sector. However, the potential usage of bamboo as floor and structural support in a large-scale Malaysia's construction project is restricted due to the limitation of the bamboo sources. Bamboo is currently underdeveloped and very few bamboo plantations in Malaysia are owned by small and private enterprises. Even though the majority of bamboo can be found in Malaysia's natural forest, the cost of harvesting can high and will require government's permit for access purpose. Therefore, establishment and commercialising the bamboo should be prioritised by government due to its potential in Malaysia. The advantages and disadvantages of using bamboo for replacement are tabulated as below:

Table 82: Advantages and disadvantages of using bamboo for replacement

ADVANTAGES	DISADVANTAGES
Ecologically friendly and highly renewable resource Higher tensile strength than steel because its fibers run axially Has elastic feature - Resistant to earthquake	Consistently expose to water can make the bamboo weathered and decay Need to ensure free from insect or fungus attack before use Flammable

5.3.2.4.7 Alternatives for Ceramic Tiles

Ceramic tiles have been associated with high EC due to the energy-intensive production processes. Many researchers suggested that improving the spray drying and combustion process in ceramic tiles production can reduce carbon emissions. This could be done by switching the fuel from coal to natural gas, use energy-efficient equipment, using a microwave drying process and use a low-temperature quick-firing process. Other than the improvement made during the production processes,

[83] https://www.dezeen.com/2015/11/17/eleena-jamil-bamboo-playhouse-lake-island-kuala-lumpur-malaysia-perdana-botanical-gardens/

alternative materials for ceramic tiles with much lower embodied carbon is widely available in the market[84].

Cement Concrete Flooring

Cement concrete flooring is one of the most common types of flooring that suitable to be used in residential, public buildings and outdoors. It made of cement, aggregates (coarse and fine) and mix thoroughly with water. Some of the cement concrete floorings finished with a layer of coating surface to improve its colour, texture, and water resistance feature. In general, cement concrete flooring exhibits non-absorbent nature, durable, smooth, easy maintenance, smooth and flexible appearance and low cost to install.

One of the key advantages of cement concrete flooring in the aspects of the environment is most sub-floors of residential houses in Malaysia are already made of concrete. Just a bit of refinishing is needed to improve its appearance. The freshly concrete floor can be carved with patterns to mimic the pattern of tiles (as shown in Figure 56). No additional flooring materials such as ceramic tiles are required for the floor. Therefore, cement concrete flooring can be considered environmentally friendly compared to ceramic tiles.

Figure 56: Cement concrete floor with pattern and surface finishes[85]

Cement concrete not only can be used as a floor but also on the walls. It can be decorated by carving the cement concrete with a pattern suitable to use outdoor.

[84] Comparison of Environmental Impacts of Flooring Alternatives, Jim L. Bowyer et al. Dovetail Partners, Inc., January 14, 2019.
[85] https://www.cemcrete.co.za/outdoor-areas.html

Figure 57: Outdoor patterned cement concrete wall[86]

The advantages and disadvantages of using cement concrete flooring for replacement are tabulated as below:

ADVANTAGES	DISADVANTAGES
Low cost to refinish the concrete subfloor Durable, tough surface and can last a lifetime Eco-friendly	Require professional such as contractor to install if the subfloor is not concrete Too hard surface may danger small children (for risk of falling)

Hardwood Flooring

Solid hardwood floor is 100% made of wood plank sources from various types of timbers. Timber has been cut and processes to become a plank that suitable to be arranged as a flooring material. They are usually installed by bling-nailing boards to the subfloor. Solid hardwood flooring is highly attractive and can be considered as a premium building material due to its strength, durability, appearance and having a long-life span. Solid wood floors have a thicker wear surface and can be sanded and finished multiple times. It required a professional installer and thus make the material expensive.

Figure 58: Example of hardwood flooring[87]

[86] https://www.cemcrete.co.za/uploads/2/4/1/1/24115635/1_84_orig.jpg
[87] Banner photo created by fwstudio - www.freepik.com

The advantages and disadvantages of using hardwood flooring for replacement are tabulated as below:

Table 83: Advantages and disadvantages of using hardwood flooring for replacement

ADVANTAGES	DISADVANTAGES
Durable. Can last forever Can increase real estate value Low carbon materials	Material is expensive and requires a professional's installation High maintenance

Laminated Flooring

Laminated flooring is an inexpensive way to create the look of real hardwood flooring. The visual look of laminated flooring is convincing if it is observed from a certain distance. As a result, it always misinterpreted as the premium hardwood. The laminated flooring is made up of fibreboard with a photo layer and a plastic protective surface. Its surface is highly water and stain resistance. They are easy to install and cleaned either under wet or dry condition. However, the laminated flooring cannot be refinished or sanded. Replacement is the only way to fix a heavily damaged laminated flooring.

Figure 59: Installation of laminated wood flooring[88]

[88] *Source: esp imaging / Getty Images*

The advantages and disadvantages of using laminated wood flooring for replacement are tabulated as below:

Table 84: Advantages and disadvantages of using laminated wood flooring for replacement

ADVANTAGES	DISADVANTAGES
Easy to DIY installation Affordable Good stain resistance	Particleboard core can easily damage by water seeping through the seams Do not add real estate value

Bamboo Tiles

Bamboo has many benefits similar to hardwood flooring replacing ceramic tiles in construction. It has a naturally appealing look and proven to be low EC materials. Unlike trees, bamboo only requires five to six years to be readily harvested compare to 20 years' maturity for trees. Therefore, bamboo can be considered as more sustainable and renewable. There are several types of bamboo flooring that commonly used in the market such as stranded bamboo, horizontal bamboo flooring and engineered bamboo flooring. Each of them required for a different type of manufacturing process and served for different type of purpose.

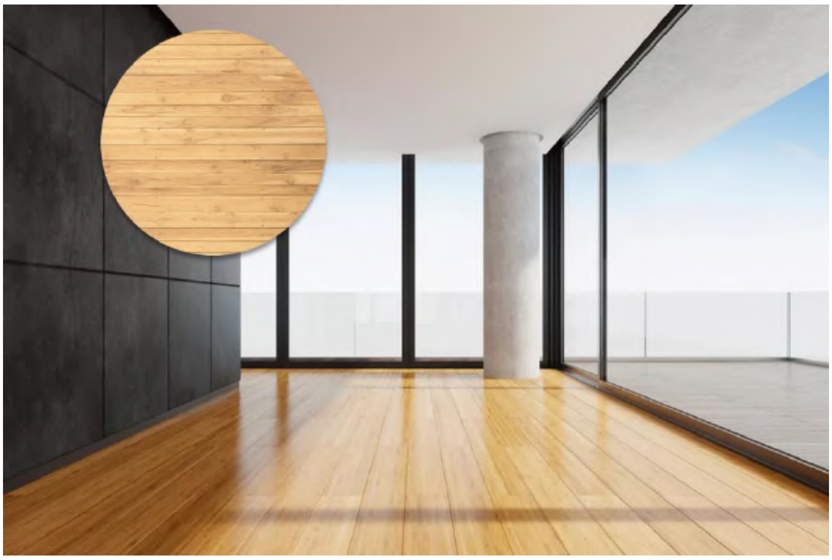

Figure 60: Example of bamboo flooring[89]

[89] Tulcarion | Getty images

The advantages and disadvantages of using bamboo flooring for replacement are tabulated as below:

Table 85: Advantages and disadvantages of using bamboo flooring for replacement

ADVANTAGES	DISADVANTAGES
Renewable materials Easily to maintain Can be refinished	Extreme humidity swings can cause cracks Easily scratch

Vinyl Flooring

Vinyl flooring is a synthetic flooring material made up of layers of vinyl printed design and protective coating layers. The material is durable, water resistance, scratch resistance, affordable and easy to install. It comes in sheets, tiles and planks which made it easy for DIY installation. Vinyl flooring is commonly installed at a location with moisture and stain resistance issues such as a bathroom, kitchen and laundry rooms.

There are two types of vinyl floorings: standard vinyl and luxury vinyl tiles (LVT) flooring. The major difference between standard vinyl and LVT is the layer of sheets bonded. Standard vinyl has a very thin layer of vinyl printed with a design coated with a protective layer and bonded to the backing layer. Meanwhile, LVT is made up of six to eight layers of material including a top-coat layer, clear protective layer and printed design layer (as in Figure 61). The extra thickness of LVT provides a cushioning attribute which makes the floor comfortable to walk on.

Figure 61: LVT composition[90]

There are many kinds of designs available for vinyl flooring. The standard vinyl usually designed to resemble the ceramic tiles look. Meanwhile, LVT can provide more natural designs such as wood and stone. For example, LVT can provide stone-look tiles which appeared to be appealing and natural to the users.

[90] https://www.fanlyplas.com/new/new-31-640.html

Figure 62: Example of LVT flooring design[91]

The advantages and disadvantages of using vinyl flooring for replacement are tabulated as below:

Table 86: Advantages and disadvantages of using vinyl flooring for replacement

ADVANTAGES	DISADVANTAGES
Durable and water resistance	Difficult to recycle
Tear and wear resistance. Can last up to 25 years	Difficult to repair if punctured or heavily damaged
Affordable and easy to DIY installation	Not as prestigious as hardwood

The summary table for proposed alternative low carbon construction materials used in Malaysia is tabulated as below:

Table 87: Proposed low carbon construction materials used in Malaysia

	Residential	Non-Residential	Infrastructure	Social Amenities
Blended Cement		✓	✓	✓
Innovative Concrete		✓	✓	✓
Alternative Bricks		✓	✓	✓
Timber – CLT	✓	✓		✓
Rammed Earth Walls				✓
Bamboo	✓	✓		✓
Alternative ceramic tiles	✓	✓	✓	✓

5.3.3 Carbon Tax

Carbon tax in general has been widely implemented in developed countries to curb the overall GHG emissions from every sector as an economy-wide tax. However, the tax system is not specifically applied to the building sector. A high amount of GHG emissions from the process of raw material extraction, production and transportation could be reduced if the tax system is applied directly to the building sector.

[91] https://multi-clean.com/wp-content/uploads/2019/10/LVT-Floor2.jpg, https://lda.lowes.com/is/image/Lowes/ht_install-luxury-vinyl-tile-flooring-grout-spacers?scl=1, https://images.homedepot-static.com/productImages/b65213c7-7368-481e-aa39-c26600d5346f/svn/atlantic-grey-shaw-vinyl-tile-flooring-hd88105062-64_1000.jpg

Nevertheless, a new tax such as carbon tax will be considered as a burden to businesses sector such as manufacturing companies. The tax may affect the operation of the manufacturing company like steel, tiles, porcelain and ready-mix companies. The GHG emissions perimeter will control and limit the operation unless the companies are willing to pay the heavy fine to impose.

KASA is currently conducting a scoping study on the development of climate change legislative framework. One of the focus components is to study the implementation of the carbon tax in Malaysia. Feasibility and the overall structural framework should be outlined before the actual implementation is enforced. A carbon tax must be complemented with a mandatory GHG reporting policy to ensure GHG emitted is correctly measured, reported and verified. Take Singapore as an example, the government has made the announcement of the details of the carbon tax was in early 2018 while the Carbon Pricing (Tax) Act was enforced in January 2019 (approximately one year). It shows that thorough planning and execution must be made to avoid objection from industrial players.

In terms of medium to long term goals, the carbon tax on selective construction materials can be considered at the early stage of implementation of the tax system in the construction industry. Construction materials with alternatives such as ceramic tiles shall be prioritised in the tax system. For an example, developers that intend to use construction materials with higher than permissible EC shall be subjected to tax based on the quantity of the construction materials use. This will shift the favour of developers gradually towards a more sustainable and eco-friendly materials as it will not incur extra cost to them.

Summary: Carbon Tax

Key agency: **KASA, MOF**

Figure 63: Proposed workflow to establish a carbon tax

5.3.4 Cap-and-Trade System

The cap-and-trade system is a preferable policy compares with a carbon tax to be introduced in Malaysia. It offers the possibility of gaining profit for companies that able to reduce their emission at a lower cost. The government set the emissions cap and issues the quantity of emissions allowance based on the emissions cap. This provides a high level of certainty of future emissions but not the price of the emissions. The price of emission will be determined by the market which can be a main driver to the companies in order to reduce the emissions in a cost-effective way.

A scoping study should be conducted by a government agency such as KASA to outline the policy framework. Key design elements such as annual reduction target, the scope of emissions, allowance allocation and complementary policy need to be determined. A feasibility study centred on the business-as-usual operation of the companies should be conducted to determine the GHG emission limit and the sectors which to be included in the cap-and-trade system. The construction sector also has the potential to be included in the cap-and-trade system. With mandatory GHG reporting to be in place for construction players, the construction projects will have to record GHG emissions annually. Hence, a cap-and-trade system can be applied amongst the construction projects that emit GHG beyond the set limit.

Summary: Cap-and-Trade System

Key agency: **KASA, MOF**

Figure 64: Proposed work flow to establish a cap-and-trade system

6.0 CONCLUSIONS AND RECOMMENDATIONS

The Study has concludes that the construction sector contributes significantly to GHG emissions in Malaysia. Based on the scope of the Study, the average total GHG emissions from cradle-to-site for the year 2017 – 2019 was calculated to be 76 million tCO_2eq. which is equivalent to approximately a quarter (24%) of the total national GHG emissions.

The majority of the emissions from the cradle-to-site emitted from the EC of the construction material (90%), where the emissions at construction site attribute to another 7% while the remaining 2% due to transport of construction material.

The projection of GHG emissions shows that by the year 2050, the baseline emissions (business as usual) will grow by 92% if no mitigation measures are put in place.

In order to achieve 4 million tCO_2eq. emission reduction target set under the CITP, it is recommended to focus on the embodied carbon of construction material as it contributes to approximately 90% of the total GHG emissions. It can be narrowed down to the five (5) highest GHG contributors i.e. ready mixed concrete, steel reinforcement, bricks, cement (finishes) and steel and metal whereby it is estimated that the target can be achieved by reducing around 6-7% of the GHG emissions of these five (5) materials alone.

Three (3) main categories of incentive and disincentive mechanisms were proposed. It is recommended that the construction-related industries to start accounting and reporting their GHG emissions. Various support measures are encouraged to be given to reinforce the wide usage of low carbon construction material. Carbon tax or carbon cap and trade system is recommended in the medium to longer-term to support the market players to adopt low carbon investment.

Recommended Future Studies

The Study recommended follow-up researches to be carried out to establish “Low Carbon Construction Road Map” which including but not limited to following:

- Revision on the 4 mil tCO_2eq. GHG reduction target which set under CITP based on findings of this Study and set the reduction strategies;
- Detailed target setting plan for the potential reduction of the embodied carbon in consultation together with the stakeholders;
- Detailed study on benchmarking carbon labelling scheme for construction material;
- Detailed feasibility study on low carbon construction material replacement and recycling of C&D waste; and
  Detailed feasibility study of the proposed incentive and disincentive mechanisms that mentioned above, including pilot testing and implementation of the proposed measures.

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