Development of comprehensive carbon footprint and environmental impact indicators for building transportation assessment

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Abstract

Purpose – The purpose of the study is to consolidate a set of indicators for assessing design and construction phase strategies for reducing operational greenhouse gas (GHG) emission. They will also estimate the quantity of operational GHG emission and its associated reduction over assessment period.

Design/methodology/approach – Five steps framework adopted include defining the purpose of the indicators and selection of candidate indicators. Others are defining the criteria for indicator selection, selecting and defining the proposed indicators. Relevancy, measurability, prevalence, preference, feasibility and adaptability of the indicator were the criteria used for selecting the indicators.

Findings – The study consolidated public transport accessibility, sustainable parking space, green vehicle priority, proximity to amenities and alternative modes as indicators for design and construction phase strategies. Transportation accounting and carbon footprint (CFP) and their associated reduction are indicators for operational GHG emission while plan and policy is an indicator for policymakers and stakeholders.

Practical implications – The study shows that providing correct indicators for assessing direct and indirect GHG emission with easy to obtain data is essential for assessment of built environment. Stakeholder can use the indicators in developing new rating systems and researchers as an additional knowledge. Policy makers and stakeholders can use the study in monitoring and rewarding the sustainability and activities of building related industries and organisations.

Originality/value – The study was conducted at the Center for Energy and Industrial Environmental Studies (CEIES) Universiti Tun Hussein Onn Malaysia and utilises existing rating systems and tools, Intergovernmental Panel on Climate Change (IPCC) and GHG protocol reports and guides and several other standards, which are open for research.

Keywords Building, Carbon footprint, Greenhouse gas emission, Indicators, Sustainability, Transportation

Paper type Research paper

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1. Introduction

Greenhouse gases (GHGs), mainly cause global warming and extreme weather, gravely harm the ecosystem and human security. They are principally generated from carbon emissions caused by human activities (mainly engineering activities) such as fuel burning in the production, processing and transport sectors (IPCC, 2006; Li *et al.*, 2015). To reduce the GHG emissions, United Nations (UN), European Union (EU), and many other countries and organisations have adopted legislation and designed a variety of mechanism for regulating the total amount of emissions. Carbon emission trading and development of rating systems are among the most important and cost effective mechanisms broadly adopted by the UN, EU, Africa and Asian countries (Li *et al.*, 2015; Zhu and Gao, 2019). Li *et al.* (2015) reported that, the environmental impact of freight transport operations has attached great attention because it is one of the major source of CO_2 emission it account for up to 14% of total GHG, and three-quarter of these emissions are from the road sector.

Buildings which uses less water, optimise energy efficiency, conserve natural resources, generate less waste and provide healthier spaces for occupants, as compared to conventional buildings are called green buildings (Hedaoo and Khese, 2016; Khan *et al.*, 2021). In other words, it is a design concept that reduces environmental impact of buildings through innovative land use, construction strategies and appropriate site selection. A specified professional have to assess these design concepts for the building to be green or sustainable (Khan *et al.*, 2021; Koranteng *et al.*, 2021). To have proper building design, construction and operation, several countries have moved forward to establish rating systems. Among the pioneers environmental certification system are the UK BREEAM, US LEED, HK BEAM, Australia Green Star and Singapore Green Mark. The latter ones are South African Green Star and Malaysian Green Building Index, GreenRE and MyCrest (Adegbile, 2013; Usman *et al.*, 2018; Schamne *et al.*, 2022).

Transportation is one of the primary sources of GHG emission from direct burning of fuel. Therefore, all the rating systems have some transportation parameters identifying it as important requirement. It is evident that several rating systems consider only social, environment and economic impact of buildings transportation on the environment. Nevertheless, the GHG emission aspect was not directly covered as proposed by the GHG protocol and IPCC. These propositions include product life cycle and projects GHG emission accounting and reporting standards and GHG emission guidelines among several other reports and standards. These propositions made it clear that accounting and reporting of GHG emission will help in determining the sustainability of buildings (GHG Protocol, 2011; GHG Protocol, 2016). Product life cycle GHG accounting is a subset of life cycle assessment (LCA). It seeks to quantify and address the potential environmental impacts throughout product's life cycle from raw material extraction through to end-of-life waste treatment (GHG Protocol, 2011). This will help in accounting of overall building life cycle GHG emission. The accounting starts from the product used (cement, rods, sand, water etc.) in constructing the building and components or equipment (air conditioning systems, heating devices, trucks, vehicles etc) used. Finally, product consumed (energy, water, food, secondary materials etc.) and waste generated during operation. Avestian *et al.* (2012), Melanta *et al.* (2013) and EPA (2014) conducted research on carbon footprint (CFP) quantification for construction project and guide to policy makers and organisations. GBC Australia (2019) develop GHG emission assessment tool covering energy and water associated scope two and tier one emission for different types of building. CIDB Malaysia (2017) developed MyCrest which assesses emission from water, energy, construction material and transportation, machineries, waste and carbon sequestration.

McDowell and Blake (2017) defined an indicator as "a relevant variable, measurable overtime and/or space that provides information on a larger phenomenon of interest and allows comparisons to be made"; while MacDonald (2013) defined indicator as a documentable or measurable piece of information regarding some aspect of a program in question. To develop an indicator, there must be a set of criteria to be used for such purpose.

The applicability of criteria for selecting an indicator depends solely on the particular indicator and purpose of the indicator as different types of issues, assessment and/or decisions require different types and level of indicators. Indicators can be used for problem solving, policy formulation, policy implementation and evaluation, data variation assessment, environmental conditions or sustainability assessment (Brown, 2009; MacDonald, 2013; Owusu-Manu *et al.*, 2021). Steps for developing appropriate indicator by different researchers are reported in Table 1.

According to McDowell and Blake (2017), the effective criteria for selection of indicators must be related to one of the two broad themes. These are technical validity, i.e. precision, performance base and standardisation, and usability, i.e. accessibility of data, relevance and easily understood. Several studies reported a number of criteria for validating indicators for various purposes. These studies include Nathan and Reddy (2010), MacDonald (2013), Waidyasekara *et al.* (2013), McDowell and Blake (2017) and Statistics NZ (2021).

Therefore, there is a need to consolidate a suitable set of indicators for all the categories that will cover the sustainability of the built environment as well as the associated GHG emission. The aim of this study is to consolidate a set of indicators for assessing building design and construction strategies when effectively followed will reduce the operational transportation GHG emissions. The indicators will also consider quantification and reduction of the GHG emission over assessment period.

2. Methodology

The study will account for emissions from only scope one and cradle to gate transportation associated with the building activities. The study will also look into the application of a more integrated approach to the consolidated indicators in properly assessing the transport aspect of building.

2.1 Framework and indexes variables

As reviewed and reported in Nathan and Reddy (2010), McDowell and Blake (2017), Evans *et al.* (2021) and Othman and Alamoudy (2021) the current study adopted five step frameworks for developing the indicators. These include defining the purpose of the indicator, selecting the candidate indicators, selecting and defining the criteria for selecting appropriate indicator, selecting the required indicators and finally defining the selected indicators. The indexes and variables of great importance to this study are explained below.

2.1.1 Carbon footprint (CFP). This is a measure of total quantity of GHG in the form of carbon dioxide equivalent (CO_2e) released when a certain product is produced or in this situation by a considered category, i.e. energy, transportation or indicator. It is measured in $kgCO_2e$ or higher suffixes. The other GHGs are converted to CO_2e using their respective

WHO (2020)	Rice and Rochet (2005)	Brown (2009)
Purpose	User needs	Establishing the purpose
Targeted audience	Candidates list	Designing framework
Defining criteria	Screening criteria	Designing the indicators
Choosing framework	Scoring using criteria	Selection
Identification of indicators	Summarising scores	Interpreting
Defining the indicators	Numbers needed	Reporting
Characteristics to measure	Reporting indicators	Maintaining
Pilot testing		Reviewing over time
Reviewing the indicators		

Table 1. Summary of steps for developing indicators by various authors

global warming potential (GWP) (GHG Protocol, 2016; Wang *et al.*, 2018; Usman, 2019; Li *et al.*, 2020).

2.1.2 Carbon dioxide equivalent (CO_2e). This is used to converts all the various GHGs emissions based on their GWP. The CO_2e for a gas is obtained by multiplying the mass of the GHG emitted by its associated GWP (IPCC, 2006; EPA, 2014). The sum of CO_2e of all the GHGs considered in a given process gives the CFP of that product, category or indicator. It is expressed as $kgCO_2e$ or higher suffixes (EPA, 2014; Wang *et al.*, 2018; GBC Australia, 2019; Li *et al.*, 2020).

2.1.3 Global warming potential (GWP). This is defined as the cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas. For the purpose of climate change, the time horizon is 100 years and the reference gas is carbon dioxide and is consistent with international GHG emissions reporting under the Kyoto protocol. The GWP for some important GHGs are shown in Table 2 (IPCC, 2006, 2014a, b; GBC Australia, 2019).

2.1.4 Emissions factor (EF). This is defined as the quantity of CO_2e emitted when a given quantity of fuel is burnt or certain km is covered in a unit transportation made. It is the amount of GHG emitted in $kgCO_2e$ for covering unit km or using unit quantity of fuel for transportation with building own vehicles or trucks in case of scope one emission. It is measured in $kgCO_2e$/km or $kgCO_2e$/ltr or higher suffixes (EPA, 2014; IPCC, 2014a; Usman, 2019).

2.1.5 Building transportation index (BTI). This is defined as the measure of density of transportations made by building or organisation owned vehicles or trucks in kilometre (km) or fuel used (ltr, m^3) per either average number of occupant or gross floor area (GFA). This index is measured in km/m^2 or ltr/m^2 for BTI_X and km/occupant or ltr/occupant for BTI_Y (Usman, 2019).

2.1.6 Building transportation performance (BTP). This is the measure of building performance in relation to specified standard stipulated by policy makers or other stakeholders. The index can be measured as percentage compliance to the standard specified by stakeholders.

2.1.7 Building transportation reduction index (BTRI). This is defined as a measure of monthly or yearly transportation reduction over a specified period. This index is also measured as a percentage of transportation reduction over assessment period (Usman, 2019).

2.1.8 Building transportation carbon index (BTCI). This is defined as the measure of the density of CFP from transportation category. It is measured per either average number of occupant or GFA of the building per year (Usman, 2019).

2.1.9 Building transportation carbon reduction index (BTCRI). This is defined as the measure of reduction in total transportation CFP of the building or organisation in question over a specified period. It is measured in $kgCO_2e$/employee/year or $kgCO_2e$/year (Usman, 2019).

2.2 Development of the indicators

2.2.1 Defining the purpose of the indicator. The purpose of the developed indicators is to assess the strategies for reducing GHG emission in relation to building transportation from design and construction phase of building life cycle (LC). In addition, the indicators are

Table 2. Global warming potential for common GHGs

GHG	Symbol	GWP
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrogen Dioxide	NO_2	265

intended to consider transportation associated GHG emission quantification and reduction over specified assessment period.

2.2.2 Selecting of list of candidate indicators. For selecting the available candidates for the indicators, the study reviewed eleven (11) existing rating systems. These are Breeam UK (2020), Green Star Australia (2017), Green Star SA (2017) and Green Star NZ (2017), LEED US (2017), GBI Malaysia (2017) and GreenRE Malaysia (2020). Others are BeamPlus Hong Kong (2017), Green Mark (2017), Greenship Indonesia (2017) and Indian GBC (2017). Out of several rating tools developed by these rating systems, 43 were selected comprising of up to 102 parameters allocated to transportation as described in previous studies of Usman *et al.* (2018) and Usman (2019). The parameters considered were grouped in to four as shown in Table 3 and Figure 1 to show the neglection of GHG emission accounting in the reviewed rating systems.

From Figure 1, the parameters in the strategies group have the highest number followed by plan and policy. This shows that, direct quantification and reduction of GHG emission (with 3 parameters) was given less preference in the reviewed rating systems and tools. The factors used for arranging and ranking of the candidates parameters are average points allocation, frequency and percentages of appearance in 11 rating systems, 43 tools and among the 102 parameters as shown in Table 4.

2.3 Selecting and defining the criteria

As reported earlier, the applicability of a criterion is solely dependent on the nature and purpose of the indicators to be selected and/or used. Therefore, criteria considered especially those reported by Nathan and Reddy (2010), Waidyesekara *et al.* (2013), Usman (2019) and Statistics NZ (2021) were summarised below. The selection of these authors was based on their consideration of sustainability of built or community environment.

(1) *Preference:* This defines the preferential treatment given to parameters and points allocation in the assessment category as well as the reviewed rating systems. It also defines the importance of parameters to policy makers and other stakeholders.

(2) *Prevalence:* This defines the appearance of a given parameter in a number of rating systems. Does the parameter frequently appear in most of the considered assessment tools? This defines the parameters acceptability by international and local stakeholders.

(3) *Adaptability:* This criterion defines the ability of a parameter to be use by different countries in relation to environment, affordability, communicability and policies etc. Can all the stakeholders from nonprofessional point of view understand the indicator?

(4) *Feasibility:* This criterion defines the affordability and feasibility of the parameter as well as it inputs for the assessment of the building components. The indicator should make use of data that are readily available, and easily accessible and affordable to the stakeholders. It also accounts for the feasibility of the building assessment

S/No	Grouping	Term used
1	Strategies for reducing GHG emission	Strategies
2	GHG emission quantification and reduction	Quantification
4	Plan and policy of GHG emission reduction	Plan and Policy
3	Other environmental issues	Environmental

Source(s): Developed by authors

Table 3. Grouping of considered parameters

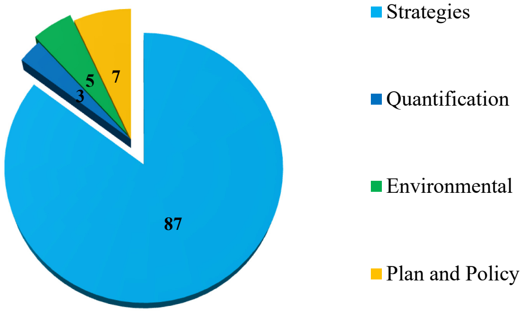

Figure 1.
Summary of number of parameters for each group

Source(s): Developed by authors

Table 4.
Ranking factors against the candidate indicators

Candidates parameters	Average points allocation	Frequency in 11 rating systems	Frequency in 43 tools and percentage in 102 parameters	Percentage in the 43 tools	Ranking
Sustainable transport	3	8	22	51	1
Public transport accessibility	5	10	21	49	2
Car parking capacity	2	5	20	47	3
Cyclist/bicycle facilities	7	4	12	28	4
Vehicle operating emission	3	3	7	16	5
Alternative modes of transport	1	3	6	14	6
Trip reduction and travel plan	2	2	5	12	7
Proximity to basic amenities	2	2	4	9	8
Local connectivity	2	1	3	7	9
Home office	1	1	2	5	10

Source(s): Developed by authors

components and its input to all classes of people. Are the parameters and categories as well as their inputs feasible for easy assessment?

(5) *Relevancy:* This criterion defines the relevancy of the parameters to the assessment of building transportation and it associated GHG emission. It also defines the ability of the indicator to be sensitive to changes in the conditions in question.

(6) *Measurability:* This criterion defines the ability of indicators to provide an easier measurable characteristics and understandable. The variables and their inputs must be consistent, robust and standard and must have a reasonable accuracy and quality.

3. Results and discussion

3.1 Selecting appropriate indicators

The candidate parameters in Table 4 were used to select the appropriate indicators for this study. In addition to selecting appropriate indicators using the above criteria, the study also, compare the IPCC, GHG protocols and other country's GHG emission standards and reports and researches such as MacDonald (2013) and McDowell and Blake (2017). Additionally, ISO 14067:2018 (2018) a standard for GHG and CFP of products describing requirements and guidelines for quantification was considered in selecting and defining the parameters and sub-parameters related to GHG emission. The aim of comparison was to find suitable sub-parameters for the assessment of GHG emission from the vast information provided by such reports and standards. Using the above criteria, the summary of selecting the indicators is giving in Table 5.

According to Rice and Rochet (2005) it is necessary to have fewest possible numbers of indicators to serve all uses. Clearly, to be cost effective and to provide clear management guidance, suites of indicators should be kept as small as possible while still fulfilling the needs of all the purposes as well as stakeholders. Table 6 show the summary of the proposed indicators. The study considered vehicle operation emission or CFP as they form the basis for the study. The study divided the section into accounting of building transportation emission and its associated reduction over assessment period. The parameter cyclist facility was considered under sustainable parking space while the last two parameters were not selected due to their low score and ranking. The selections of sub-indicators were to cover a wide range of emission sources related to transportation. Transportation plan and policy was to cover any other needs from stakeholders in the policy makers. These processes of selection of criteria and indicators and the criteria fulfilment describe the indicator's potentials in covering wider scope in relation to GHG emission of transportation assessment and its applicability to variety of buildings or organization.

3.2 Defining the proposed indicators

The study consolidated ten (10) indicators and categorises them into two different sections comprising of twenty-one (21) sub-indicators as described below.

3.2.1 Design and construction strategies assessment. This section considers activities that occur during design and construction phase that can reduce the overall impact of the building on the immediate environment. Several literature were used for describing the indicators in addition to rating systems including Fenner and Ryce (2011), Abolore (2012), Adegbile (2013), Nurul *et al.* (2014) and Kshirsagar *et al.* (2015). Further, the description, points distribution and score as well as other conditions regarding these indicators may be based on policy makers or other stakeholders need.

3.2.1.1 Public transportation accessibility (PTA). The description of this indicator was obtained from National Roads Authority (2014) and Department of Transport (2007). The indicator was considered in Breeam, BEAM, GBI, LEED, Green Star and Greenship rating systems. This indicator encourages development in close proximity of good public transport networks, thereby helping to reduce owner transport emissions and congestion from private transportation. The environmental benefits of travelling by public transport include the reduction in the emission of GHGs by private cars, thereby reducing urban pollution and traffic congestion. The indicator may be assessed using public transport accessibility index (PTAI) and the equations can be used for all the building types. Depending on the countries standards, the required variables may be calculated using equations (1)–(6) (Department of Transport, 2007; Breeam, 2020; Usman, 2019).

$$PTAI_{POI} = \Sigma(AI_{mode1} + AI_{mode2} + AI_{mode3} + \ldots + AI_{mode\ n}) \tag{1}$$

Table 5.
Summary of indicators selection process

Ranking	The parameters	Factors: Preference	Prevalence	Adaptable	Feasibility	Relevance	Measurable	Frequency in criteria
1	Green vehicle priority	√	√	√	√	√	√	6
2	Public transport accessibility	√	√	√	√	√	√	6
3	Car parking capacity	–	√	√	√	√	√	5
4	Cyclist facilities	–	–	√	√	√	√	4
5	Vehicle operating emission	–	–	√	√	√	√	4
6	Alternative modes of transport	√	√	–	–	√	√	4
7	Trip reduction and travel plan	–	–	√	√	√	√	4
8	Proximity to amenities	–	–	√	√	√	√	4
9	Local connectivity	–	–	–	√	√	–	2
10	Home office	–	–	–	√	√	√	3

Source(s): Developed by authors

S/No	Indicators	S/No	Sub-indicators
1	Public Transport Accessibility	1	Public Transport Accessibility
2	Sustainable Parking Space	2	Sustainable Parking Space
3	Green Vehicle Priority	3	Green Vehicle Priority
4	Proximity to Basic Amenities	4	Proximity to Basic Amenities
5	Alternative Mode of Transport	5	Alternative mode of Transport
6	Transportation Plan and Policy	6	Transportation Plan
		7	Transportation Policy
7	Building Transportation performance	8	Total Transportation in (km or ltr)
		9	Building Gross Floor Area (m^2)
		10	Building Allowable Occupant (Occupant)
		11	Building Transportation Index (BTI_X) (km or ltr/m^2/year)
		12	Building Transportation Intensity (BTI_Y) (km/occupant/year)
8	Building Transportation Reduction	13	Total transportation for the ith year in (km or ltr)
		14	Total Transportation for ($n - i$) year (km or ltr)
		15	Transportation Reduction index (BTRI) (%)
9	Transportation Carbon Footprint	16	Total Transportation Carbon Footprint in (kg.CO_2e)
		17	Transportation Carbon Index ($BTCI_X$) (kg.CO_2e/km/year)
		18	Transportation Carbon Intensity (kg.CO_2e/occupant/year)
10	Transportation Carbon Footprint Reduction	19	Transportation Carbon Footprint for ith year (kg.CO_2e)
		20	Transportation Carbon Footprint for ($n - i$) year (kg.CO_2e)
		21	Transportation Carbon Reduction Index (BTCRI) (%)

Source(s): Developed by authors

Table 6. Summary of the proposed indicators and sub-indicators

$$AI_{mode_i} = EDF_{max} + (0.5 * All\ other\ EDFs) \tag{2}$$

$$EDF = \frac{30}{TAT};\ Minutes \tag{3}$$

$$TAT = Walk\ Time + Average\ Waiting\ Time \tag{4}$$

$$AWT = SWT + Reliability\ Factor \tag{5}$$

$$SWT = 0.5\ *\ (60/Frequency) \tag{6}$$

where

AI = Accessibility index

EDF = Equivalent doorstep frequency

$Route$ = Number of route in the points of interest

$Mode$ = Means of public transportation (i.e. bus and trains)

POI = Points of interest (points where the building is locate)

TAT = Total access time

SWT = Standard waiting time

The value of PTAI determines the proximity of the building to public transport systems (i.e. the higher the value the closer the development to the public transport access).

3.2.1.2 Sustainable parking space (SPS). This indicator provides reward for not over-providing parking space thereby reducing private vehicles usage and encourages the use of public transport. The points distribution can be based on the design number of person per parking space. The descriptions and some other conditions regarding the indicator will be based on the need of the country's standard on the parking provision. As reported in Breeam (2020), points distribution and score also depends on the PTAI of the building as it depends on the accessibility of the building by public transport. Parking spaces set aside specifically for the disabled, old people and parent with baby users of the building are exception in the assessment. The exception is possible if these spaces are set aside for such uses, i.e. sized accordingly with the appropriate signage or markings (Usman, 2019).

3.2.1.3 Green vehicles priority (GVP). This indicator encourages the use of green vehicle for minimising the GHG emission. Provisions of parking areas for green vehicles encourage the use of such vehicles (e.g. hybrid or electric vehicles, bicycle and motorcycles). Building can score points for this indicator by providing the building with the preferred parking space, charging point and any other fixture that will specify the parking space is for green vehicle. Depending on the greenness of the building required, up to 40% of the parking space may be reserved for green vehicle (Usman, 2019).

3.2.1.4 Proximity to basic amenities (PBA). This indicator encourages and reward building located in close proximity and facilitates easy access to local services and basic amenities. This reduces multiple or extended building user journeys, including transport related emissions and traffic congestion. Number of amenities required can vary between different types of buildings. These should include and not limited to appropriate food outlet, access to cash, recreation, fitness or leisure facility, roads and Linkages, postal service providers and security outlets. Others include health facilities, provision outlets, childcare facility or schools, hospitality, religious facilities and other community facility (Usman, 2019).

3.2.1.5 Alternative modes of transport (AMT). This indicator provide facilities which encourage building users to travel using low carbon modes of transport and to minimize individual journeys. Modes of transports include rails, road and air transport. Building can score points for this indicator by providing the building with access to different transport modes routes (i.e. the number of alternative modes determines the rewards for the building) (Usman, 2019).

3.2.1.6 Transportation plan and policy (TPP). This indicator encourages the provision of plan and policy by the management of the building or organisation as well as government on ground to control travelling to reduce the overall emission associated with building transportation. This indicator can be measured using two sub-indicators. These are providing a necessary transportation reduction strategy in the running of the affairs of the organisation. The other sub-indicator encourages the use of any available national and sub national regulations regarding transportation. It involves providing necessary laws and policies that will provide reduction in unnecessary transportation by policy makers or stakeholders. The assessment of these sub-indicators can be by abiding by these strategies, standards and policies (Usman, 2019).

3.2.2 Transportation carbon footprint assessment. This section describes indicators that are concerned with construction and operational GHG emission quantification and associated emission reduction over a specified time interval. Below are the descriptions of indicators in this category.

3.2.2.1 Building transportation performance. This indicator recognises improvements in the transportation performance of the building above national building regulations in relation to number, type and quality of vehicles used, quantity of fuel used and total distance travelled. This can be assessed using building transportation index (BTI_X) or building transportation performance (BTP) and building transportation intensity (BTI_Y). BTP measures the relationship between the design transportation need or operational building transportation and national regulation provision (standard transportation provision). BTI_X measures the relationship between operational transportation with the GFA while BTI_Y measures relationship with average building occupant. The point's distribution and score is based on the ratios and percentage calculated. Therefore, the BTP and BTI can be calculated using equations (7) to (11) (Usman, 2019).

$$BTP = \frac{Design\ Transportation\ need}{Standard\ Transportation\ Provision} \times 100\% \tag{7}$$

$$BTP = \frac{Operational\ Transportation}{Standard\ Transportation\ Provision} \times 100\% \tag{8}$$

$$BTP = \frac{Operational\ Transportation}{Design\ Transportation\ need} \times 100\% \tag{9}$$

$$BTI_X = \frac{Operational\ Transportation}{Building\ Gross\ Floor\ Area} \left(\frac{km}{m^2/yr}\ or\ \frac{ltr}{m^2/yr}\right) \tag{10}$$

$$BTI_Y = \frac{Operational\ Transportation}{Average\ Occupant} \left(\frac{km}{Occupant/yr}\ or\ \frac{ltr}{Ocuupant/yr}\right) \tag{11}$$

3.2.2.2 Building transportation reduction. This indicator defines the transportation reduction and can be assessed using building transportation reduction index (BTRI). If T is the distance travelled in (km) or fuel consumed in ($ltr\ or\ m^3$), n is the assessment year and i is any considered year of comparison before n as approved by stakeholder then BTRI can be calculated using equation (12) (Usman, 2019).

$$BTRI = \frac{T_{n-i} - T_n}{T_{n-i}} \times 100\% \tag{12}$$

3.2.2.3 Transportation carbon footprint quantification. This indicator measure the total fuel consumed and/or distance travelled by the organisation transportation together with its associated emission. The description of this indicator was from consideration of several literatures among which are IPCC (2006), Avestian *et al.* (2012) and ISO 14067:2018 (2018). To measure this indicator, the assessment considers transportation-associated emission from construction and operational activities. For construction, it covers fuel consumption and emissions for the entire construction period comprising site preparation, building development and landscaping and road construction. It may also involve other transportation related to supply of materials and from stationary machineries. For the operational transportation emission, the sources includes number of vehicles, trucks and bikes own and used by the building, and other transportation and machineries consumption for a given assessment period. GHG emission may be calculated by considering the type of fuel used, the emission factor of that fuel, quantity of fuel used, number of equipment and vehicles used and hours and/or distance travelled using equations (13) and (14) (IPCC, 2006; ISO 14067:2018, 2018; Usman, 2019).

$$GHG_{Fuel} = \sum_{f=1}^{n} (FC_f * EF_f) \tag{13}$$

$$GHG_{Distance} = \sum_{D=1}^{n} (DT_D * EF_D) \tag{14}$$

where:

$Emissions$ = emission in kg

EF_f = emission factor in $kgCO_2e$ per TJ, ltr, gal of fuel consumed.

FC_f = fuel consumed in TJ, ltr, gal and m^3

f = fuel type a (e.g. diesel, gasoline, natural gas, LPG.)

EF_D = emission factor in $kgCO_2e$ per distance travelled

DT = distance travelled in km

D = distance type i.e. km for miles

Building transportation carbon index (BTCI) is used to measure this indicator using equations (15) and (16).

$$BTCI_X = \frac{Total\ carbon\ footprint\ from\ transportation}{Building\ Gross\ Florr\ Area\ (GFA)} \left(\frac{kgCO_2e}{m^2/yr}\right) \tag{15}$$

$$BTCI_Y = \frac{Total\ carbon\ footprint\ from\ transportation}{Average\ yearly\ Occupant} \left(\frac{kgCO_2e}{Occupant/yr}\right) \tag{16}$$

3.2.2.4 Transportation carbon footprint reduction. Further, to assess the impact of building towards CFP contribution to the built environment, there has to be a measure of reduction of such emission over a specified period. This indicator encourages monitoring of overall vehicles usage and its associated GHG emission reduction over the operational period. The assessment of this indicator utilises transportation carbon reduction index (BTCRI). BTCRI assessment considers determining the percentage reduction in the entire transportation associated CFP. If n is the assessment year and i is any considered year of comparison before n as approved by stakeholder then BTCRI can be calculated using equation (17) (Usman, 2019).

$$BTCRI = \frac{CFP_{n-i} - CFP_n}{CFP_{n-i}} \times 100\% \tag{17}$$

The boundaries of the point's distributions depend on the countries' national emission inventories for the transportation and its associated CFP. This index in comparison with the country's vehicles and equipment usage and GHG emission inventories and standard determines the point's distribution for the indicators.

3.3 Building transportation assessment model

3.3.1 Points scoring assessment model. Building can be assessed using points scoring by all the proposed indicators points scored (*PS*) for GHG emission reduction strategies (*s*) can be calculated using equations (18) and (19).

$$PS_S = \sum_{P1}^{Pn} Ir_s \tag{18}$$

$$\sum_{P1}^{Pn} Ir_S = PTA_{P1} + SPS_{P2} + GVP_{P3} + PBA_{P4} + AMT_{P5} + TPP_{P6} \tag{19}$$

where P is the points scored by the indicator *1* to *n*.

Ir_s is the indicator under consideration in the emission reduction strategies (*s*).

Points scored (PS) for the GHG emission quantification (q) can be calculated using equations (20) and (21).

$$PS_q = \sum_{P1}^{Pn} Ir_q \tag{20}$$

$$\sum_{P1}^{Pn} Ir_q = BTP_{P1} + BTI_{X\,P2} + BTI_{Y\,P3} + BTRI_{P4} + BTCI_{X\,P5} + BTCI_{Y\,P6} + BTCRI_{P7} \tag{21}$$

where Ir_q is the indicator under consideration in the emission quantification (q).

The average value gives the overall points score (OPS) for BTP building transportation performance using equation (22).

$$OPS = \frac{PS_S + PS_q}{2} \tag{22}$$

3.3.2 Emission quantification assessment model. Outputs to the quantification assessment process include values obtained from the computation of BTIs, BTP, BTRI, BTCI and BTCRI in their respective units. Total transportation conducted in km or fuel consumed in ltr and CFP in $kgCO_2e$ obtained using appropriate EF and GWP are also reported (Usman, 2019; Usman and Abdullah, 2019). The total CFP associated with the transportation (CFP) can be calculated using equations (23) and (24).

$$CFP = \sum_{\substack{i=1\\m=1}}^{n} TCE_{i,m} \tag{23}$$

$$\sum_{\substack{i=1\\m=1}}^{n} TCE_{i,m} = TCE_{1,1} + TCE_{2,1} + \ldots + TCE_{n,1} + \ldots + TCE_{1,12} + TCE_{2,12} + \ldots + TCE_{n,12} \tag{24}$$

where:

CFP = total yearly CFP (GHG emissions)

TCE = total carbon dioxide equivalent ($kgCO_2e$)

i = type of fuel or distance measurement

m = number of month in a year (1 to 12)

4. General discussion

Transportation is very important in sustainable building LCA as it involves direct fuel combustion. BREEAM, Green Star Australia, New Zealand and South Africa, and LEED rating systems consider transportation as separate category. While GBI, Green Mark, BEAM, Indian GBC, GreenRE and Green Ship rating systems consider transportation as sub-category in other categories. The consideration of transportation category and its associated indicators defines its importance in the given rating system.

The major contribution of this study is the inclusion of the measure of fuels and/or distance travelled and the associated direct GHG emissions from building own vehicles and equipment usage. The other contribution of this study is the assessment of GHG emission reduction over some specified operational periods. The division of the consolidated indicators into two and their sub-division in to indicators and sub-indicators give the indicators wider coverage in terms of importance, GHG emission and climate change consideration. The adoption of five-step framework for successful development of the indicators makes the study adequate in the indicator selection as compared to existing rating systems indicators.

5. Conclusions

From the outcome of the study, the authors made the following conclusions.

(1) The consideration of transportation category and its associated indicators in several rating systems defines its importance in the rating system and consequently motivation to this study.

(2) Most of the rating system around the world did not cover transportation associated GHG emission, which prompted its inclusion in the development of proposed indicators.

(3) The adoption of five-step framework for successful development of the indicators makes the study adequate in the indicator selection. This together with the criteria adopted increase the universal acceptability of the indicators.

(4) The major contribution of this study is the inclusion of the measure of fuels and/or distance travelled. It also includes their associated direct GHG emissions from building vehicles and equipment usage combustion in to assessment of built environment.

(5) Other important contribution of this study is the introduction of GHG emission reduction assessment over some specified operational and assessment periods.

(6) The consolidations of transportation indicators and their division into ten indicators and twenty-one sub-indicators give the indicators wider coverage in terms of importance, GHG emission and climate change consideration.

(7) The indicators assess the operational GHG emission in the form of CFP using BTIs, BTP and BTCI and their associated BTRI and BTCRI.

(8) The importance of transportation-associated emission to sustainable development makes current study introduce transportation alongside its associated GHG emission quantification and reduction aspect in the consolidated indicators.

(9) The most important contribution of this study in addition to the emission reduction strategies is the consideration of the propositions from the GHG protocol and IPCC reports in the sustainability of build environment.

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