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Abstract The city's 2-dimensional spatial structure and 3-dimensional form significantly influence its energy and GHG emission intensity. In rapidly developing urban-regions, the ability of the local planning authorities to quantify the spatial structure and form of existing urban areas, new developments and the emergent urban-region in terms of GHG emission is vital to any effective local, national and global climate change mitigation effort. While a wide array of tools has been developed for assessing built environment sustainability at various spatial scales, these are predominantly eco-efficiency rating tools that do not model the 'spatial structure-GHG' relationship and do not illustrate the GHG implications of urban structure and form, which crucially inform local planning decisions with respect to climate change mitigation. This paper takes the first steps in analysing three spatial-based planning models (Envision Tomorrow, GHGProof, URBEMIS) that estimate GHG emissions towards assessing their adaptability for application in Malaysian cities. It looks into the models' "inner working", unpacking the variables and their relationships; assumptions and conversion rates used; and their data requirement and structure. The models' characteristics and features are critically compared to evaluate their capabilities, limitations and relevance to the Malaysian urban planning context, particularly in terms of data availability.

1. Introduction

The strategic importance of cities and urban and regional planning in tackling global climate change has been well articulated [1, 2, 3]. Being areas of high concentration of physical assets, and being geographic epicentres of social and economic functions, cities and urban-regions are massive consumers of resources and energy; generators of wastes; and emitters of CO_2. On the whole, the built environment has been found to be accountable for approximately 50% of human induced greenhouse gas (GHG) emissions, due particularly to heating and/or cooling buildings and transporting people and goods [4].

Nonetheless, the same asset concentration and functional intensity also mean that any effective low carbon society (LCS) measures would go far in mitigating CO_2 emissions. Key to this is the cities' and urban-regions' overall spatial form and internal structuring. At the local level where decisions about urban form and structure are made, the ability of local planning authorities (LPAs) to quantify the spatial structure and form of existing urban areas, new developments, and the emergent urban-region in terms of GHG emission is vital to any effective local, national and global climate change mitigation effort. The availability of effective spatial planning tools that are able to model the relationship between urban-regional structure and form and GHG emissions becomes highly essential to support judicious decision making in urban and regional planning towards reducing the energy intensity and GHG emission of urban-regional growth [5].

A wide spectrum of tools for assessing the sustainability of the built environment exist and are being utilised by decision makers in a number of developed countries. For example, there are a few internationally-known neighbourhood eco-efficiency rating tools in assessing development at the neighbourhood and township scales, such as LEED for Neighborhood Development (US based), BREEAM for Communities (UK based) and CASBEE for Urban Development (Japan based). In

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Malaysia, the Green Building Index (GBI) for building scale and GBI Township Tools [6] for neighborhood scale have been developed by GreenBuildingIndex Sdn. Bhd. These tools are used to assess the sustainability and eco-efficiency of individual buildings and of townships. However, GBI evaluation is not conducted by LPAs for the purpose of measuring and evaluating development projects' eco-efficiency but is more a private sector initative in the form of a "commercial auditing" service. Furthermore, the assessment is not compulsory on all development proposals and it appears to appeal to land developers as a tool for marketing and enhancing commercial gains of development projects, apart from some attempts at contributing to the environment; many developers choose to adopt the GBI assessment to showcase and promote the 'ecofriendliness' and 'greenness' of their development projects to potential buyers.

The tools mentioned so far may be categorised under 'rating' tools which do not yield exact quantification of energy consumption and/or GHG emissions of development projects based on relevant spatial design variables. These tools generally provide relative rating to development projects in terms of their overall eco-efficiency that is aggregated from scoring assigned to preset eco-efficiency performance criteria. As a result, they cannot be used to test and compare spatial design alternatives in terms of estimated GHG emissions to support planning decision; specifically, the tools do not inform LPAs of the potential contribution of proposed developments to GHG emission reduction targets that have been set.

At the national and regional scales, the Asia-Pacific Integrated Model (AIM) developed by the National Institute for Environmental Studies (NIES), Japan has been used in the calculation of national- and regional-level GHG emissions of a number of countries, regions and cities, including that of Putrajaya, Cyberjaya and Iskandar Malaysia [7]. This model helps to identify which sectors are the most critical in emitting GHG and next use the quantitative output to propose policies to achieve the target emissions of a country, region or city. Nonetheless, the tool is mainly a socioeconomic model and does not emphasise the physical-spatial aspect of cities. The data used are mainly census and socioeconomic statistics data that are relatively easily available at the national, state and regional levels. However, it would be difficult to use the model at the site or neighbourhood level due to the lack of micro-spatial scale data.

As in the process of planning application at the local level, socioeconomic models like the AIM are not directly applicable as they lack the capacity to model the land use-GHG relationship. Application for Planning Permission to the LPA requires the submission of a layout plan that illustrates the physical arrangement of land uses, infrastructure and urban form, of which the socioeconomic models have not been designed to take into account. Therefore, another kind of spatial based tools, which can translate the data in layout plans and model this aspect and its relationship with GHG emissions is needed to support effective planning and regulatory decisions especially at the local level that ensure sustainable development with minimum carbon footprint.

The purpose of this paper is to take the first steps in analysing three spatial-based planning models (Envision Tomorrow, GHGProof, URBEMIS) that estimate GHG emissions towards assessing their adaptability for application in Malaysian cities. It looks into the models' "inner working", unpacking the variables and their relationships; assumptions and conversion rates used; and their data requirement and structure. The models' characteristics and features are critically compared to evaluate their capabilities, limitations and relevance to the Malaysian urban planning context, particularly with respect to data needs and availability.

2. Criteria of an Ideal Tool

In order to compare and evaluate the tools, a set of criteria is needed, which is developed through a review of relevant literature. From this, the characteristics and criteria of an ideal spatial-based GHG assessment tool are identified and form the basis for comparing the tools/models that have been selected for this study. While literature on this aspect appears to be rather limited at the time of study, a list of 11 criteria has been generated based on three recent publications. Table 1 summarises the criteria of the ideal tools mentioned by Condon et al [1] and the criteria used in tools assessment studies by Fehr & Peers [8] and the Scottish Government [9]. The table gives an overall picture of the key criteria that should be emphasised in studies that involve evaluation of GHG assessment tools.

Table 1. Summary of criteria on ideal tools from various literatures.

Literatures / Criteria of Ideal Tool	Condon et al. (2009)	Fehr & Peers (2009)	Savills, AFA Technology and MVA Consultancy (2011)	Remarks
Comprehensive	/	/	/	Fehr & Peers (2009) address the sensitivity of tools to land use change and transportation change under 'Sensitivity'
Three dimensional	/			-
Multi scalar	/	/	/	-
Policy Relevant	/	/	/	Fehr & Peers (2009) address the sensitivity of tools to policy under 'Sensitivity' Scottish Government (2010) addresses the response of the tools to the Climate Change Act, Scottish Planning Policy
Iterative	/	/	/	-
Additive	/		/	-
Accessible	/	/	/	Prefer Excel Based by Scottish Government (2010)
Affordable	/	/		-
Accuracy		/		-
Transparency			/	-
Other GHG Sources		/	/	-

Apart from the above, tools that also meet the need of this study need to be able to incoporate 'three dimensional' urban form attributes; model the actual condition of the urban environment; and describe the relationship of various urban form configurations and design alternatives. Quite importantly, the tools included in this study should meet the 'affordable' criterion to enable acquisition of the tools within the study's budgetary constraint.

3. Exploration and Overview of Models

The study begins with an exploratory search in the literature and websites for GHG assessment tools/models that have been utilised in different parts of the world. This leads to the identification of a total of 31 tools/models that have been applied in actual planning projects, most of which have been featured as case studies in the literature and websites. From here, attempts at acquiring the tool/models are taken by sending requests to the tool/model developers. For readers' reference, publications such as Condon et al [1] and Fehr & Peers [8], and the BC Climate Action Toolkit website have been especially helpful as they provide listings of GHG emission tools/models with their respective sources from which the tools/models may be obtained and queries about them may be made.

Two major factors have been considered in selecting the tools to be analysed and compared. With respect to the 'affordability' criterion, the tools selected are mostly open source tools, free use of which has been authorised by their developers with the motivation that users would return constructive feedback that will feed into the enhancement of the tools/models. Secondly, as a key interest of this study is in identifying and evaluating planning tools/models that have the ability to quantify urban spatial structure and form into estimated GHG emissions for the purpose of supporting planning decisions at the local planning level, the tools/models selected should have the capability to take in township and/or neighbourhood project-scale physical-spatial data and translate them into GHG emissions. In other words, tools/models that enable spatial-scenario based modeling of GHG emission will be preferred as these have great potential to be used as planning/design review tools for improving

spatial planning and design or as evaluation tools for quantitative checking of potential GHG emissions of proposed development projects.

The results of the screening process based on the above factors zero in on three GHG emissions tools that fulfill the needs of this study, especially in terms of ease of acquisition and spatial modeling ability, viz. 'Envision Tomorrow', 'URBEMIS' and 'GHGProof'. These three models are then further explored in terms of their "inner working", including variable relationship and data requirement, towards eventually assessing their adaptability to the Malaysian urban planning context.

In order to obtain the overall picture of the 'inner workings' of the models to understand the logic behind their running and function, the model variables are abstracted from their original spreadsheets or user interface form accordingly. The models are then collapsed into 'tree charts' to clearly show their data structure and the relationship between the extracted variables as well as the underlying camputation logic that links them to the GHG emissions output. Comparison is then made across the models to identify the strengths and limitations of each of them followed by a 'gap analysis' on the data requirements of the models to analyse the adaptability of the models into the Malaysian context.

4. Analysis and Findings

4.1."Inner working" of the models
Each of the models have been "unpacked" by extracting their variables from the model interface platforms. This leads to the identification of data required; assumptions and conversion rates used in the model; and the algorithm which links them in yielding the GHG emission estimation. These are presented in a series of 'tree charts' (unable to be shown here due to page limitation) to clearly depict the models "inner working".

Generally, Envision Tomorrow requires detailed data input of building prototypes, such as the'floor area ratio' and 'land use mix'. It also has advantages in assessing development in detailed urban design context as it includes data input from the building scale and street dimensions, which indirectly enable it to address mitigation measures of mixed use and compact developments in reducing the developments' carbon footprint.

Meanwhile, GHGProof covers four sectors that are buildings, transportation, waste and biomass (agriculture and forest) in the overall estimation for a project's GHG emission. It also addresses a few climate change mitigations, as it considers distance from the site to the city centre and transit.

URBEMIS has embedded mitigation measure for all three emission sources (construction, area,operational) that will affect a project's total emissions. URBEMIS has the options of calculating mitigated emissions or unmitigated emissions separately for all three emission sources of the projects.

By comparing the data structures, GHGProof has advantages as being a more comprehensive tool as it considers emissions of four sectors. By comparing the tools in their methodologies, Envision Tomorrow and GHGProof blend both the top-down and bottom-up approaches, while URBEMIS uses the bottom-up approach. All the tools are using end-state assessment methodologies, as their data requirement can describe future land use conditions and behavioral patterns. However, Envision Tomorrow stands out due to its more detailed data requirement in building prototypes that may assist in policy formulation at the building level. It also has the strength of performing cross-scalar analysis and assessment of emissions while the other two models do not have the ability, as their data are input in a 'snapshot' manner within a geographical boundary. All of the tools are policy-making supportive, as all of them have the ability to assess scenarios with climate change mitigation, although with different approaches.

4.2. Comparison of the tools based on criteria of ideal tools
The models are then compared with each other based on the 11 criteria of ideal tools identified from the literature to assess each model's relative ability, strengths and limitations. This comparative analysis shows that no one model investigated addresses and achieves all the criteria; each model has its own strengths (indicated by bold texts with respect to the a particular criterion) and limitations, clearly shown in Table 2. The choice of models to be adopted therefore depends on the specific needs and prioritisation of the criteria by the user.

Table 2. Comparison of the models to the criteria of ideal tools.

Criteria	Envision Tomorrow	GHGPro	URBEM
Comprehensive	It is found that it can assess buildings' emissions only after exploring	Assesses emissions of buildings, transportation, waste and biomass (agriculture and forestry) sectors	Assesses construction emissions, area source emissions (building) and operational
Policy relevant	Addresses mitigations on buildings and arrangement of land uses (development	Addresses mitigations on community energy and energy efficiency (buildings) and transportation mode shift	Addresses mitigation on energy efficiency (buildings) and various trip reduction strategies (transportation)
Multi-scalar	Can assess at the building scale through to the regional scale; cross scalar assessment is	Can assess any geographical scale; however, cross scalar assessment is not possible	Can assess only at the site and project level
Iterative	The variables can be easily adjusted, as it uses the Excel platform	The variables can be easily adjusted, as it uses the Excel platform	The variables embedded are fixed
Accessible	Uses the Excel spreadsheet which is commonly used for data input; GIS extension	Uses the Excel spreadsheet and simple GIS analysis for data input	Simple data key in with built in data requirement platform.
Other GHGs	Only carbon dioxide emission can be quantified	Only carbon dioxide emission can be quantified	Quantifies reactive organic gases (ROG), nitrogen oxides (NOx), carbon monoxide (CO), sulphate dioxide (SO_2), particulate matters (PM10) and
Additive	Ability of these models to be linked to other models is unknown, as this study is conducted on individual models		
Affordable	Open source	Open source	Freeware
Three Dimensional	Can translate spatial information from layouts into the model	Can translate spatial information from layouts into the model	Can translate spatial information from layouts into the model
Accuracy	Cannot be discussed as no application of these models is conducted in this research and therefore no actual results cannot be compared		
Transparency	Calculation can be traced back through the Excel formula bar	Calculation can be traced back through the Excel formula bar	The algorithm cannot be traced back and not shown in the model platform

4.3. Gap analysis of data requirement of the models versus data availability

In order to assess the immediate adaptability and applicability of the models in Malaysian cities in terms of the models' data need and the data's availability in the Malaysian urban planning context, a gap analysis has been conducted to provide a quick view of the availability of data required by each model. The gap analysis shows that:

- Envision Tomorrow requires less data. However, the data on mix of use in the building prototypes may not be adapted directly, as land use zoning in most plans are single land uses.
- The district heating system as the variable of GHGProof is not relevant to the Malaysian climatic context.
- Some data requirement of GHGProof needs preliminary work of preparing related GIS layers for analysing and provide data input for the model.
- The data requirement about fireplaces and day of summer to calculate the landscape equipment emissions in obtaining total Area Source Emissions is not relevant to the Malaysian climatic context.
- URBEMIS has a simpler data requirement with data readily available from documents in the planning permission process. However for Operational Emissions Mitigation, some GIS layers need to be prepared for analysis to determine the availability of related mitigation options offered in the model.

The gap analysis of the data requirement of the models generally shows that there are some data requirements of all the models that may not be relevant in the Malaysian context. The models therefore need to be adapted and improved to be suited to application in Malaysian cities, especially in

terms of using readily available spatial planning data. Two models, which are GHGProof and URBEMIS need preliminary work such as GIS analysis results as the source of their data input.

5. Conclusion

Each of the models explored has its unique data requirement and structure and each of them is different from another in terms of its "inner workings" and data processing approaches. Methodologies or techniques for GHG emission estimation are continuously evolving as our understanding of the dynamics behind GHG generation and technologies improved, which lead to the emergence of a variety of models. This study takes the first humble steps in analysing three available spatial-based GHG emission models which are currently in use in real practice overseas in order to gauge their degree of immediate adapatibility and applicability in Malaysian urban planning based especially on the models data need and data availability in Malaysia. It is found that each of the three models presents its own strengths, limitations and potential for adaptation and adoption; and the choice of models depends on the purpose of modeling as well as prioritisation of model criteria by the user.

In fact, more detailed analysis needs to be conducted into the models, including additional models as they become available, towards exploring the potential of synthesising the models' strengths, while considering the unique urban spatial characteristics of Malaysian cities, to construct an effective spatial planning model that may function as a design review tool used by master planner and designers for improving the eco-efficiency of development proposals as well as an evaluation tool used by LPA planners to support and guide local planning decision making. This is especially crucial towards helping Malaysia to contribute to global climate change mitigation through providing a clearer pathway towards reducing GHG emissions of urban growth as the country continues to urbanise rapidly; and towards materialising the country's voluntary 40% reduction in carbon emission intensity of GDP by 2020 based on the 2005 emission level.

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