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Towards a generic multi-criteria evaluation model for low carbon cities

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A R T I C L E I N F O

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A B S T R A C T

The low carbon city concept has surfaced over the past decade and has been increasingly integrated with urban planning. Likewise, assessment methods of Low Carbon Cities have been initiated. Of these, are the Entropy weight method, fuzzy comprehensive evaluation and multi-criteria evaluation. This paper attempts to propose a multi-criteria evaluation model for city performance using a set of criteria and a benchmark with a view to determining whether the city is low carbon or not. Ten pilot cities were selected for which twenty indicators were utilized for model calibration and testing. First, a standard entropy model was employed featuring three cities as low carbon namely; Stockholm, Vienna and Sydney. Second, with the modification of entropy model by adding relative weight to indicators, two more cities were quite rightly added to the list: London and São Paulo. Third, the proposed model was calibrated and tested, the result of which was compared with the results of both entropy and modified entropy models. Luckily, the proposed model showed great similarity to the modified entropy model. Moreover, the model was subsequently tested independently on five additional cities comprising Copenhagen, Bogota, New Delhi, Singapore and Seoul to ascertain results. Copenhagen and Bogota were low carbon cities, the others were not. When populated with relevant data, the proposed model can readily determine whether a particular city is low carbon or not thereby obviating the need for benchmarking and score adjustment every time a new city is added to the study list.

1. Introduction

Though Cities are major centres of economic growth, they are nonetheless the largest producers of global carbon emissions. Rapid urbanisation, coupled with global warming, increasingly threaten environmental quality, social well-being and quality of life (Edstrand, 2015). Some cities have initiated programs to promote reductions of carbon emissions and thereby, mitigate the impacts of climate change. London, for example, attempts to reduce 60% of Green House Gas (GHG) emissions by 2025. Similarly, Rotterdam and Iskandar seek to cut 50% of carbon emissions by 2025 and 2030 respectively. Chicago has set out an ambitious target to reduce 25% by 2020 and 80% by 2050 compared with the 1990 level (Tan et al., 2015).

Various models have been built to measure carbon emissions to substantiate studies of climate change and sustainability. In Beijing for example, nexus modeling of energy and carbon flows was considered with urban size and population density (Chen and Chen, 2016). Liu and Wang (2017) suggested a multiproxy distribute on a system that included a series of transport-related demand and supply indicators. In Oslo MARKAL/TIMES modeling was used to analyse the transition to a low-carbon energy system (Lind and Espegren, 2017).

By building on previous research and filling a gap in the literature, this paper attempts to develop an evaluation method that affords a generic multi-criteria model which can be applied in every city to assess its performance with regard to carbon emissions and subsequently establish whether it is low carbon or not. Ten pilot cities were selected to construct the indicator framework and validation. City selection was based on its carbon emission level and the assessment of credible institutions. The selected cities consisted of Stockholm, Vancouver, London, New York, Johannesburg, Beijing, Sydney, São Paulo, Mexico City and Tokyo. Thereafter, the model was subsequently tested independently on five more cities comprising Copenhagen, Bogota, New Delhi, Singapore and Seoul with a view to ascertain results.

Two assessment methods are used here. First, is the entropy weight method which was originally devised by Tan et al. (2015). The model's criteria and indicators of low carbon city elements includes inter alia, energy, water, land use, air quality, and mobility and builds on the studies of Lin, Jacoby, Cuia, Liu, and Lin (2014); Han, Tang, Fan, Liu, and Wei (2016); and Zhou, He, Williams, and Fridley (2015). It must be noted however, that in Tan et al., (2015), the model has applied equal weight to each criterion, despite differences of carbon emissions levels. However, this deficiency has been rectified by Kourtit, Macharis, and Nijkamp (2014) who have employed multi-actor multi-criteria analysis (MAMCA) to identify the relative importance of indicators and cities.

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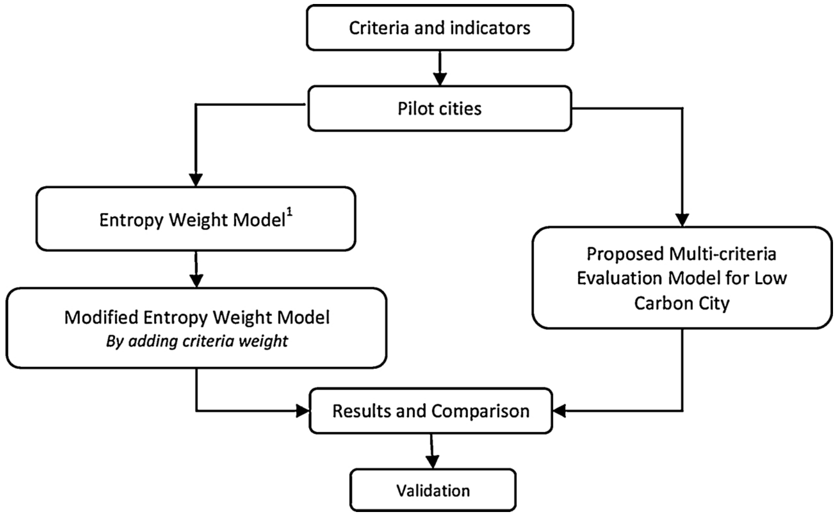

Fig. 1. Research Framework.

Apparently, human activities produce most carbon emissions, the preponderance of which comes from combustion of fossil fuels (Poumanyvong and Kaneko, 2010). In fact, the International Energy Agency has identified three sectors that use fossil fuels and appreciably contribute to carbon emission levels, namely; electricity/heat, transportation, and industry. This study draws on seven sources as references to determine the weight of each category which proved helpful in refining the proposed evaluation model. Arguably, the addition of weight to the proposed model has made it more realistic as it accommodates real condition of city and changes its score and results which were derived by previous research.

Second, is a proposed evaluation model that has been formulated to afford a summary of multi-dimensional criteria thereby facilitating the determination of a city being low carbon or not. Moreover, the proposed model assesses city's performance and readily establish new calculations independently.

2. Literature review

Over the past few decades, economists and operations researchers have been concerned with building optimisation decision-making tools which are widely known as multi-criteria analysis (Yager, 2016). Central to this evaluation tool is the qualitative multi-dimensional environmental effects which provide an adequate representation of all relevant criteria (Nijkamp and Voogd, 1980). The criteria could be physical, planning, socio-economic or environmental (Munda, 2003).

Multi-dimensional evaluation models serve two purposes: multivariate data analysis and multi-dimensional decision analysis (Nijkamp and Voogd, 1980). In fact, multi-criteria analysis has been reformed and applied by (Akgun, Leeuwen and Nijkamp, 2012) in their endeavour to evaluate sustainable development. However, Vaz et al. (2012) have noted that their model has been limited to the evaluation and prediction of urban growth pattern and land use development. Likewise, Deveci, Demirel, John, and Ozcan (2015) have confined their analysis to the modeling of strategic development and locational decisions for CO2 storage.

It is widely held that the well-known multi-criteria evaluation is a fuzzy analysis because it deals with uncertainty which in turn increases the complexity of model building (Yatsalo, Korobov and Martínez, 2017). Furthermore, multi-criteria evaluation has taken many forms such as Fuzzy Numbers (FNs), FRAA (Fuzzy Rank Acceptability Analysis) and FMAA (Fuzzy Multi-criteria Acceptability Analysis). It is quite common to combine fuzzy MCDA with weighting indicator to reflect the relative importance of indicators in determining the overall performance. Known as entropy weight, this method employs parameters which describe certain attributes using specific scoring methods (Becker, Saisana, Paruolo, & Vandecasteele, 2017). Originally, entropy belongs to the area of thermodynamics on nonlinear theory. The value of entropy reflects the state of order of a system (Wang et al., 2015). Recently, the Entropy Weight Coefficient Method (EWCM) has been recognisably used to evaluate sustainable development (see (Qi, Wen, Wang, Li, & Singh, 2010) and (Han et al., 2016)).

In an effort to measure sustainability performance, various models have been proposed. Munda (2003) has employed multi-criteria to measure the economic impact on ecological cost by indicators. Sala, Ciuffo and Nijkamp (2015) have formulized Sustainability Assessment (SA) in a structured procedure involving analytical methods and models from various fields (Sala et al., 2015). They went on to conduct scenario design using various measurable multi-criteria and indicators. Furthermore, by developing an objective weighting approach of interdependent criteria, Zhang, Xu, Yeh, Liu, and Zhou (2016) built a model that is equipped with novel optimization on multi-level hierarchy and tested this on 13 cities in China.

3. Methodology

The authors have initiated this study by identifying criteria and indicators which are widely used in sustainability and energy efficiency. Then, ten pilot cities were selected to construct the indicator framework comprising Stockholm, Vancouver, London, New York, Johannesburg, Beijing, Sydney, São Paulo, Mexico City and Tokyo. The authors have also refined Tan et al. (2015) model by adding weight to criteria and obtaining new results which were subsequently used to compare with the proposed model (Tan et al., 2015). Tan's model requires several samples of cities to calculate the benchmark and rank and of a city; when done the same has to be repeated with the addition of a new city to the list. On the contrary, the proposed model allows the addition of new cities without re benchmarking and readily establish new calculations independently. In other words, the proposed model is generic and can be employed to assess new cities other than pilot cities (Fig. 1).

3.1. Criteria and indicator selection

Initially, a group of criteria has been identified, namely; economic, energy, land use, carbon emission level, transportation, water and waste. Quantifiable indicators under each criterion are then selected to measure carbon performance and compare it with the low carbon city benchmark (Tan, Yang and Yan, 2015).

Benchmark setting is important because it aims to sufficiently differentiate between cities of various performance. In other words, benchmark should not be too high to the extent that makes low-performance city difficult to be differentiated and *vice versa*. Tan et al.