Journal of Environmental Management 223 (2018) 57–73

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Carbon dioxide emission and bio-capacity indexing for transportation activities: A methodological development in determining the sustainability of vehicular transportation systems

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ARTICLE INFO

Keywords:
Carbon dioxide (CO_2) emission
Transportation sustainability rating
Bio-capacity
Urban transport
Low carbon transport

ABSTRACT

CO_2 emissions from urban traffic are a major concern in an era of increasing ecological disequilibrium. Adding to the problem net CO_2 emissions in urban settings are worsened due to the decline of bio-productive areas in many cities. This decline exacerbates the lack of capacity to sequestrate CO_2 at the micro and meso-scales resulting in increased temperatures and decreased air quality within city boundaries. Various transportation and environmental strategies have been implemented to address traffic related CO_2 emissions, however current literature identifies difficulties in pinpointing these critical areas of maximal net emissions in urban transport networks. This study attempts to close this gap in the literature by creating a new lay-person friendly index that combines CO_2 emissions from vehicles and the bio-capacity of specific traffic zones to identify these areas at the meso-scale within four ranges of values with the lowest index values representing the highest net CO_2 levels. The study used traffic volume, fuel types, and vehicular travel distance to estimate CO_2 emissions at major links in Dhaka, Bangladesh's capital city's transportation network. Additionally, using remote-sensing tools, adjacent bio-productive areas were identified and their bio-capacity for CO_2 sequestration estimated. The bio-productive areas were correlated with each traffic zone under study resulting in an Emission Bio-Capacity index (EBI) value estimate for each traffic node. Among the ten studied nodes in Dhaka City, nine had very low EBI values, correlating to very high CO_2 emissions and low bio-capacity. As a result, the study considered these areas unsustainable as traffic nodes going forward. Key reasons for unsustainability included increasing use of motorized traffic, absence of optimized signal systems, inadequate public transit options, disincentives for fuel free transport (FFT), and a decline in bio-productive areas.

1. Introduction

Urban transportation produces significant amounts of overall carbon dioxide (CO_2) emissions in urban areas (Li, 2011). Given an era of global warming and climate change, controlling CO_2 emissions, in support of sustainable development is a major concern in maintaining overall global sustainability and livability. According to the International Energy Agency (IEA), the transportation sector of the global economy was the second highest sectoral emitter of CO_2 emissions in year 2008; accounting for 22% of global CO_2 emissions (Loo and Li, 2012). Urban areas of the global economy with 54.5% (rising to 60% by 2030) of the global population are responsible for 75% of global CO_2 emissions, and intra-urban transportation contributed 17.5% of those CO_2 emissions (Fan and Lei, 2016). Dodman (2009), noted that, major cities around the world produced massive amounts of CO_2 from daily traffic movements. CO_2 emissions in representative cities such as: London (22 percent), New York (23 percent), Toronto (36 percent), and São Paulo (59.7%) support Dodman's observations. Additionally, fast developing countries with large populations such as India and China, are now experiencing steadily intensifying emissions of CO_2 from their burgeoning transportation sectors (Li, 2011; Dodman, 2009). It has long been projected that increasing traffic movements induced globally by

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https://doi.org/10.1016/j.jenvman.2018.06.010
Received 22 January 2018; Received in revised form 30 May 2018; Accepted 4 June 2018
0301-4797/

both growth and increases in prosperity would be likely to increase transportation CO_2 emissions if energy consumption based on fossil fuels is not reduced (Li, 2011). Therefore, low CO_2 emissions and sustainable transportation initiatives are rising in importance in global agendas related to climate along with initiatives to change energy consumption patterns and production paradigms.

In addition to an ongoing global increase in transportation induced CO_2 emissions from urban areas, previous studies have identified a decline in bio-productive areas in cities, due to both a loss of area and both losses and degradation of vegetation in the remaining bio-productive area. Researchers have explored this reduction in bio-capacity, and concurrent increases in greenhouse gas (GHG) emissions (primarily CO_2) which jointly result in a widening deficit between the ecological footprint and bio-capacity, in turn resulting in a lack of environmental sustainability going forward (Mancini et al., 2016; Niccolucci et al., 2012). In a transport context, this can be a major indicator of the ability to maintain sustainability going forward. Several studies have linked transportation and CO_2 emissions; for example Shu and Lam (2011) studied traffic related CO_2 emissions and found spatial variations in CO_2 emissions from traffic activities correlated to differences in traffic intensity. Fan and Lei (2016), analyzed CO_2 emissions from traffic with a multivariate generalized Fisher index (GFI) decomposition model to examine the relation between energy structure, intensity and traffic turn-over. Zahabi et al. (2012) explored the effect of the built-environment on urban transport emissions. Labib et al. (2013) investigated the ecological footprint of urban transportation at city scale. Most of the existing transport-environment studies illustrated that growing populations, and the resulting demand for transportation when combined with a lack of available public transportation, influxes of new private vehicles to urban areas and a lack of energy efficient vehicles contributed to increases in CO_2 and other pollutant emissions (Perveen et al., 2017; Fan and Lei, 2016; Yigitcanlar and Kamruzzaman, 2014).

Currently, in the extant literature there is a paucity of research that studies specific locations, zones, and routes within urban transportation systems particularly those areas with high net CO_2. However, these same areas are those that would appear to require the most urgent near-term attention from policy-makers, to formulate and implement effective strategies for local CO_2 emissions reduction. This is a matter of particular urgency due to the ongoing decline of micro-climatic conditions in such areas as well as the need to address the decline in the already limited extent of bio-productive areas in cities (Shakil et al., 2014). Most often, transportation related studies have, in past, focused on mobility, accessibility, speed, or shifts in transport modes (Kamruzzaman et al., 2015). However, these studies do not provide data on existing conditions related to traffic related pollution as defined by net GHG emissions at particular locations. Nor do they provide data on co-located bio-productive areas with the capacity to diffuse or absorb emissions from local traffic.

Available ecological footprint studies at local scale (e.g. city or neighborhood level) have provided gross estimations of CO_2 emissions from residential energy, food, waste generation and fuel consumption, and compared these with area based bio-capacities (Shakil et al., 2014; Minx et al., 2013). However, such studies do not focus on the particulars of transportation related problems. Such studies have measured overall fuel consumption for transportation movements, without either breaking down transportation movements by types or making specific transportation related recommendations to improve transportation sustainability. Hence, there is a gap in the current literature in terms of understanding how traffic related carbon emissions correlate with local available bio-capacity particularly on the specific transportation routes or given zones in cities that have the highest net levels of CO_2.

In order to potentially create real world scenarios that implement sustainable transportation strategies, characterized by low CO_2 emissions and full carbon sequestration, it will be required to understand currently existing conditions related to CO_2 emissions from traffic as well as current carbon sequestration capacity. To facilitate such understanding the present study has rigorously utilized traffic volume and image-based remote sensing technologies to identify traffic zones which are critical, i.e. very heavily loaded, traffic nodes adjacent to bio-productive areas wherein the traffic zones are defined as the area within a 500 m radius of the critical traffic node as areas of interest (AOI). This study measured net CO_2 emissions from transportation activities/movements in these AOIs utilizing an inventory based carbon estimation methodology (Iqbal et al., 2016). The study specifically focused on the meso-scale level of analysis, in order to gain detailed insight into the differing characteristics of transport movement at study identified AOIs.

The present study presents a new index specifically created to correlate CO_2 emissions at critical traffic nodes with adjacent bio-capacity within the studied AOIs in order to calculate a net CO_2 emission value. This quantitative index will provide an opportunity to compare CO_2 emissions with sequestration capacity at specific locations in transport networks. In aggregate, data generated by applying this index to each critical node in a transport network will provide further data supporting policy and remediation both in real-time and as part of computer-simulations of 'what-if' scenarios. Furthermore, changes in the index values for a location based on either changes in traffic composition or changes in local vegetation will allow policy makers to easily grasp the effect of changes to environmental parameters which will, in turn, allow them to correlate index values to any costs of changing traffic or environmental parameters allowing for easier cost-benefit calculations.

2. Materials and methods

2.1. Conceptual design of "Emission, Bio-Capacity Index (EBI)"

Calculation of EBI values requires two types of activities; the first is related to the determination of CO_2 emissions from different vehicle types, based on different levels of activity, fuel type and emissivity (Fig. 1). EBI calculations determine the total daily and yearly CO_2 emissions from vehicular traffic activities for a given area AOI, and converts the yearly CO_2 emission value into the equivalent carbon uptake land measure (C, in global hectare) (Wiedmann and Barrett, 2010). The second type of activity requires determining the land cover types within the AOI and finding the corresponding bio-capacity for each land cover type. Index values are then generated by dividing the carbon uptake land estimated from yearly traffic CO_2 emissions by the total bio-capacity of the AOI, thus providing the value for the EBI for that AOI (Fig. 1). This relatively simple index combines the emissions of CO_2 emissions from traffic in a given area and co-located bio-capacity at the meso-scale into a single value. The basis of the model was derived from the concept of ecological footprints, and their relationship with biological capacities (Mancini et al., 2016; Ontl and Schulte, 2012; Wiedmann and Barrett, 2010).

The index developed for the present study is a new approach to providing tools that are easily and quickly comprehensible to policy-makers and non-experts and which will assist in determining the sustainability of a given transportation network as defined by net GHG emissions. Thus, this index will provide a sustainability-rating system for given locations and/or zones within a transportation network. Previously transportation networks' ecological footprints have been estimated by researchers; however combining the ecological footprint with co-located bio-capacity has heretofore only been explored in non-transport sectors such as housing, food and energy consumption (Nakajima and Ortega, 2016; Moore et al., 2013).

2.2. Case study area

In order to conduct the present study of traffic-related CO_2 emissions and co-located carbon sequestration capacity, a detailed spatial extent was selected. The present study was conducted at meso-scale, at ten major intersections (nodes) within the transportation network of