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Ecological Threshold As An Approach for Balancing Carbon Metabolism in Cities

[Marwa Adel El Sayed, Nourhan Magdy Mohamed]

***Abstract*— Rapid urbanization and population growth since 1980 have become central issues in big cities of developing countries like Egypt. As Egypt was experiencing active modernization processes in the twentieth century, its urban population has increased very significantly both in its numbers and proportions. With the rapid economic growth and urban expansion, the demand for building and infrastructure construction has also increased rapidly, particularly in the residential sector. Undoubtedly, the urban system plays a dominant role in establishing Egypt's energy consumption profile, where the CO2 emissions from Egyptian cities and their share in country emissions have a powerful influence on achieving the country's national carbon emission reduction target. While many countries have recognized the significant role of urban planning in the reduction of carbon dioxide emissions, the spatial planning framework in Egypt is still lacking applications in this aspect. The scope of this paper is to develop a method for calculating carbon emission associated with urban activities at the city scale. Thus, the study proposes a new model for accounting the CO2 emitted from the different land uses within the city and to balance the carbon cycle with green structure planning based on the Ecological factor threshold method.**

***Keywords*— Urban Metabolism, Carbon Emissions, GIS, Ecological Threshold Method**

I. Introduction

The world is currently experiencing diverse environmental challenges, in conjunction with the prospect population growth in urban areas. As a result, cities are becoming a great burden on energy and resource consumption, contributing significantly to the global emissions. As we are now living under the threat of diverse climatic problems, the shift towards constructive policies has become imperative to meet these challenges. Hence, the implication of effective transformations in urban areas has become indispensable in the face of the rapid urban growth. Among these vital changes is the reduction of energy consumptions and carbon dioxide emission in urban areas.

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For several decades, cities have witnessed what can be argued as a brisk urban population growth. Currently, three out of six human beings live in cities, two of whom live in developing countries (World Bank, 2008a). These statistics exemplify the scale of the challenges associated with urban areas in today's world and the growing pressure it presently places at all city levels. Moreover, development trajectories over the last twenty years have been characterized by prodigal energy demands and resource consumption that was pooled with environmental dilapidation at the time of a high-rate population growth.

To deal with the issues of energy consumptions and emission mitigation, intense focus is to be put on the urban sector. Studies on global energy demands showed that urban areas contributed around 67% to 71% of the total primary energy use and associated carbon emissions (World Energy Outlook, 2010). These approximate estimates emphasize the decisive role that urbanization play in the global emissions (Dhakal, 2008a; Poumanyvong and Kaneko, 2010; C. O'Neillet, 2010).

In this sense, a comprehensive scrutiny of the urban environmental collisions is essential to address the future of the world population in a sustainable mode. Relating the impacts of urban activities in the urban environment is not considered a new research trend under the umbrella of urban sustainability. For example, Glaeser and Kahn examined urban centers to trace the carbon emissions that are coupled with urbanization, by using data of U.S. cities and analyzing different patterns of activities such as public transportation, driving, and household energy use (Glaeser, 2010). Thence, analyzing carbon flows and accounting emissions in urban areas is critical for the amendment of urban activities to balance the carbon cycle and attain sustainable livable cities.

II. Urban Metabolism as a City Metaphor

Urban Metabolism presents an efficacious method in the analysis of cities. It is interpreted as a comprehensive framework of city's flows analysis; that includes energy flows, flows of water, and material flows (Gandy, 2004). The first discussion on urban metabolism was conducted in 1883 by Karl Marx; where he incorporated the paradigm of metabolism to envisage the exchanging relation of material and energy between nature and society in his critique analysis of industrial metabolic regimes (Marx, 1981). Later, there was Wolman's study on "The Metabolism of Cities," where he depicted the

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city as an active ecosystem to present a conceptual model of city's metabolism, portraying the city as a consuming parasite dependable on its immediate environment (Wolman, 1965). In that study, Wolman re-launched the concept of urban metabolism by modeling a hypothetical U.S. city, in response to the strapping decline in the environmental quality of American cities at that time.

The depiction of cities as a natural ecosystem was influenced by the studies of system ecology that espoused ecosystem as its core analysis element (Slocombe, 1993). Thus, some architects envisioned the city from this perspective, for instance, the Japanese architect Kisho Kurokawa proposed an analysis approach for cities' metabolism similar to the process of natural life forms (Kurokawa, 1999a). In his study, he argued that resilient cities can be achieved by sustaining their development cycle without the annihilation of their whole resources (Kurokawa, 1977b).

Modern cities are commonly characterized by "linear flows", where missing linkages between urban systems and consumption functions are extant (figure 1). This notion of the city as a consuming parasite highlights the problematic characters of the organization of inputs and outputs in urban areas (Girardet, 1990a). Thence, to achieve long-term viability and sustainability of cities, an inclusive framework that is reliant on shifting from linear flows to circular model of metabolism is essential, where outputs are recycled back into the system to become inputs (Girardet, 2008b).

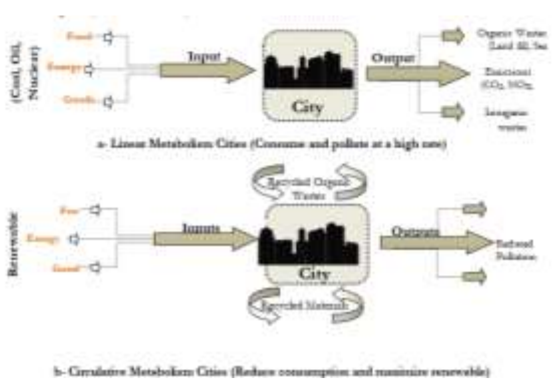

Figure 1: Cities Metabolism, a: Linear metabolism where cities consume resources and create waste at a high rate, b: Cities minimize new inputs and maximize recycling.

In this context, the notion of "urban metabolism," is now being sparingly used by urban planners and ecologists in material cycle and energy balance in cities. Thus, the concept of city's metabolism has returned to the public sight due to its potentials in comprehending carbon balance explicitly (Kennedy, 2011a). Where, the tracking of carbon fluxes and pathways within the metabolic processes of a city will facilitate the control of anthropogenic carbon fluxes and the adjustment of the major sectors in cities. With this mindset, it is critical to adapt metabolism-framed methodology to the current understanding of carbon balance. The main aim of this study is to calculate CO2 emissions in an efficient mode to establish a metabolic framework for carbon cycle balance in cities, derived from CO2 emissions, CO2 uptake and Oxygen discharge. The proposed framework modeled carbon flows for three main sectors within the city: building sector, transportation sector, and industrial sector.

A. *The Global Consumption and Carbon Cycle:*

With the rapid socioeconomic development within cities in juxtaposition with rigorous human activities, urban areas are becoming centers of intractable environmental and ecological problems. The year 2010 marked a milestone in urbanization, as it was the year that world urbanization has encroached by 50% (World Bank, 2010b). Since urbanization in developing countries continues to increase, they are expected to experience the greatest increase levels in the upcoming twenty years. By the year 2020, urbanization will pass 50% in the less-developed regions of the world. Over and above, it's expected that urban population in developing region will go from 18% in 1950 to 67% in 2050, which represents triple the amount that these regions possessed in the late 20 century (UN, 2012). Thus, these significant changes in urbanization will have vast influences on economic growth, energy consumption and carbon dioxide emissions.

With urban areas are now hosting the majority of the world's population, they however, represent a linear metabolic model for resource consumption. In that, the process of inflows consumption from non-renewable materials, energy and food, and the resulting outflows from wastes and emissions are being carried out in an inept manner. This mode of linear metabolism in resource consumption is problematic for the natural environment entity to maintain a competent urban structure (Dunn and Steinemann, 1998; Girardet, 2008). Over the last twenty years, the concept of urban metabolism has been applied as a proficient framework for evaluating energy efficiency, and resource consumption in different urban systems (Coelho and Ruth, 2006; Kennedy et al., 2007b).

Direct and indirect CO2 emissions resulting from urban consumption have outweighed the global overall CO2 emission. Thus, urban emissions from both urban activities and resource consumption are arousing the global CO2 emissions (Dhakal, 2009b; IEA, 2010a; Satterthwaite, 2008; UN-Habitat, 2011). In accordance with The International Energy Agency report (IEA, 2009b), urban energy consumption took up 67% of the global energy ration, and associated CO2 emissions accounted for 71% of global CO2 emissions in 2006; with an expected increase, up to 76% by 2030. In this sense, it is no surprise to treat cities as energy/resources-intensive interactive ecosystems where the regulations of social, economic and ecological activities parallel the rules in nature (Newman, 1999).

Hence, to grasp the carbon metabolic behavior in the urban structure, it needs to be analyzed on two discrete scopes: outside the urban structure, city consumes energy and materials from its hinterlands and emit wastes in the contiguous direction to its urban boundary (figure 2) (Decker,

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2000). Within the urban boundaries, the carbon flows are largely affected by the allocation of land use and human activities (Pouyat, 2006).

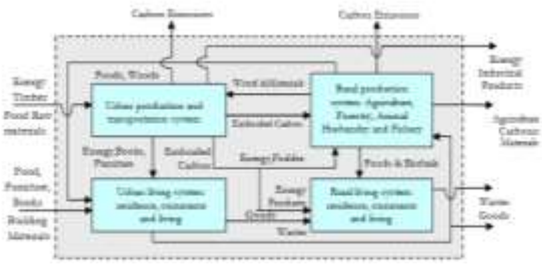

Figure 2: Carbon Cycle flow within The Urban System, (Source: Zhao, 2014)

There is a coherent relation between low-carbon, low energy strategies and the type of urban activities that are dispersed within the urban structure (Dhakal 2010c; Grubler et al. 2012; Rosenzweig et al. 2011; UN-HABITAT, 2011). By examining the framework of Industrial Ecology, it can be noted that, the role that energy use and resulting emissions play is as pivotal as the energy consumption and associated emissions that result from materials, resources and energy inflows to cities. In this regard, through the investigation of literatures in the past years, two key confines are observed: (i) the paucity of reliable accounting method for direct urban emissions, especially in the context of developing countries; and (ii) the limited approach of available accounting methodologies that denote energy and emissions embodied in the flows of services and urban activities.

B. *Egypt: An Evolving Parasite:*

Egypt is one of the largest populated countries in the MENA region (Angus Maddison, 2010). Since 1952, Egypt has witnessed a rapid growth in the urban population, where it doubled from 21,200,000 to reach 42,600,000 in 1980 (Anton Dobronogov, 2005) and this growth rate continued to grow during the past thirty years (figure 3). While Egypt was experiencing a brisk modernization during the twentieth century, Cairo was undergoing an ample urban growth that surpassed other cities in Egypt.

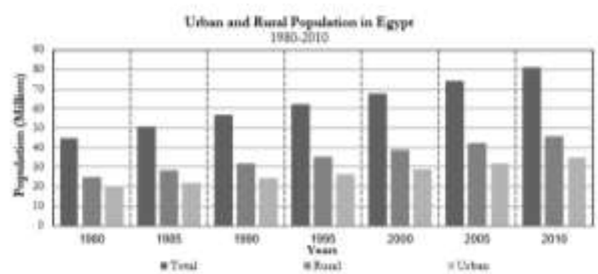

Figure 3: Egypt population, including Urban and Rural Areas (1980-2010), with a significant increase in the urban population from 2000 to 2010, (Source: United Nation, 2012).

As a result of this vast urban growth, Egypt's energy demands have been growing at a rapid pace, increasing its annual average rate of energy demands by 4.5% during the last two decades (Hossein Razav, 2012). While, this high growth in the energy sector was directly linked to the economic and urban growth, it was mainly met by an amplified consumption of fossil fuels and non-renewable materials, which led to higher-energy intensity. Although the average per capita energy consumption in Egypt equaled 0.89 tons of oil (ESMAP, 2009), it is considerably high compared to other countries in the MENA region that have been more conscientious about energy efficiency, such as Tunisia and Morocco. During 2010, Egypt's total energy consumption was approximately 50 Mtoe (IEA, 2010a) with the majority of the demands linked to transportation and industrial sectors. Regardless of the residential sector's share in energy demands, it is expected that Egypt will witness the largest growth in demands by 2030 (IEA, 2007c).

The increase in energy consumption is echoed in both direct and indirect CO2 emissions associated with urban resource consumption. However, the impact of urbanization on CO2 emissions varied between different urban sectors in Egypt. For example, the residential sector, public services sector, construction with the industrial sector, and transportation sector account for more than a half of Egypt's total CO2 emissions as of 2010 (figure 4) (CAPMAS, 2013a). On the other hand, the industrial sector represents around 28% of the total carbon emissions as of 2005 (CAPMAS, 2013a). Thus, with the rapid growth of new industrial cities established within the Egyptian government employment agenda, the emissions from industrial sectors are expected to grow up to 33% by 2030 (CAPMAS, 2011).

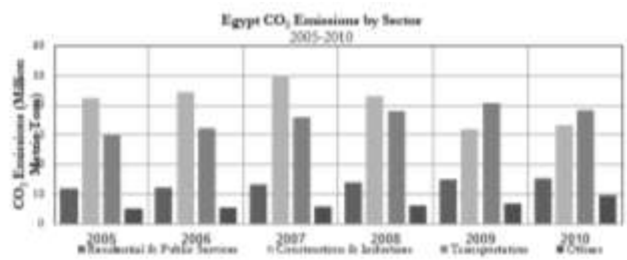

Figure 4: Carbon emissions from urban sectors; Construction and Industrial sectors hold the highest percentage of the total emissions. (Source: Carbon Dioxide Information Analysis Center, 2010).

III. Method

During the 1970s, industrial cities have become an integral part of Egypt's development agenda, with twelve new industrial cities have been established from 1970 to 1991 to accommodate around 3500 factories. The study proposes a new model that employs three main approaches for carbon balance (see figure 5). First, a carbon metabolic approach based on carbon emission calculation and carbon uptake, to quantify the carbon fluxes within an urban system. The proposed model categorized carbon flows into four main sectors: buildings, transportation, industrial zones and land uses. Second, the ecological factor threshold method to quantify how much green area is required to maintain carbon-oxygen balance within the city. Zhang et al. (2007a) was one of the pioneers who applied this method in green structure planning based on analyzing the key ecological elements, including: the population carrying capacity, and carbon

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emissions. Third, land suitability analysis (LSA) to assist in the selection of suitable locations in the study area for urban green area development. The LSA is based on GIS application through raster analysis, using land use maps, lithology map, climate properties, groundwater extraction, and water network system. The LSA was supported by the spatial analysis functions in GIS, including: identification and collection of spatial data, and weighting with the analytic hierarchy process method (AHP).

A. *Area of study*

The 10th of Ramadan City is one of the first New Cities planned in Egypt that has developed over the past 30 years as the largest industrial city in Egypt. The city was established in 1977 as an intermediate city with an easy access to Cairo, Port Said, Ismailia and Suez. It is located in Al-Sharqia governorate between latitude lines 30 degrees 20 min N and 30 degree 17 min N, and longitude lines 31 degrees 37 min E and 31 degrees 50 min E. Also, it is one of the largest industrial cities in Egypt with about 1400 factories, and a total population of 260,000 (CAPMAS, 2013b).

The spatial pattern is an orthogonal street network with commercial, mixed use, industrial and high-density residential buildings along its higher volume arterial street (see figure 6). Buildings' footprint covers around 60 %, ground vegetation 20%, trees 8%, and non vegetated surfaces around 12%. In this study, carbon emissions for four sectors of a city's carbon inventories are calculated, including building energy consumption, transportation, industrial processes and waste (oxidation lakes and dumps). Moreover, the study area is considered of particular interest for the data sets of directly measured CO2 emissions gained from the industrial areas (CAPMAS, 2013b).

Figure 6: The study area of 10th of Ramadan City, Al-Sharqia, Egypt.

B. *Modeling Carbon Flows*

Building sector CO2 fluxes are calculated according to their total area and building uses following the methodology described in (Anna Pagès Ramon, 2008) using building energy use and total population. The transportation sector included ground based transportation that transforms imported fossil fuels (gasoline, diesel) into emissions. The outputs from the transportation sector are calculated based on their impact per km (or passenger-km, tonne-km) and according to the vehicle type and size within the study area. As for the industrial sector, CO2 emissions are calculated with reference to the total number of factories & type of industrial products following the methodology applied in (Ruben van Der Helm, 2008). Finally, carbon emissions linked to land uses within the city are calculated based on the methodology applied in (Chang, T.C., 2000) and Serio Oglio to study carbon footprint based on land uses. The modeling approach taken in each of these four sectors is elaborated below.

1. *Buildings Sector*

The study applied a building typology approach to calculate total CO2 emissions based on energy consumption following the methodology of (Anna Pagès Ramon, 2008). Table (1) illustrates total CO2 emissions for different building uses within the city.

Table 1

Comparison of building type, CO2 Model and Emissions.

Building type		CO_2 Emissions Model	CO_2 Emission (Ton/year)
Mixed Residential	Above Average Pattern	Total area* 30ᵃ / 1000	17.8647
	Average Pattern	Total area* 24 / 1000	129.1622
	Below Average Pattern	Total area* 20 / 1000	3.2087
Administrative		Total area (m2)* 67ᵇ / 1000	11.2864
Hospital		Total area (m2) * 80 / 1000	2.7818
Commercial		Total area (m2) * 164 / 1000	28.0114
Cultural		Total area (m2) * 35 / 1000	0.0827
Education		Total area (m2) * 13 /1000	1.3287
Entertainment		Total area (m2) * 80 / 1000	0.9620
Religious		Total area (m2) * 5.6 / 1000	2.0658
Utilities		Total area (m2) * 121 / 1000	5.7290

a CO2 emission factor of energy consumption (Norman, 2006)

b Carbon metrics based on energy consumption (UNEP, 2010)

This approach is applied on all the building sector components in the city by categorizing buildings into 11 main types. The residential sector is categorized according to living standard and building area to calculate total CO2 emissions. Other building types are categorized based on the total area and different uses of buildings. The carbon calculation model used to account total emissions from the building sector can be expressed in equation (1) as:

Emission = Σ (Building Area * EF of energy consumption CO2/MJ) [1]

Where:

EF: Emission factor of energy consumption

2. *Ground Based Transportation Sector*

Calculation of emissions attributable to ground based transportation depends on detailed aggregated transportation

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data. These data include vehicle stock; average vehicle fuels consumption, and vehicle kilometers traveled (VKT) for each vehicle type. Annual aggregated CO2 emissions were calculated based on detailed travel data, including: number of vehicles, vehicle type, and the length of trips. In this study, the ground-based transportation sector is categorized according to the vehicle type and its impact per km (see table 2). The average number of vehicles for each type is extrapolated from related data sources (CAPMAS).

Table 2

Ground based transportation sector carbon emissions by type

Vehicle Type	Engine Size	Size Label	G.CO₂ Per Km	Litre Per Km	CO₂ Emissions Model	CO₂ Emission Ton/year
a.1. Gasoline car	< 1.4 l	Small	180.9	12.8	Length in (Km) * fuel consumption* 58.3ᵃ / 1000000	**198.88**
	1.4 – 2.0 l	Medium	212.9	10.8		
	> 2.0 l	Large	291.8	7.8		
Diesel car	< 1.7 l	Small	131.3	17.4	Length in (Km) * fuel consumption * [illegible] / 1000000	[illegible]
	1.7 – 2.0 l	Medium	180.1	14.5		
	> 2.0 l	Large	[illegible]	10.2		
a.2. Regular taxis and taxi Cairo cap						
Taxi		–	161.3	–	Length in (Km) * fuel consumption * [illegible] / 1000000	**[illegible]**
Cairo Cap		–	173.1	–		
b.1. Diesel Heavy Vehicles						
Diesel		Up to 3.5 tons	271.8	–	Length in (Km) * fuel consumption * [illegible] / 1000000	**[illegible]**
b.2. Buses (Diesel)			111.8	–	Length in (Km) * fuel consumption * [illegible] / 1000000	**[illegible]**
c. Long distance Heavy Vehicles			81.3	–	Length in (Km) * fuel consumption * [illegible] / 1000000	**[illegible]**
d. Gasoline Motorcycle	Up to 125CC	Small	72.9	31.8	Length in (Km) * fuel consumption * [illegible] / 1000000	**[illegible]**
	125 to 500 CC	Medium	91.9	24.5		
	Over 500 CC	Large	128.6	17.9		

a CO2 Emission Factor (EPA, 2012).

b CO2 emission factor for Vehicle Business (EPA, 2008).

c CO2 Emission Factor (Sutthicha Nilrit, 2012).

The following data were applied on the local streets in 10th of Ramadan city (see figure 7) as the numbers of different transportation types were available. The conversion factors for total annual fuel consumed varied according to fuel type. For gasoline vehicles, the conversion factors used are 65.8 g C l−1 and 75.3 g C l−1 (Ronald Colette, 2013) and the resulting values are attributed proportionally by vehicle class to each local street.

Figure 7: Current traffic map with main streets applied in the study for transportation emissions analysis.

Fuel consumption and resulting carbon emissions are estimated based on a vehicle type, conversion efficiencies, and distance traveled. Vehicle types included in the analysis are as follows: (a) light vehicles, such as cars, and transit vehicles primarily moving people to jobs and services; (b) medium freight vehicles primarily moving goods and materials between the study area and surrounding local destinations, and local buses used by other workers who live outside the city to commute to the city daily from Cairo and Sharkia; (c) heavy vehicles primarily moving goods and materials to more distant locations; and (d) light motorcycle with two wheels that are most common in residential areas attached to the city. CO2 emission calculation for the transportation sector can be expressed in the following equation (2) as:

CO2 Emissions = Σ (Distance travelled* EFij* Activityij) [2]

Where:

EF: Emission Factor (g/MJ or g/kg fuel)
i: Fuel type

Activity: Fuel Consumption (MJ or kg)
j: Engine type

3. *Industrial Zones along the city*

During the last decade, 10th of Ramadan city held the largest number of industrial establishments in Egypt. So, calculating carbon emissions from industrial zones gives a more solid notion of the carbon cycle inside the city. Calculation applied in the study that is attributable to the industrial zone depending on the type of industrial product, and the total number of factories associated with each product. Table 3 summarizes CO2 emission according to factory type, number; factories size and production. Total carbon emissions from the industrial zone can be expressed in equation (3) as:

CO2 Emissions = Σ (Number of Factories* Eij) [3]

Where:

Eij: Carbon Emission (ton/year)
i: Factory Type

j: Carbon Emission per factory

Table 3
Industrial Sector along 10th of Ramadan, including: Industry type, factory numbers, and CO2 emissions

Type of Industry	Number of Factories	CO_2 emitted per Factory Ton per year	CO_2 Emission ton/year
Agriculture and livestock products	1	310.7	**310.7**
Food processing, beverages and tobacco	158	303.4	**47937.2**
Textiles, garments and leather	288	277.7	**79977.6**
Wood and wooden products	38	987.6	**37528.8**
Paper, printing and publishing	82	949.9	**77891.8**
Chemicals	319	5977.8	**1906918.2**
Building materials	116	2176.5	**252474**
Metals	28	10578.2	**296189.6**
Engineering, electrical and electronics	444	789.5	**350538**
Manufacturing	17	1767.6	**30049.2**
Repair and maintenance centers	1	473.8	**473.8**
Total			3008429.1 (**3.08 Million Ton / Year**)

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4. *Land Uses within the city*

Calculation of emission associated with land use was based on the land use area and carbon emission factor for each type. The emission factor multiplied by the activity data will provide the total emission estimate for the land areas. Emission factors for calculating CO2 emitted from different land uses along 10th of Ramadan city are summarized in Table (4).

Table 4
CO_2 emission for different land uses

Land Use	Mean above ground carbon (AGC)	Emission Model	CO_2 Emission Ton/year
Oxidation Lakes	1300^a mg ha^{-1}	Area *1300 * 5.5 (Lake depth) / 1000000	48771.5369
Agriculture Land	11.2^a mg ha^{-1}	Area * 11.2 / 1000	20635.2032
Forests	32^a mg ha^{-1}	Area * 32 / 1000000	386.6599
Public Molds	220^b mg ha^{-1}	Area *220 * 15 (Mold depth) / 1000000	27208.4287
Total Co2 emitted from Land Parcels			97.4 Thousand Ton / Year

a CO2 Emission factor for Land use (Fahmuddin Agus, 2013);
b Emission factor for Molds (Houghton, R. A , 2012).

IV. Result

The results highlight several points that are central to the city as follows; the spatial distribution of CO2 emissions in 10th of Ramadan showed cluster hotspots in terms of carbon emissions. A number of carbon hotspots existed within the residential area; the largest one is coincident with the industrial zones. Other small ones were located at the edges of the city. The industrial area of the city is characterized by high-energy intensity because most of the established industries largely rely on power generation, petrochemical and cement production, as well as mechanical and metalworking manufacture. This has resulted in a high level of primary energy consumption and a large amount of direct CO2 emissions of total 3.08 Million Ton/Year.

Based on the carbon cycle analysis of the study area, it has been found that activities import around 8.72 kg C m^{-2} $year^{-1}$ in the form of fuels, food and materials. Sources within the study area emit around 9.66 kg C m^{-2} $year^{-1}$ or 90% of total imported carbon into the atmosphere. In addition to 10% of imported carbon is exported laterally by wastes, and 0.58 kg C m^{-2} $year^{-1}$ are an uptake though photosynthesis of urban vegetation, with 5.20 kg C m-2 year-1 through agriculture land distributed along the city edges.

Total CO2 emissions linked to the four urban sectors yield large differences in total emissions and their spatial diffusion within the city. The carbon emission calculation showed that, building sector emissions presented 0.6% (0.0002 million tons/year) of all modeled CO2 emissions. Around 48% of all local fossil-fuel CO2 emissions and emissions from residential and non-residential buildings were significantly less than the industrial sector. Average annual emissions related to transportation presented 1.4% (0.0006 million tons/year) of total emissions. Of the 48% that resulted from local activities, 52% were attributable to traffic moving industrial products to and from the industrial area; making main roads as ‘hot spots’ for emission. As for emissions attributable to industrial zones presented approximately 96% (3.08 million tons/year) of all emissions. Finally, land uses annual emissions presented 2.0% of the total emissions (0.09 million tons/year).

A. *The Ecological Factor Threshold Method*

With these modeled results above, it can be estimated the degree to which locally regulated urban planning interventions could mitigate carbon emissions by using the ecological threshold method. The ecological factor threshold method is based on the principles of ecological balance to quantify how much green area is needed for the city to maintain carbon-oxygen balance. The proposed method relates the total carbon emissions by human as well as urban activities, to the process of absorbing carbon dioxide and releasing oxygen through photosynthesis in plants. The balance is carried out on the basis of constant adjustment of green spaces and various kinds of oxygen consuming activities. The study considered the quantification of green areas based on total O2 production presented in green structures to maintain the carbon-oxygen balance.

The presented model aimed at organizing green areas on three different scales within the city, green structure along the regional scale, green structure along the city scale, and the green structure along the neighborhood scale. The current green area per capita in the 10th of Ramadan Master Plan is estimated around 7.5 m2. So, based on an estimate of Zhang et al. (2011b), for efficient green urban spaces, the annual per hectare O2 production of trees should be around 54 tons. To retain the carbon-oxygen balance within the calculation of the annual carbon emissions, the total oxygen production required is equal to 170 tons. Therefore, the city needs to develop an extra green area of 12411.7 Hectare (124.11 Km2). The next step would be to consider how to organize urban green spaces in order to optimize their benefits by using landscape-ecology principles.

B. *Land Suitability Analysis*

In this study, LSA for building a green space map was carried out based on air pollution maps, water body system maps, industrial zone maps, existing green areas, and existing land-use maps. These maps are considered as a significant input, since it expresses the human impact, and influences of developing urban green spaces. The LSA was supported by the spatial analysis function in GIS, including: identification and collection of spatial data, weighting with the analytic hierarchy process (AHP), using the weighted sum tool in GIS, considering all the weights that have been assigned to each map, and the suitability score of each cell.

The weighted sum tool was used for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors. For instance, choosing the most suitable site for green areas development means assessing a set of different factors such as: current land use map, type of existing green areas, water network system, source of carbon emissions, climate maps (mean monthly

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maximum temperatures, mean monthly minimum temperature, wind speed, wind direction, average annual rainfall, and Humidity); lithology, and groundwater extraction (figure 8). This information exists in different raster layers with different value scales: degree Celsius, m3/year, and so on. The planner can't be able to add a raster of Climate (degree Celsius) to a raster of ground water extraction (m3/year) and obtain a meaningful result.

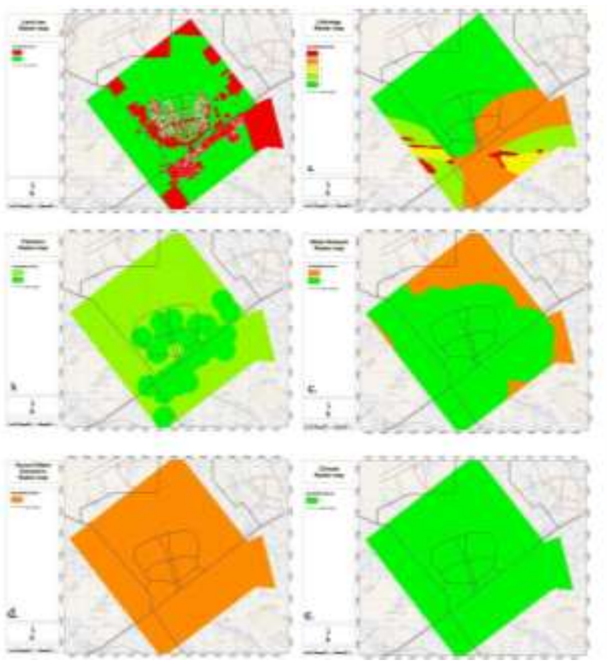

Figure 8: Suitability scores for existing land use in (a), Lithology (b), air quality (c), water body system (d), ground water, and climate (e).

Additionally, the factors in the analysis may not be equally important. For example, the lithology is more important in suitability to green areas than the Climate. Within a single raster layer, the planner should usually prioritize values from 0 to 4 representing the degree of suitability of each constrain to green areas. Moreover, the weighted sum only accepts integer raster as input, such as a raster of land use or soil types. Generally, the values of continuous raster are grouped into ranges, where each range should be assigned a single value before it can be used in the weighted sum tool. The cells in the raster will already be set according to their suitability for green areas planning. Finally, the study attained the weighting score on each factor and then used spatial analysis function of GIS to produce a composite map.

The data maps were overlaid to analyze the overall ecological structure and function of the city. With respect to the potentials and limitations of the case study (10th of Ramadan) the following results were obtained in land suitability analysis: (a) lithology played an important role in the suitability of green areas as it was ranked with first priority; (b) current land use ranked a second priority in the suitability of green areas that were high in desert and vacant lands; (c) water network system took the third priority since the city depends mainly on Ismailia Canal as a main feeding source of water; (d) sources of pollution took the same influence as the water network system; (e) climate properties took the fourth priority in determining lands suitable for green areas, and finally (f) the ground water extraction came in the last priority as the quantity of water that extracted from the soil is too small (see table 5).

Table 5

The weighting scores for each layer to develop the composite map

Climate	Ground	Land Use	Lithology	Pollution	Water Network	Overlaying to create the Composite map
12	3	23	28	17	17	

The natural and built patches, including open and green spaces were analyzed, due to their fundamental role in the ecological structure of the city. Main access road networks, and highways were considered as the main structural elements, especially in the densely built-up urban areas. These layers have been analyzed to locate the most efficient ecological patches in the city matrix based on their suitability. The overall ecological structure was then obtained by merging the layers of natural and man-made ecological patches into one single overlay map, which contains all the effective features in the city urban structure.

C. ***Green Structure at the Regional Scale***

Green structure at the regional scale can be called green wedges or patches. These green wedges or patches are composed of parks, gardens, farmlands, rivers and wetlands. The development of green wedges in this study was based on open spaces and agricultural lands. Based on land form data, landscape ecology principles, and the assessment of the planned green spaces; five green wedges (28.3 Km2) were proposed to connect outer green spaces and inner green spaces (see figure 9). This can be regarded as an efficient strategy of green structure planning at the regional scale, and bringing nature into the city.

Figure 9: Proposed green wedges for 10th of Ramadan city.

D. ***Green Structure at the City Scale***

Based on the above analysis, the total existing green area is 34 km2, while the total required green area to reach the carbon-oxygen balance is 124 km2. So, the remaining required area to be distributed within the city is 90 km2. In this sense, the green structure within the city will be amplified by an inner

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greenbelt. Other green spaces located in the inner greenbelt might be difficult to be augmented, due to land budgeting and pressure of urban development. The proposed greenbelt of 26 Km2 (see figure 10) is representing a transitional zone with the function of resisting the urban sprawl, constraining the urban development, maintaining biodiversity, and enhancing recreation. Therefore, maintaining this proposed greenbelt is necessary not only for the above benefits but also for the improvement of the urban environment.

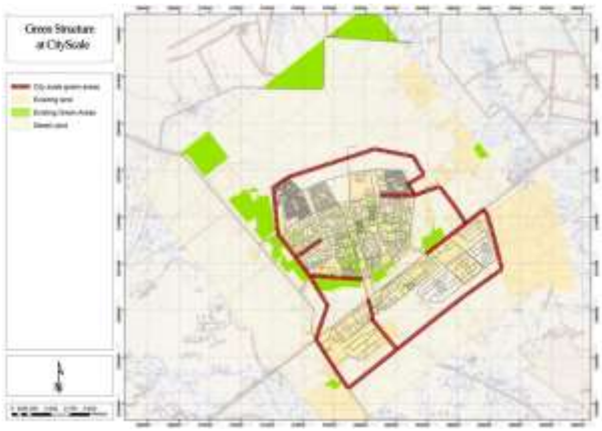

Figure 10: Proposed green belt for 10th of Ramadan city.

E. Green Structure at the Neighborhood Scale

Each part in the 10th of Ramadan city is a mixture of residential, industrial, business and organization-owned areas. Each of them is allocated within a plot of land with scant space for developing green spaces; however, available green spaces are distributed unevenly and are somewhat isolated. Attached green spaces are composed of self-organized green spaces and residential green spaces. Green spaces on a neighborhood scale play an important role in providing opportunities for residents to get in contact with nature (see figure 11). Moreover, their function is to enhance the local beauty, and to act as ecological stepping stones. The proposed road green structure at neighborhood scale is of 36 Km2 and is considered an important component of Greenways' network in urban areas.

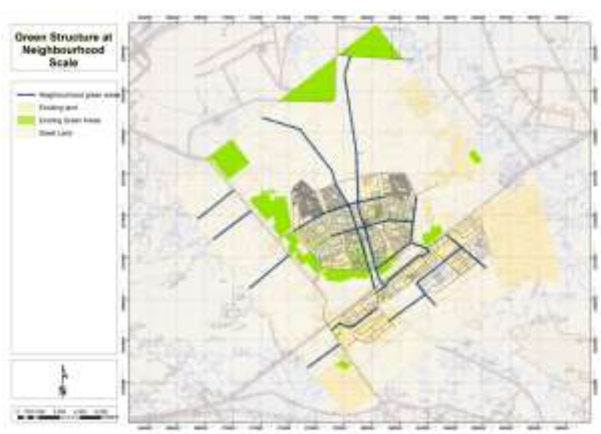

Figure 11: Proposed green ways for 10th of Ramadan city.

V. Discussion

The study developed a model for new cities in developing regions to analyze the carbon cycle and related emissions. It also estimated the effect of green space planning on reducing CO2 emissions within city scale, by applying land suitability analysis that is based on identifying suitable sites for carbon balance in cities. The main conclusions are described below.

The study has introduced a new model to balance the carbon cycle with green space planning. The proposed model integrated GIS building modular technique to calculate the CO2 emissions from different land uses within the city. The proposed model gives the opportunity for the urban planner to calculate the total amount of CO2 emitted by dividing the city into three main sectors; living territory sector, transportation sector, and the industrial sector. Analysis findings illustrated that the city total CO2 emissions equal to 3.17825041 Million tons/year, which in return needed 124.11 Km2 green areas to achieve the carbon oxygen balance.

Applying land suitability analysis based on GIS is a very practical and efficient tool in indicating suitable sites for green space development. One of the other important findings of this study is that results showed that the majority of planned green spaces in 10th of Ramadan were compatible with land suitability analysis. This approach will assist in green space's suitability more accurately, adequately, and comprehensively. With respect to ecological and environmental significances in the study, six main components (current land-use map, water network map, lithology map, Ground Water Extraction Map, and pollution map) were implemented in this analysis. The study applied methods were based on GIS technique (weighted sum), which gives the urban planner the availability to study and assess the suitability of any land area through determining the influence of each map of six main components mentioned above.

The study proposed green structure development on three main scales; Regional scale, City scale and Neighborhood scale. At the regional scale, five green wedges were proposed with total area of 28.3 Km2. At the city scale, an inner green is proposed with total area of 26 km2 to support the city ecological structure and provide potential areas for oxygen release within the city. Also, this inner green belt will act more efficiently in decreasing informal urban expansion within the city.

The proposed green space system might face some obstacles in the implementation process such as the inefficient management in urban development practices within the city, changes in land use and the rapid economic and urban growth. Thus, to achieve the goal of CO2 emissions reduction, the Egyptian government should establish firm initiatives in achieving low carbon targets such as the improvement of industrial structure and performance, supporting energy-efficient technology application, and establishing inclusive procedures for emission reduction on a city scale. Furthermore, this study did not estimate the effect of technical

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innovations in the process of balancing the carbon cycle within the city. Hence, proposed future policies should put into consideration the implementation low carbon techniques such as energy efficient systems with low emissions in all future developments.

VI. Conclusion and Policy Implications

There is a strong link between urbanization, economic growth, and carbon emissions. As it has been concluded, the most important sector that is responsible for carbon emissions is the industrial activity, followed by utilities and transportation, then finally the living territories' activities. And, if the industrial activity is not one of the main activities within the city, then utilities and transportation ranked as one of the main activities that are responsible for carbon emissions.

As industry and transportation sector play a vital role in carbon emission within the urban system, the following is a set of recommendations for both sectors in addition to homes and offices to minimize their carbon emissions. These recommendations are going to describe a number of actions to be taken by urban planners to reduce CO2 emissions within the master plan of new cities. Furthermore, it will include a number of strategies to reduce carbon emissions such as: well insulated buildings; city structures where people can live within walking distance; and the development and spread of energy-saving devices which enable energy demand to be reduced while satisfying the service demands.

A. *Actions for Transportation sector*

Greenhouse gases in the transportation sector are mainly emitted when people travel by car or public transportation, and when goods are transported by truck and ship. Concentrating residential areas, offices and commercial facilities at the center of cities will reduce the distances traveled by people and hence reduce greenhouse-gas emissions. In this sense, municipal government, together with citizens, should develop land-use plans that consider such low carbon designs. Realizing such strategies will raise market competitiveness of public transportation systems, such as buses, railways and Light Railway Transit (LRT), and thus these systems should be actively constructed. On the other hand, in regions where people live far away, they will need cars to move, so the efficiency of cars should be greatly improved by switching engines to electric motors and reducing vehicle weight, resulting in the drastic reduction of CO2 emissions from transportation.

To support low-carbon mobility, active use of solar and wind energy available locally for cars will contribute to a sharp reduction of CO2 emissions. While, purchasing low-carbon electricity is also effective, it is also necessary to encourage the use of hydrogen fuel cell cars and Bioenergy fuels.

Finally, to achieve low-carbon logistics, infrastructures for mass transportation systems such as railways and ships need to be reconstructed. Diverse forms of support should be given to increase the transportation capacities of these systems, such as by improving and expanding harbors and the railway network and developing high-efficiency transportation devices. Systems and infrastructures should also be constructed to enable the smooth transshipment at distribution centers.

B. *Actions for Industrial Sector*

Companies should minimize carbon production in the life-cycle of their products (production, transport, sales, consumption, and disposal). The entire business process should also be optimized using advanced information technologies to synchronize supply and demand and to construct efficient production-transportation systems. Thus, the government should provide economic support to low-carbon businesses, such as strengthening public investment and giving tax benefits; so that companies can continue to develop leading technologies with high energy-efficiency and low carbon intensity.

To shift to lower-carbon business model, industries and/or commerce should shift to leasing of devices and appliances. This business style will complement the pathways towards sustainable and/or recycling society. Under this approach, companies will be responsible for keeping the devices operating at maximum efficiency.

For farm products, farmers should intend to produce in-season foods, and information on production should be actively publicized to consumers to enable them to select low carbon products. In forestry, the timber market should be expanded to replace steel and cement, which consume high energy in manufacture, and competitiveness should be enhanced by rationalization. Also, the energy industry should aim to supply zero-carbon power by combining renewable energies, nuclear power, and fossil-fired power. The introduction of hydrogen- and biomass based fuels are also indispensable for achieving low-carbonization of industries.

C. *Actions for Homes and Offices*

Many energy-consuming devices are used in homes and offices to make life and work more comfortable and efficient. Such devices are a major source of CO2 emissions. To reduce the energy load sharply, houses and buildings need to be designed to prevent heat from escaping and penetrating inside; solar heat and natural wind should be used for temperature control of buildings, and solar power should support lighting. To encourage the construction and the incorporation of such houses and buildings; policies should be implemented to reduce the economic burden on their owners. Also, systems should be introduced for assessing and labeling the environmental performance of buildings.

Energy-efficient appliances and devices also contribute towards the CO2 reduction in homes and offices. In order to accelerate the improvement of energy efficiency, the coverage of the conventional top-runner system should be extended to include all energy devices, and the improvement targets

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should be revised every few years. Thus, rewarding systems for entities to develop excellent technologies should also be adopted for strengthening market penetration of energy-efficient technologies.

However, these newly-developed efficient devices will not be widely used unless users actively adopt them. To support such low-carbon consumption, advertising systems and infrastructures should be constructed to enable consumers to obtain correct information about total emissions from their consumption behavior. Through these activities, CO2 emission from production of goods and services could be cut indirectly.

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