A System Dynamic Based DSS for Ecological Urban Management in Alexandria, Egypt

Mona M. Salem, Khaled S. Al-Hagla, Hany M. Ayad

***Abstract*—**The concept of urban metabolism has increasingly been employed in a diverse range of disciplines as a mean to analyze and theorize the city. Urban ecology has a particular focus on the implications of applying the metabolism concept to the urban realm. This approach has been developed by a few researchers, though it has rarely if ever been used in policy development for city planning. The aim of this research is to use ecologically informed urban planning interventions to increase the sustainability of urban metabolism; with special focus on land stock as a most important city resource by developing a system dynamic based DSS. This model identifies two critical management strategy variables for the Strategic Urban Plan Alexandria SUP 2032. As a result, this comprehensive and precise quantitative approach is needed to monitor, measure, evaluate and observe dynamic urban changes working as a decision support system (DSS) for policy making.

***Keywords*—**Alexandria SUP 2032, DSS, ecology, land resource, LULCC, management, metabolism, model, scenarios, System dynamics, urban development.

I. Introduction

LIKE all ecosystems, the city is a system, having inputs of energy and materials. The main environmental problems are resulted from the increase of these inputs in addition to managing the escalated outputs. By concidering the city as a whole and by tracing the pathways along which materials move, management systems and technologies can be conceived; which permit the reintegration of natural processes, enhancing the efficiency of resource use and the conservation or production of energy [1].

The goal of sustainability in a city can be defined as the reduction of the city's use of natural resources and production of wastes while simultaneously improving its livability, so that it can better fit within the capacities of the local, regional and global ecosystems [2].

In a model that is called the `Extended Metabolism Model of the City'. Metabolism is a biological systems way for looking at the resource inputs and waste outputs of settlements [3]. This concept cannot be considered brand new as it had been discussed numerously through literature but it hardly been used in policy development for city planning.

The proposed model state the physical and biological structure and processes of the city, much like the human body metabolic processes of converting resources into useful output and waste or that of an ecosystem [2]. They are based on the laws of thermodynamics, which mean that any material which inhert a biological system must move forward and that the amount of output is therefore dependent on the amount of resources required.

For physical expansion in land, Alexandria city witnessed several deteriorations from the end of the roman era until the beginning of the 19`" century [4]. After this period Alexandria city witnessed rapid expansion in all available directions, which caused uncontrolled, uncoordinated and ill growth pattern resulting in several indirect impacts such as inflated infrastructure and public service costs, energy inefficiency, impacts on wildlife and ecosystem, loss of farmland, increase in temperature, poor air quality, impacts on water quality and quantity and impacts on public and social health [5].

The research is an attempt to analyze and assess urban dynamics through an ecological urban metabolism approach. Thus, it is concerned with developing an SD simulation model and decision support functionalities using STELLA software, which can evaluate urban planning development with focus on land management strategies based on the metabolic system of the city.

II. Methodology

The modeling process is divided into three hierarchical tiers, as shown in (Fig. 1) the physical level, the SD modeling level, and the decision-making level.

The physical level identifies past and current situations and potential problems, that are, consumption of city resources - specifically land resource- and ecosystem under pressure from human activity.

The SD modeling level represents human impact on the environment and ecosystem based on the previous level studies.

SD model integration is further divided into four subsystems—urban metabolism subsystem, urban ecology subsystem, urban growth subsystem and management subsystem.

The decision-making level performs certain scenario analysis following SD model formulation and validation.

III. Model Development

The SD modeling approach is used as a tool to understanding the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops. A casual-loop diagram is showing the cause–effect relations among system variables. Cause–effect variable when positively related; they are represented by a plus sign; otherwise, a minus sign results. A casual-loop diagram includes diverse positive–negative-

Mona Salem is with the Faculty of Engineering, Alexandria University, Egypt (e-mail: haytham.salem.vf@gmail.com).

feedback-loop structures with closed circulation arrangements. A positive feedback- loop could arouse an existing system variable growth process through time, supposedly driving system loss of control and collapse. A negative-feedback on the opposite, requires a target and responds through acquiring a steady state [6].

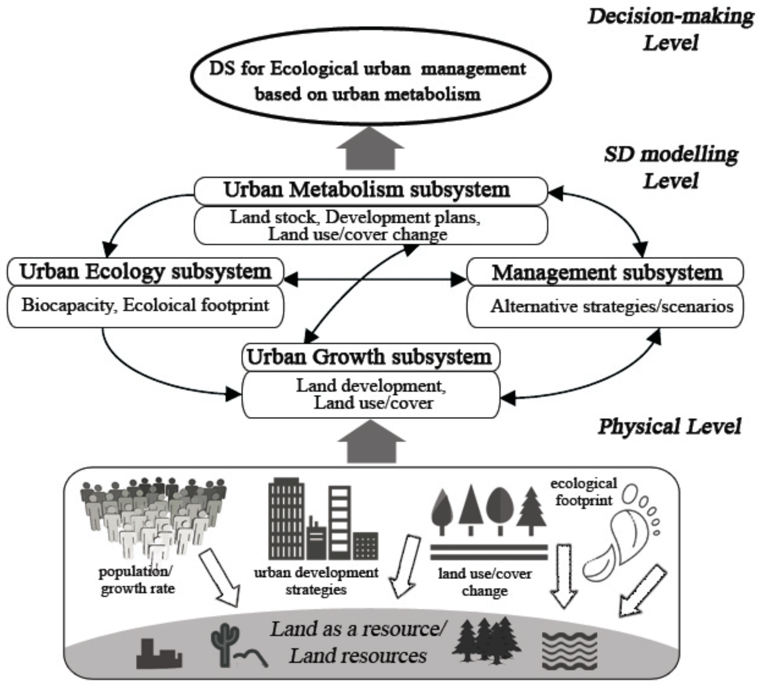

Fig. 1 Diagram of methodology

A. Causal Loop Diagram

The left side of Fig. 2 shows the macro-view of causal-loop diagram for the current urban metabolism. One positive feedback- loop and one negative-feedback-loop, which all start and end with urban development node, appear in the system concurrently. The negative-feedback-loop describes the following relations: the increasing land expansion would change land usage and coverage, and consequently the declining natural land coverage should suppress urban development plans. However, the delay between land use/ cover change and urban expansion, along with the positive-feedback-loop, would eventually cause serious land resource degradation.

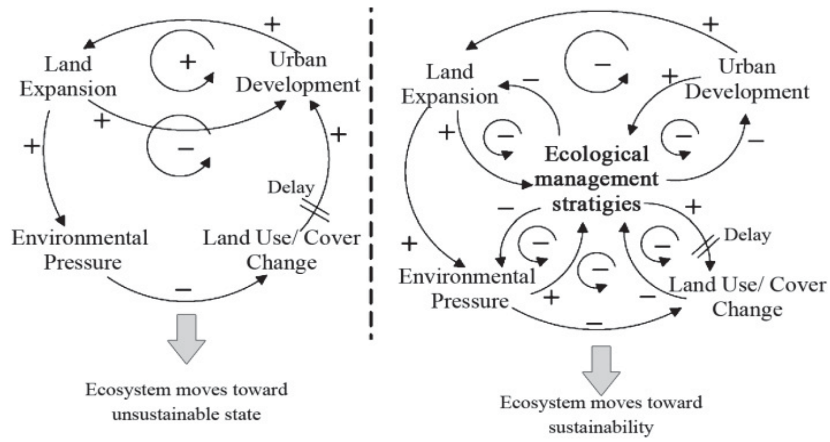

Fig. 2 Macro-view of the causal-loop diagrams for the original and the proposed SD models, Author 2017

The causal-loop diagram of the proposed SD model for ecological city interventions is displayed on the right side of Fig. 2. The central node -which is ecological management strategies- links with all key elements in the system and generates several negative feedback-loops. These negative-feedback-loops would mitigate the negative human impact to the ecosystem and move the system state toward ecological sustainability.

B. Stock and Flow Diagram

Fig. 3 is the stock-flow diagram of the urban metabolism subsystem linked with ecosystem subsystem. The variable Productivity links two key elements in the system, which is the land demand and the ecological foot print, each represented by the stock variables Land and Biocapacity accordingly. Productivity used for Ecological foot print calculation, affects the standard of living (rise of income) which in turn decrease migration and so population and mitigate stress on land demand. Conversely, when population increases in a given area, the increased demand on production can induce stress and consequent degradation of the land resource. If no other source of income can be tapped (e.g. by migration to urban areas) people's standards of living decrease.

Multiplying population and consumption by equivalence factor, which is the quantity of global hectares contained within an average hectare of cropland, built-up land, forest, pasture, or fishery, and divide the total by productivity; can find an ecological foot print value.

The major ecological subsystem concern is to outline a reasonable city ecosystem structure involving land stock, and urban development plans. Ecosystem intrinsic functions are very complex, and some are either highly uncertain or remain unknown to scientists. Simple cause and effect mechanisms therefore acquired from related research assembly preserve major system interactions. Excessive consumption of resources has outpaced the sustainable capacity of the ecosystem.

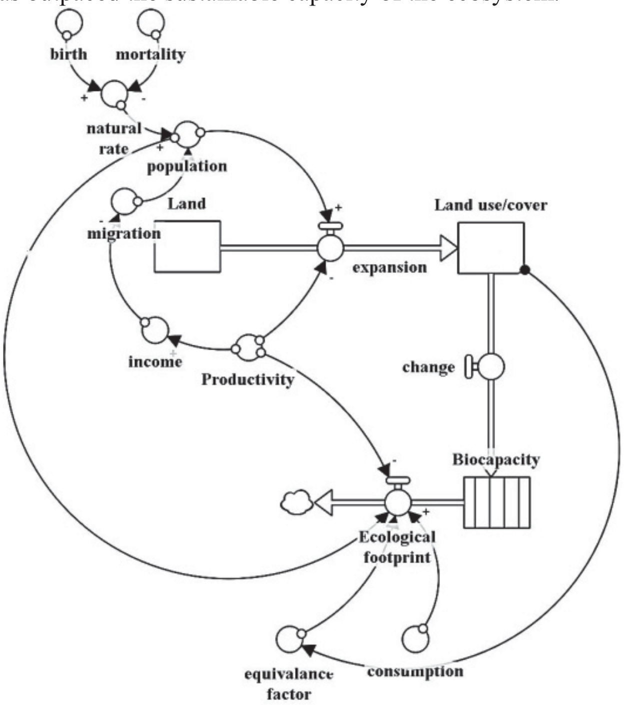

Fig. 3 Stock-flow diagram of the urban metabolism subsystem linked with the ecosystem subsystem

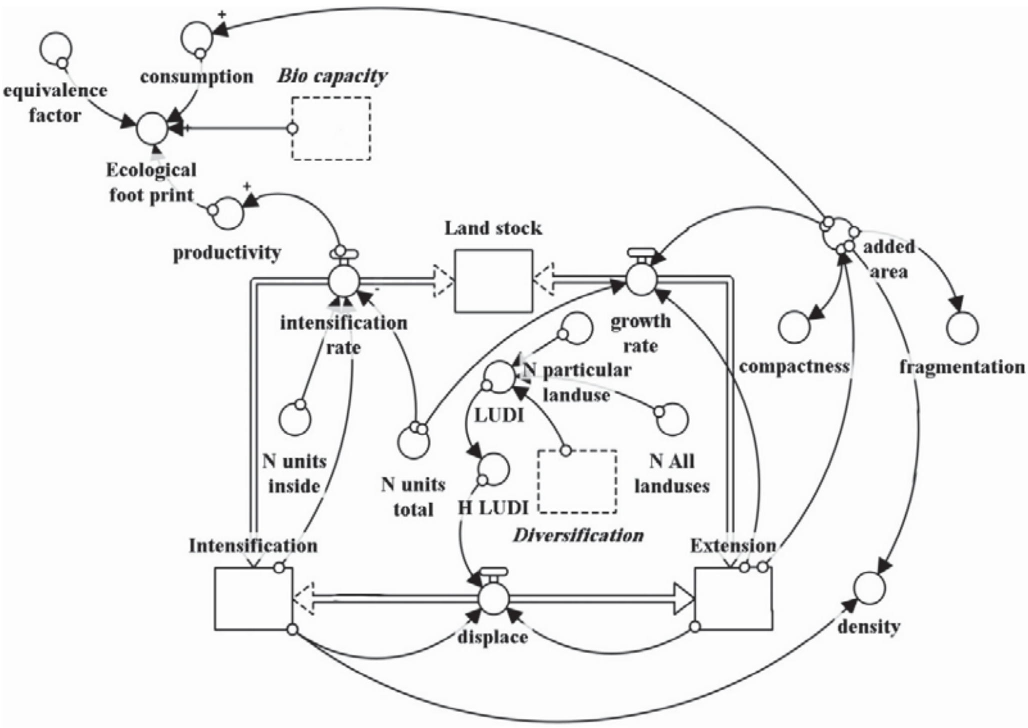

Fig. 4 Stock-flow diagram of the ecological subsystem linked with management subsystem

The ecological subsystem stock-flow diagram, based on the above relative studies is represented in Fig. 4. The kernel of the diagram illustrates competition between intensification and extension for land. There are three variables, which are the land that can be expanded on and one each for expansion scenario; intensification and extension. Three types of system flow rates include: intensification rate, growth rate and replacement rate between the two scenarios. Adequate circularity of subsystems allows each flow rate outstanding nomination by the variables linked with it. For example, intensification rate is linked with number of new units built within the already built boundary over the period of the study and the total number of units inside and outside the built boundary; hence (5) computes intensification rate involvement in all these variables. The growth flow rate can be estimated using a similar equation by replacing the number of new units with the added area needed to absorb the total new units and the total number of units with land stock. Displace rate depend on the targeted ratio by the development plan between intensification application and to what extent it may expand. In both scenarios there is a hidden scenario that must be applied which is diversification scenario. There are two variables in the equation for calculation diversification index which are number of particular land use/patch and the total number of land uses. Equation (3) calculates the diversity index by using the same concept of (5).

Intensification rate is a main variable for calculating productivity value conversely growth rate is the main variable for calculating consumption, which both; productivity and consumption with equivalence factor are linked and used for calculating the value of the ecological foot print for each scenario.

C. Equations

The calculation of ecological footprint and biocapacity according to the method of Wackernagel can be expressed as:

$$\mathrm{Ef} = \mathrm{N\ Ef} = \mathrm{N} \sum_{\mathrm{I=1}}^{\mathrm{N}} \mathrm{R_J} \left({}^{\mathrm{C_I}}/_{\mathrm{P_I}} \right) \tag{1}$$

where i is the category of items, ci is the amount of consumption per capita of i item, pi is the average productivity of i, R_j is equivalence factor, n is population, ef is ecological footprints per capita, ef is the total ecological footprints.

Moreover, by showing the footprint equation as in (1), a more direct linkage with biocapacity accounts is provided. For any given nation, the biocapacity (Bc) is assessed by multiplying the land area available annually for production of each product i, by the appropriate yield and equivalence factors as shown in (2).

$$\mathrm{Bc} = \sum_{\mathrm{i}} \mathrm{a_{n_i}} \times \mathrm{yf_{n_i}} \times \mathrm{eqf_i} \tag{2}$$

where a_{ni} represents the estimated bioproductive area expressed in nation-specific hectares that is available for the production of each product i at the national level. Note that this area is equal to the ratio between the annual amount of tones locally produced and the nation average yield of the land producing each product i.

Equivalence factors and yield factors in the method of ecological footprint and biocapacity are listed in Table I [8]. Specifically, an equivalence factor is the quantity of global hectares contained within an average hectare of cropland, built-up land, forest, pasture, or fishery. Yield factor is the factor by which a country's (or region's) ecosystems are more productive than the world average. Yield factor describes the extent to which a biologically productive area in a given country or a given region is more (or less) productive than the global average of the same bioproductive area.

TABLE I
EQUIVALENCE FACTOR AND YIELD FACTOR APPLIED IN THE MODEL

	Equivalence Factor	Yield Factor
Fossil Energy	1.1	0.0
Built-Up Land	2.8	1.66
Cropland	2.8	1.66
Pasture	0.5	0.19
Forest	1.1	0.91
Fish	0.2	1.0
Freshwater	1.0	--
Total	9.5	5.42

Simpson's diversity index is calculated as followed:

$$\mathrm{D} = \frac{\sum \mathrm{n(n-1)}}{\mathrm{N(n-1)}} \tag{3}$$

where N = the amount of structures of a particular class, n = the total number of structures of all classes, the value of D ranges between 0 and 1. With this index, 0 represents infinite diversity and 1, no diversity. To evaluate and present the performance of the land use diversity index (LUDI)

$$\mathrm{H'} = \sum ({}^{\mathrm{M}}/_{\mathrm{n_j}}) \,\mathrm{Ln}({}^{\mathrm{m}}/_{\mathrm{n_j}}) \tag{4}$$

The intensification rate is the amount of unprecedented units built within the urban boundary through the duration of study relative to the total amount of unprecedented units inside and outside the border.

$$\text{Intensification rate} = \frac{\text{new development inside the built boundary (intensification)}}{\text{all new development (greenfield+intensification)}} \tag{5}$$

$$\text{population growth} = \text{the births - deaths + net migration.} \tag{6}$$

IV. MODEL VALIDATION

Validation is the task of demonstrating that the model is a reasonable representation of the actual system: that it reproduces system behavior with sufficient constancy to fulfill analysis objectives. While model verification techniques are standard; the approach taken to model validation is likely to be much more specific to the system. A model is usually developed to analyze a specific problem and may subsequently explain various parts of the system at various levels of abstraction. As a result, the model may have different levels of validity for different parts of the system across the full spectrum of system behavior.

There are three methods to model validation and any combination of them may be implemented as appropriate to the special components of a particular model. These methods are:

- Expert intuition
- Real system measurements
- Theoretical results/analysis.

Beside this, as proposed above, ad hoc validation techniques may be determined for a specific model and system [7].

A. Real System Measurements

To be compared with a real system is the most genuine and appealed way to validate a simulation model. However, this is often useless because of the actual system that does not remain or because the mensurations would be too costly to proceed. Hypothesis, input values, output values, configurations, system behavior and workloads should all be compared with those spotted in the actual world. In the case of simulation models, when full mensurations data is obtainable it may be possible to use trace-driven simulation to monitor the model under the same states.

TABLE II
DATA OF MODEL PARAMETERS USED IN VALIDATION

		Built up Land	Carbon	Crop land	Fishing grounds	Forest products	Grazing land
EF	2003	10050052	49324551	36697356	2679001	10742883	2964646
	2013	12213346	83908899	51149326	3092444	14056793	6871247
	Change	2163294	34584347	14451970	413443	3313910	3906601
	Rate	2.15%	7.01%	3.94%	1.54%	3.08%	13.18%
BC	2003	10050052	0	26803389	1657420	36725	0
	2013	12213346	0	29633373	16482134	40806	0
	Change	2163294	0	2829984	-9206	4080	0
	Rate	2.15%	0.00%	1.06%	-0.06%	1.11%	0.00%

TABLE III
DETAILED DATA OF MODEL PARAMETERS USED IN VALIDATION 2013

Model Parameters		2013	Unit	Rate (%)
Land use type/ Cropland	Bio-productive Area	2829000	w ha	-0.26
	Products	867000	hg/ha	7.24
Yield Factor	YF	1.66		0.00
Equivalence factor	EQF	2.8		0.00
Population	Births	2,621,902	p	4.75
	Deaths	511,000	p	1.61
	Population	80,721,900	p	1.88
	Net Migrants	-275,026	p	-0.03
GDP	GDP/Capita	3213.39	usd	18.67
Biocapacity	BC	29633373	g ha	0.0
Ecological footprint	EF	51149326	g ha	0.0

The STELLA model was populated with data for the years 2003 and 2013, obtained from the global footprint network for Egypt country to make sure that model is ready for use to be applied for Alexandria city's vision 2032. As in all stock-flow systems, the contents of each stock or reservoir are updated at regular intervals by solving a set of difference equations representing the inflows and outflows from that stock. Validation was carried out by running the model for the years 2003 and 2013, using the certified data, and comparing the output with the real-life system measurements which had not been used in the construction of the model to give confidence that the model was producing sensible output.

V. ALEXANDRIA SUP 2032: EXTENSION SCENARIO

Over the last decade the government of Egypt focused on elaborating far reaching visions and future development plans and the 2050 horizon was used for plans in Cairo, Alexandria, and a few of the country's smaller cities. Prepared by the governorate of Alexandria and Gopp in cooperation with Alexandria University in 2004, the master plan for 2050 has the longest defined term of any of the governorate's master plans. Working off of the previous master plans for Alexandria, the master plan for 2050 envisioned a grand development scheme to raise the residential capacity of Alexandria to up to 8 million residents. To achieve this goal Alexandria would have to expand its administrative boundary to include neighboring towns and villages [9].

Within the new administrative boundaries, a system of regional and local growth poles will be established. The poles will be linked by multi-modal transportation systems, providing all residents with efficient public and private transport options. The primary growth poles will be the new urban communities, new Alamein in the west and new Borg el Arab to the southwest of the core city; these satellite towns are expected to safeguard agricultural land located in the delta region now threatened by suburbanization trends [9].

The master plan also puts a new focus on the socio-economic development of Alexandria governorate. It uses spatial development as a tool for improving the economic outlook of the city. Taking a multi-disciplinary instead of singular sectoral approaches to urban development, the plan divides the governorate into areas of distinctive economic and urban patterns. Rather than just expanding upon the city's current structure, this plan sets out to drive improvements in the economy and the quality of life in Alexandria; it makes economic growth potential and the curbing of unemployment (especially among young Alexandrians) one of its primary goals [9].

TABLE IV
ESTIMATED LAND USE/COVER CHANGE IN ALEXANDRIA (2017-2032)-EXPANSION SCENARIO

		2017				
		Agriculture Land	Water Bodies	Urban Area	Sandy-Calcareous Land	Total
2032	Agriculture Land	94679	858	16	28816	124369
	Water Bodies	634	13152	0	4234	18020
	Urban Area	15462	968	12724	2118	31272
	Sandy-Calcareous Land	11315	2082	1640	41302	56339
	Total	122090	17060	14380	76470	230000

TABLE V
ACTIONS, PROS AND CONS OF EXPANSION SCENARIO

Actions	Pros	Cons
▪ Extend the urban boundary ▪ Establish new development zones in the west of Alexandria and redirect population growth away from the densely populated core to these new urban centers. ▪ Build new settlements near existing centers and along the urban fringe ▪ Provide convenient links between old and new areas ▪ Introduce more green open areas ▪ Provide adequate and sufficient social and community services	▪ Higher economic production ▪ Opportunities for the underemployed and unemployed ▪ Better life because of better opportunities and better services, and better lifestyles ▪ Extend better basic services (such as transportation, sewer, and water) as well as other specialist services (such as better educational facilities, health care facilities) to more peoples.	▪ Inflated infrastructure and public service costs ▪ Energy inefficiency ▪ Disparity in wealth ▪ Impacts on wildlife and ecosystem ▪ Loss of farmland ▪ Increase in temperature

A. Model Simulation Analysis

According to the data analysis, the value of the ecological footprint of Alexandria city over the period 2010–2015 - is relatively constant. This means that the value of land productivity increases with the annual increase in population. So it could make that balance resulting in the constancy of the ecological footprint values. In other words the values of the ecological foot print along this period of time are stable due to the absorption of land demand by the same quantity of resources stock with no increase in consumption.

Expansion development scenario proposed by the governorate of Alexandria depends on increasing the land area along the eastern and southern parts of the metropolis, which means an increase in land consumption instead of land productivity. This multiplied with the increase of population will lead to an increase in the total ecological foot print of Alexandria.

The added land area form 6% of the total land area of Alexandria according to land projections estimated by Alexandria governorate for 2032. Adding this percentage as a factor in calculating the total ecological foot print (equation 1) for expansion scenario; the total ecological foot print value is 17,706,502 gha.

VI. CONCLUSION

The preceding study has demonstrated that the concept of urban metabolism can be a productive and useful way of conceptualizing the way in which urban areas function. Urban Metabolism and urban ecology analyses provide a valuable knowledge base which can feed into the development of social and environmental policy for urban areas. The idea that urban areas are ecological systems with their own metabolisms is contributing to the understanding of the impact of human activity, including particular types of urban planning interventions, on the natural environment. Thus, urban metabolism as it is understood in urban ecology appears to have permeated urban planning and engineering practice most successfully.

VII. RECOMMENDATIONS

1) Facing Land Hunger Attitude: Many institutions and even individuals desire for the ownership of land. Often these lands left vacant within the core city area and makes infill policies unsuccessful (Harvey and Clark 1965). As a result, the city grows outward leaving the undeveloped land within the city.
2) Ecological foot print should be integrated into development plans.
3) Cities should change its development path and insure utilization of natural resources stays within ecological limits.
4) Ecosystem services should be included in the future projected resource' demand.
5) Competing land use demands need to be managed effectively.
6) Productivity must be increased and over consumption must be stopped.
7) A regulatory framework must be created for sustainability finance criteria and incentives must be increased towards this goal.
8) Higher per capita consumption of built-up area (or living space) is desired in many instances. In such cases, higher per capita consumption of living space may indicate better and extended living facilities within the confines of compact urban growth.
9) Growing up instead of out, by adding more storeys instead of more hectares.

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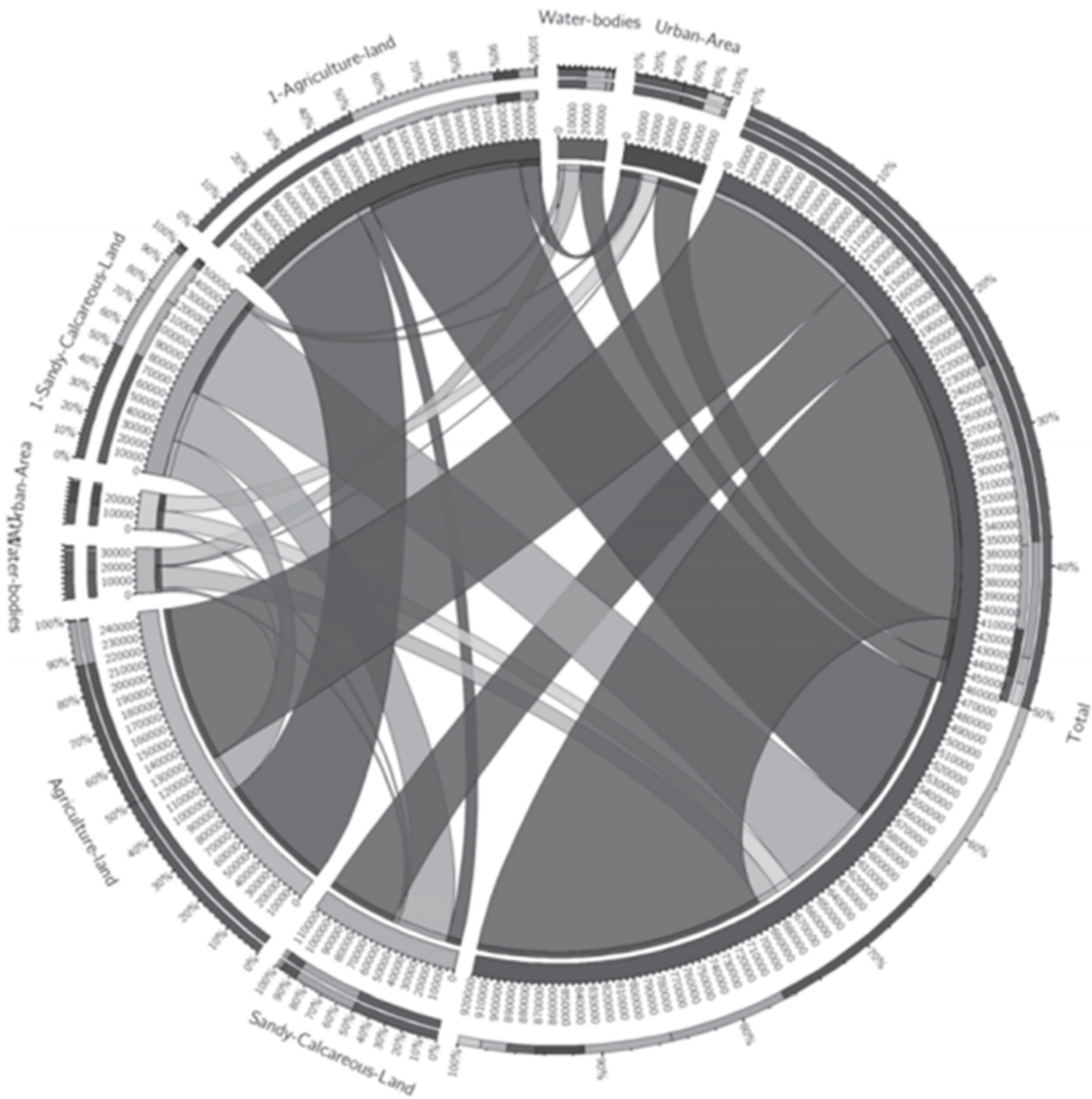

Fig. 5 Land Cover/Use Change 2017-2032 with Total (Expansion Scenario)

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