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Smart Eco-cities Conceptual Framework to Achieve UN-SDGs: A Case Study Application in Egypt

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Abstract Smart-eco cities are not a new concept, they appear while planning for a healthy and sustainable urban future. Notions like smart cities, sustainable cities, augmented cities, and ecological cities represent new norms and standards for applying the latest new smart technologies in addition to green environmental solutions in the planning of contemporary cities. The present study addresses the problem of the lack of guidelines that help in linking different principles of urban design and indicators of smart and ecological interventions in both the early planning and upgrading stage to support cities' sustainable future. Therefore, the research aims to identify smart-eco cities dimensions and indicators to use in developing a conceptual framework for developing smart-eco cities strategies, to be applied in cities nowadays. The study merges between smart and ecological urban dimensions as novel urban approaches in addition to focusing on the characteristics, guidelines, and indicators for smart and eco-cities to attain UN 2030 sustainable development goals. The present work follows a methodology that encompasses four parts. The First part is an integrative literature review for the main concepts, definitions, and dimensions for both smart cities and eco-cities in addition to SDGs. Moreover, it reviews and analyses different initiatives for cities that followed smart and ecological approaches. The Second part is an analytical approach proposing a matrix that combines both smart and eco-cities dimensions and indicators to achieve a healthier and sustainable urban future by mapping it to UN-SDGs. Moreover, a survey was administered to highlight the most effective indicators in developing smart eco-cities strategies. The Third part proposes a conceptual framework to be used for planning smart-eco cities for better urban futures. Finally, the study applies the proposed framework on a new Egyptian city as a case study to identify the potential of applying smart-eco cities concept in developing countries and limited resources settings. Research results indicate the capabilities derived by smart-eco cities that can assist in the adaptation and achieving SDGs for developing countries.

Keywords Smart Cities, Eco-Cities, Eco-Innovations, Sustainable Development, Green Solutions, SDGs

1. Introduction

Cities worldwide are now facing major challenges like global warming, air pollution, climate change, natural disasters, rapid population increase, pandemics, biodiversity, and public health issues [1], [2]. Such challenges provoke decision-makers to adopt new ideas and strategies for adopting new solutions and initiatives aiming to improve the performance of cities in terms of livability, competitiveness, and sustainability [3], [4]. This study addresses the gap in studies merging both smart and ecological interventions in the development of cities. Previous researches and prior work addressed different aspects for achieving smart sustainable solutions but not in ecological terms specifically. Correspondingly, interventions for achieving smart eco-cities need to be investigated according to its levels of action likewise; urban, social, economic, technological/technical and environmental [5]–[7]. Furthermore there is a lack in prior studies addressing social and community aspects in smart cities [8].

Therefore, the presented research aims to identify smart-eco cities indicators and guidelines to use in developing a conceptual framework for developing smart-eco cities strategies and identifying its potential in the Egyptian context. The presented study focuses on smart city interventions in ways that integrate environmental efficiency and sustainability. It aims to reduce environmental problems and face different environmental challenges in terms of control and management in ways that can be called smart eco-cities. The study targets smart cities besides eco-cities and eco-services programs and initiatives, which succeeded in creating smart and ecological urban environments. Moreover, it reviews the impact of smart city indicators for achieving UN SDGs as a part of achieving sustainable solutions for different cities and societies by 2030. The research answers three main questions (RQ1) what are the main dimensions and indicators to achieve smart eco-cities? (RQ2) what is the role that smart and ecological aspects can play together to attain UN SDGs? (RQ3) to what extent smart and ecological interventions are applied in Egypt? Figure 1 presents the structure of the presented study, which was followed to answer the presented questions. The presented study presents a deductive approach to form the relationship between smart and ecological interventions along with urban aspects in a comprehensive review of four issues namely; physical, technological, socio-cultural, and economic [9]. Accordingly, the research follows a methodology that consists of five parts. The first part is an introduction and an integrative critical literature review of the main ideas, definitions, concepts, and dimensions for smart cities and eco-cities in addition to the sustainable development goals SDGs. Moreover, it reviews different smart-eco cities initiatives and identifies their contribution to achieving UN-SDGs. The second part is an analytical approach proposing a matrix that combines both smart and eco-cities dimensions and indicators to achieve a sustainable urban future by correlating it to UN-SDGs.

Then a survey targeting a random sample of experts to rate the indicators extracted from the previous literature review according to their importance. The third and fourth parts present the results of the previous analysis proposing a conceptual framework to be used for planning smart-eco cities for a sustainable future, in addition to the final list of indicators after applying exploratory factor analysis. Moreover, it applies the proposed conceptual framework on New Administrative Capital in Egypt as a selected case study. Furthermore, the current work presents recommendations for adopting smart-eco cities interventions in contemporary urbanism strategies. Finally, the fifth part is the conclusion which points out the summary of the study in addition to considerations and recommendations for applying smart eco-cities initiatives in Egypt.

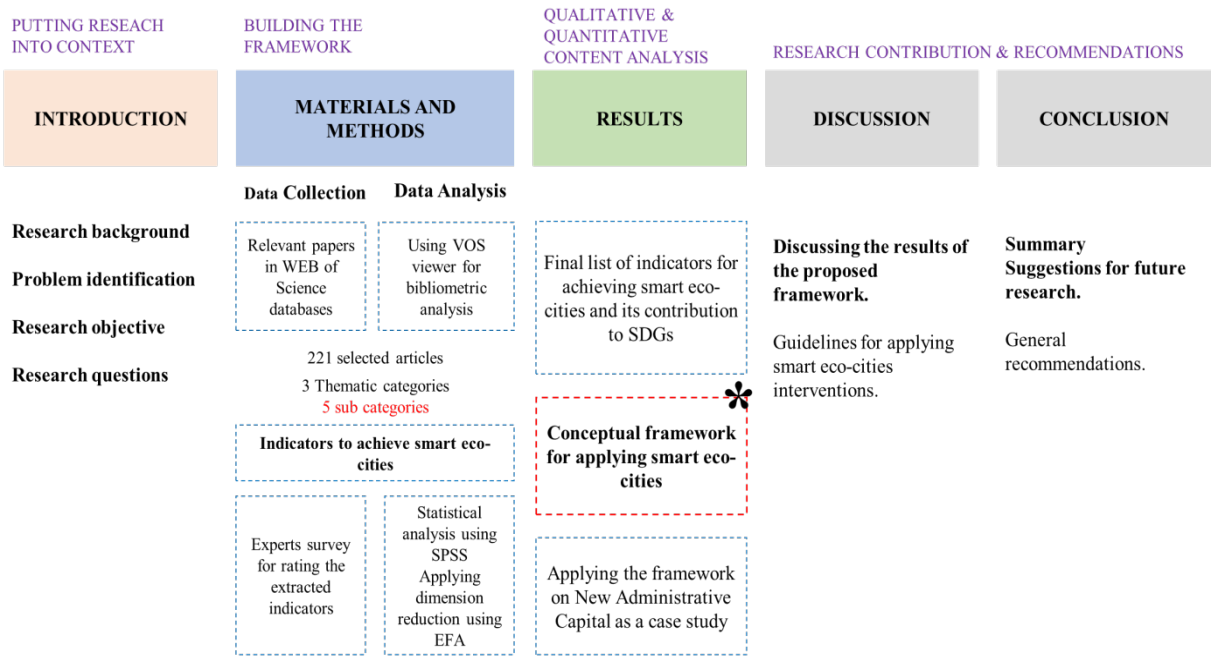

Figure 1. Research structure (author)

2. Literature Review

To identify all aspects of the theoretical findings for building the proposed conceptual framework, the presented study starts with a systematic literature review. It was performed starting from the 1st of July 2022 till the 31st of October 2022. The first part of the review was performed using a research string ("Smart Cities" AND "Ecological cities" OR "Eco-cities" AND "SDGs") on the Web of Science database 2730 sets of papers were found. To narrow down the results, more specific formula that is more related to the research objective was used: ("Smart Cities" AND "Ecological cities" OR "Eco-cities" AND "SDGs"). Accordingly, 227 papers were found presenting 25 topics covering the years from 2002 to 2022. Regarding the types of papers; 153 were journal articles, 54 proceedings, and 15 book chapters appeared in different fields of study. Papers were in different languages and to narrow down the selection papers in the English language were selected for the review. Therefore, 221 papers were selected and this was considered reliable to build on a systematic review analysis [10].

Mapping the keywords gives guidance for relevant areas to be investigated [11], [12]. Accordingly, in October 2022 VOS viewer (a bibliometric analysis platform) was used to analyze topics published in 221 papers. The analysis was based on keywords co-occurrence in the selected papers in relevance to "smart cities", "eco-cities", "sustainability" and "urbanization". Accordingly, 8 clusters were identified as a result of the analysis and four relevant clusters appeared to encompass several common linked keywords, as shown in Figure 2, which made them important to be embedded in building the conceptual framework. Thus the four categories are smartness sustainability, ecology, and urbanization.

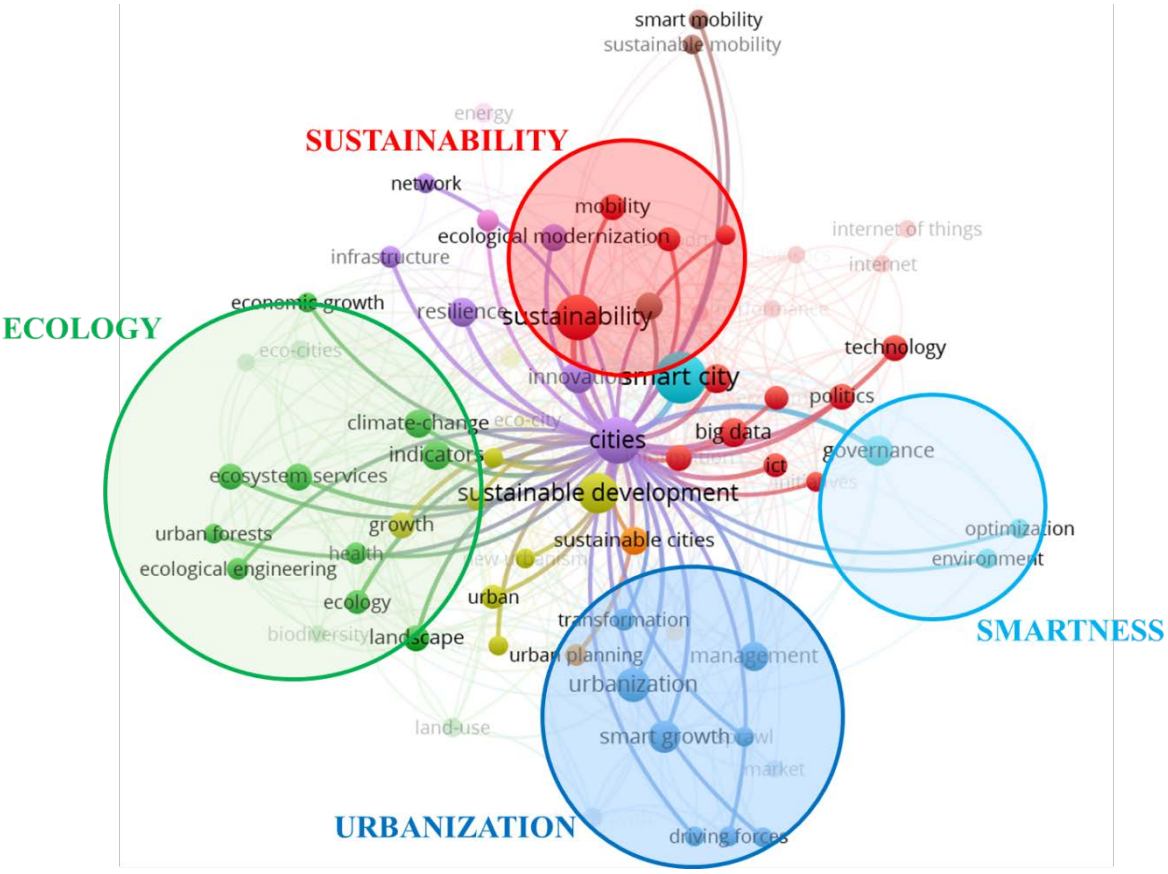

Figure 2. Bibliometric analysis (created by author using VOS viewer)

2.1. Smart Cities

The main idea of smart cities came from merging different patterns of digital technologies like ICT, IoT, 5G, blockchain technologies…etc. with contemporary urbanism [13], [14]. The rapid development of these technologies is the commonly available solution for cities around the world. Cities that combine technologies in their development strategies are known to be more efficient, socially inclusive, and sustainable [15], [16]. The different and often complementary perspectives of a smart city involve an efficient, technologically advanced, sustainable, and socially inclusive city [17]. Components and indicators of smart cities could be identified through different approaches, like the IT-oriented approach which considers the main technological impact on energy, waste, communication, transportation, water management …etc. Also, there is a people-oriented approach that considers knowledge, safety, equity, participation …etc. known as soft infrastructures and human resources [18]. Moreover, there is a European approach that recognizes a smart city as a city with a good future in terms of six main pillars namely; smart economy, smart people, smart environment, smart living, smart mobility, and smart governance [19], [20].

2.2. Eco-cities

Eco-city is an urban setting that is demonstrated on a "self-sustaining resilient" model which is utilized in the natural ecosystem [21], [22]. The term "Eco-city" was first established in 1970 after an American-based movement known as "urban ecology" was initiated [23]. After that, the idea of eco-cities was always mentioned for building healthier cities. However, making cities sustainable is not a new concept, and creating residential and industrial areas that are merged with greenery is an idea that was established post World War II [24], [25]. Eco-cities also provide equity and justice to their inhabitants, its main goal is to reach a sustainable living urban environment by reducing the consumption of resources, reducing pollution, and avoiding damage to the ecosystem [26]–[28]. To achieve the basic requirement for an eco-city, it is important to adopt green energy developments, energy-saving, and develop low-carbon cities. It is an essential part of implementing "sustainable management strategies" [22], [29].

2.3. Smart Eco-Cities Concept and Indicators

Merging smart and ecological dimensions in one city includes miscellaneous definitions that could be identified as combining both "smart" and "green" interventions. Hence, it could be identified as a city that is supported by widespread usage of ICT in a way that enhances the quality of its urban environment and preserves its sustainability [21], [30], [31]. Current active research started establishing specific notions and definitions considering integrating ICT and digital solutions to support different innovations in the environment and urbanism. Accordingly, in light of the reviewed literature, it is possible to identify the indicators for smart eco-cities by extracting them from different smart cities and eco-cities initiatives [32]–[34].

Smart eco-cities notion comprises technological, environmental, economic, and socio-cultural dimensions, thus it covers different dimensions concerning sustainable development [32], [35], [36]. Nonetheless, many well-established conceptual methods are developed to assess both smart city and eco-city concepts, such as; CITYKEYS' indicators, Smart City PROFILES, City Protocol, Smart City Ranking and methods using the Key Performance Indicators (KPIs), and Triple-helix Network Model for Smart Cities, Eco 2 cities and Eco city builders[30], [37]–[39]. These methods differ in dimensions and indicators included in their structure. However, it helped in establishing different frameworks for assessing both smart and eco-cities, thus it was adopted in the current study to extract and induce different indicators and dimensions for implementing smart eco-cities.

Table 1 shows an extracted list of indicators for smart eco-cities categorized into four thematic categories namely; economic, environmental, socio-cultural, and technological. This will help in reading the impact of each indicator and its contribution to boosting smart ecological interventions in cities. Moreover, based on the above bibliometric analysis, it is possible to identify three main dimensions for smart eco-cities namely; the Smart dimension, the Ecology dimension, and Cities/urban dimension. Hence, it is possible to map the indicators with the three dimensions as well to help build the proposed conceptual framework as shown in Table 1.

Table 1. List of indicators for smart eco-cities and their categorization (author)

Category		Indicators	Smart dimension	Ecology dimension	Urban dimension
Economic [21], [40]	1	Economic infrastructure			•
	2	Integrated building management systems			•
	3	Open-source cadastral data	•		
	4	Digital land-use and building permits	•		
	5	Public services			•
	6	Smart mobility	•		
	7	Travel time index			•
	8	Labour-related issues (employment)			•
	9	Business eco-systems		•	
	10	Integrated planning			•
	11	Mobility infrastructure provision			•
	12	Public buildings			•
Environmental [9], [21], [28], [41]	13	Energy efficiency		•	
	14	Energy demand		•	
	15	Greenhouse gas emissions		•	
	16	Building materials		•	•
	17	Water management		•	
	18	Green buildings		•	•
	19	Green areas and landscaped areas		•	•
	20	Renewable energy technology	•	•	
	21	Sustainable waste management		•	
	22	Sustainable materials		•	
	23	Green-blue infrastructure		•	•
	24	Power consumption		•	
	25	Passive houses		•	
	26	Building density			•
	27	Mix of uses			•
	28	Public spaces			•
	29	Eco-mobility		•	
	30	Environment protection		•	
	31	Clean technology	•	•	
	32	Urban development and spatial planning			•
	33	Noise exposure		•	

Table 1. Continued

Socio-cultural [42]–[44]	34	Community involvement			•
	35	Social infrastructure			•
	36	Household and internet access	•	•	
	37	Public transport network			•
	38	Health and healthy lifestyle			•
	39	Residents ICT access	•		•
	40	E-health records	•		
	41	Citizen participation			•
	42	Access to e-learning platforms	•		
	43	Available digital learning devices	•		
	44	Population equipped with real-time alert systems	•		
	45	Safety and security			•
	46	Pedestrian infrastructure			•
	47	Provision of parking spaces			•
	48	Accessibility			•
Technological [9], [45]–[48]	49	Digitization	•		
	50	Connectivity	•		•
	51	Smart traffic lights	•		
	52	Households using digital applications	•		•
	53	Available city services online	•		
	54	Buildings equipped with smart energy meters	•		•
	55	Smart electricity lights	•		
	56	Smart waste systems	•		
	57	Real-time water quality monitoring station	•		
	58	Data privacy	•		
	59	Cybersecurity	•		
	60	Digital literacy	•		
	61	Open data	•		
	62	Public Wi-Fi	•		
	63	E-governance	•		

2.4. UN Agenda 2030

The United Nations in 2015 established "The 2030 Agenda for Sustainable Development", which comprises 17 Sustainable Development Goals SDGs that are established to attain peace, wealth and prosperity for cities. All countries, stakeholders, and decision-makers should follow these SDGs to guarantee achieving sustainable life and a better world by 2030. Table 2 presents a description of the 17 goals as illustrated by the UN [49]–[52].

2.5. Smart Eco-Cities Initiatives

Recently, a tremendous number of cities all around the world are transforming into becoming intelligent and green. Smart eco-cities initiatives are aiming to implement smart technologies and green solutions to handle prevalent challenges in contemporary urban areas [53]. To understand how different initiatives of smart and ecological cities have been contributing to UN-SDGs, some smart and eco-cities initiatives around the world were selected, and their contribution to the 17 SDGs was mapped as shown in Fig 3.

Table 2. Description of the 17 sustainable development goals SDGs [48]

SDG01	End poverty in all its forms everywhere.
SDG02	End hunger and achieve food security and improve nutrition and promote sustainable agriculture.
SDG03	Ensure healthy lives and promote well-being for all at all ages.
SDG04	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
SDG05	Achieve gender equality.
SDG06	Ensure availability and sustainable management of water and sanitation for all.
SDG07	Ensure access to affordable, reliable, sustainable, and modern energy for all.
SDG08	Promote sustained, inclusive, and sustainable economic growth, full productive employment, and decent work for all.
SDG09	Build resilient infrastructure, promote inclusive, sustainable industrialization, and foster innovation.
SDG10	Reduce inequality among countries.
SDG11	Make cities and human settlements inclusive, safe, resilient, and sustainable.
SDG12	Ensure sustainable consumption and production patterns.
SDG13	Take urgent action to combat climate change and its impacts.
SDG14	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
SDG15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss.
SDG16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels.
SDG17	Strengthen the means of implementation and revitalize the global partnership for sustainable development.

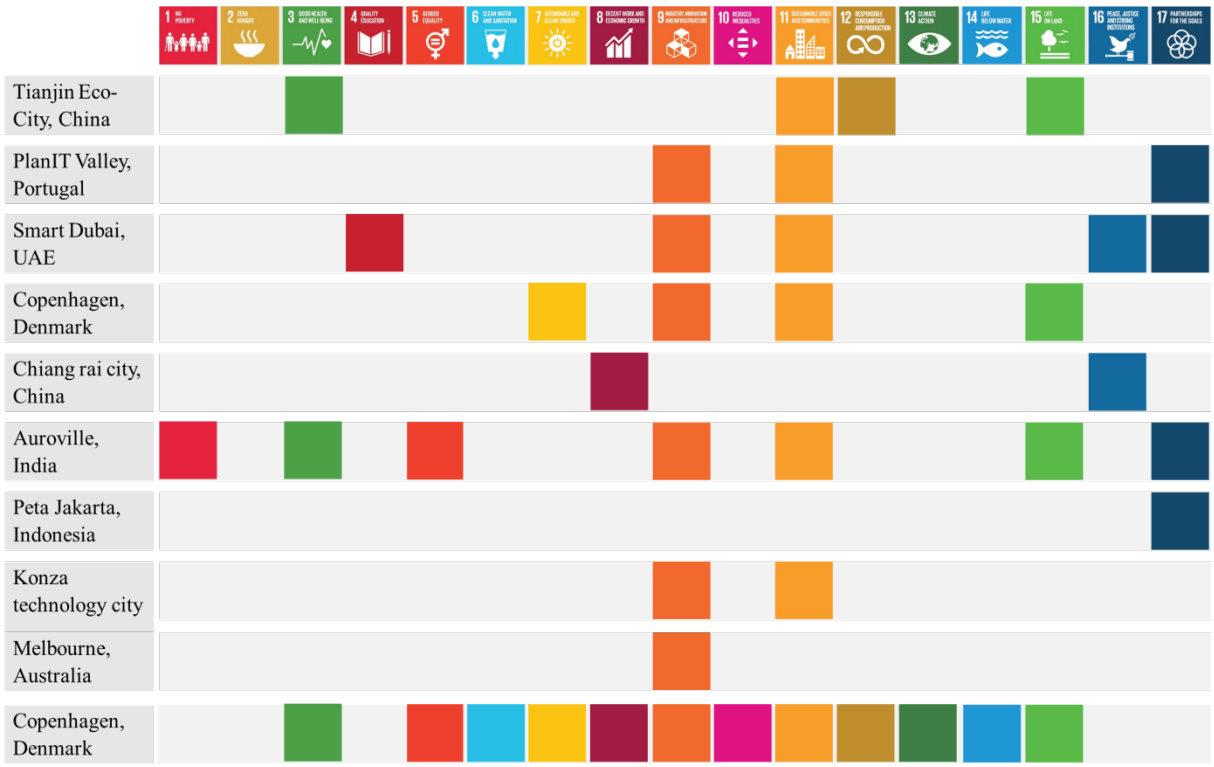

Figure 3. Mapping smart and eco-cities initiatives with 17 UN-SDGs (author based on [30], [31], [40], [45], [54]–[59]).

These initiatives were selected based on specific criteria, namely: high contribution to sustainable urban development, contribution to the UN-sustainability agenda, and application of smart interventions. Mapping the contribution of the selected initiatives to SDGs gives preliminary measures for the drivers of smartness and

ecology under each initiative. It also gives better identification of the methods these initiatives have undertaken in different contexts, utilizing digital technologies and ecological solutions to achieve UN SDGs.

Accordingly, the selected initiatives are: Tanjin eco-city in China; PalnIT valley in Portugal; Dubai in United Arab Emirates; Copenhagen in Denmark; Chiang rai city in China; Auroville in India; Peta Jakarta in Indonesia; Konza technology city in Kenya; Melbourne in Australia.

The presented illustration is an attempt to read and understand how different aspects of smart and ecological urban development cover different goals for sustainable development. The presented initiatives followed different directives for smart eco-innovations mainly; the implementation of sustainable energy policies, encouraging the use of renewable energies for sustainable urban development, utilizing digital technologies to achieve the outcomes of 2030 visions, adopting sustainable resources utilization, enhancing livability, supporting innovative strategies and delivering and promoting safe and seamless city experience. Also, these initiatives addressed sustainability challenges in innovative ways by adapting ICT and green solutions [30], [31], [40], [45], [54], [57]–[59].

3. Methods and Procedures

The presented study adopts a descriptive-analytical approach to identifying the interrelationship between both smart and eco-cities indicators and their different methods as well as levels of importance regarding its implementation in contemporary urban strategies. Figure 4 shows the methodological structure and steps adopted in the presented study focusing on the empirical part. The figure also shows merging both qualitative and quantitative methodological steps to achieve the research main objective.

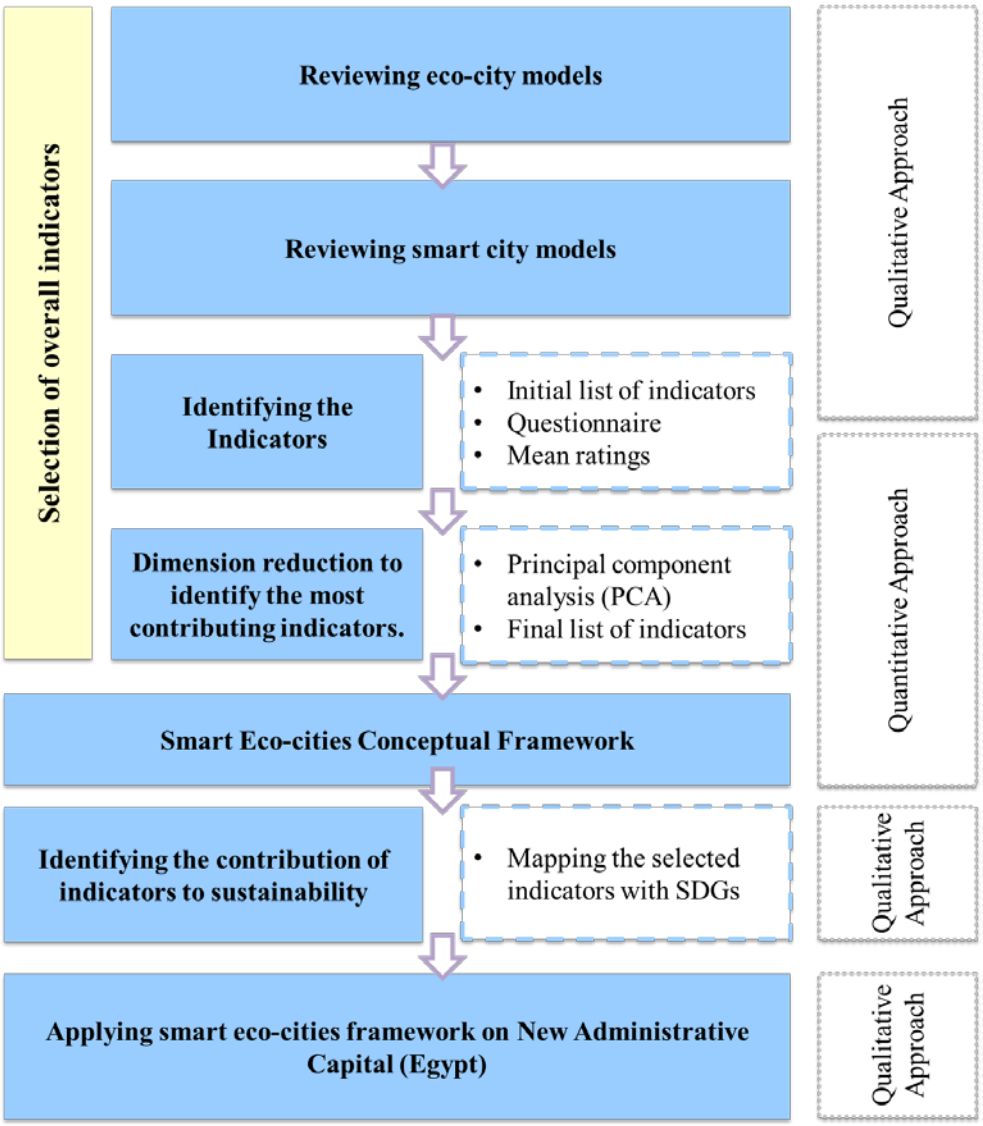

Figure 4. Methodological structure and approaches (author)

3.1. Survey

To understand the contribution of the indicators in implementing smart eco-cities solutions, a survey was designed targeting group of experts in urban design and urban planning field. An online questionnaire was selected as an efficient survey method [60]. The questionnaire was designed and administered using Google forms and was distributed online from September to October 2022. The questionnaire was divided into three parts as follows; an introduction and a consent of agreement to participate in the study, personal information questions, and 63 rating questions for the indicators of importance shown in Appendix A. Participants were requested to evaluate the importance of each one of the 66 indicators in achieving smart eco-cities using a Likert scale from 0 to 5 (0= no importance – 5= high importance).

3.2. Sampling and Participants

To afford a statistically representative and diverse sample, a stratified sampling technique was adopted [61]. Accordingly, a stratified sample of 84 respondents was collected during administering the questionnaire. The sample included 23 architects (27%), 27 urban designers (32%), 19 urban planners (23%), and 15 landscape architects/designers (18%), with ten years (or more) of practical experience.

3.3. Method of Data Analysis

Descriptive statistical analysis for the questionnaire results was adopted for this study using Statistical Package for Social Sciences (SPSS) software [61]. It is considered appropriate software for refining variables using several extraction techniques to explore the implicit theoretical configuration of the study objective.

3.4. Conceptual Framework

Different research studies were conducted to identify dimensions for both smart cities and eco-cities in addition to different models and frameworks to achieve sustainability. However, the concept is still inconsistent and changing according to the rapid changes in smart technological applications and different environmental practices [62]. Hence, it is important to develop appropriate and specific indicators for smart-eco cities on different levels for rapid attainment of the UN Agenda 2030 on sustainable development goals (SDGs) [49], [63].

3.5. Case Study

To test the proposed conceptual framework, New Administrative Capital (NAC) in Egypt was selected based on specific criteria mainly; it is an Egyptian fourth-generation city whose planning is based on smart and sustainable solutions. It is a part of the Egyptian sustainable development strategy aiming for achieving UN SDGs by 2030.

New administrative Capital is planned to cover a 146,000-acre land area, in three phases targeting a population of 15 million people. It is located 45 kilometers east of Cairo metropolis; between "Cairo - Suez" road and" Cairo - Al Ain Sukhna" road as shown in Figure 5. It is planned to adopt renewable energy power-driven utilities and sustainable green infrastructure, with a connected multimodal transport network.

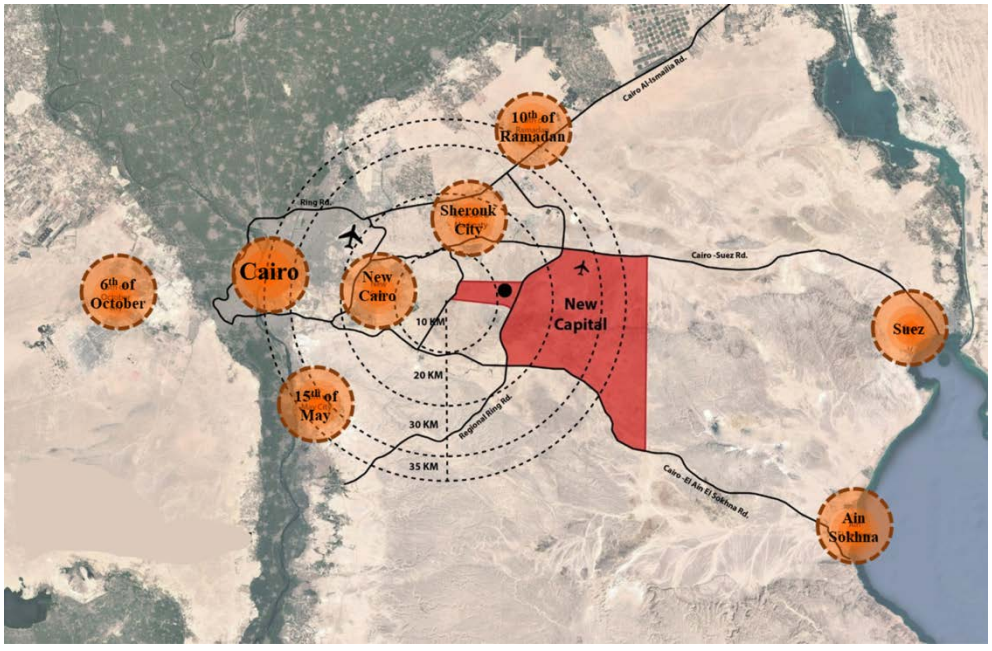

Figure 5. Location of NAC ([64] presented by author)

4. Results and Discussion

This section presents the data collection, analysis and findings for the demonstrated study.

4.1. Reliability Analysis

In order to check the reliability and consistency of the responses for the questionnaire, reliability analysis was conducted. Cronbach Alpha value was 0.96 which is considered to be reliable and therefore responses were considered consistent. Moreover, Table 3 shows the Cronbach Alpha for each thematic category.

Table 3. Reliability analysis (created by author using SPSS)

Categories	Cronbach Alpha
Economic	0.794
Environmental	0.927
Socio-economic	0.919
Technological	0.885

4.2. Exploratory Factor Analysis (EFA)

In order to identify the most effective indicators in terms of achieving smart eco-cities, and to reduce the number of indicators to understand deeply the correlation between them through a smaller number of components, exploratory factor analysis (EFA) was conducted using principal component analysis (PCA) as an extraction method. PCA was performed on 63 indicators using varimax rotation, the commonalities between the variables were greater than 0.4, thus a sample of 84 participants was considered adequate. Moreover, the Kaiser-Meyer-Olkin method of sampling adequacy scored 0.698 which was greater than 0.6, this means that data were fit for EFA. Accordingly, it was safe to draw conclusions based on this data. Also, the commonalities ranged from 0.68 to 0.916 which is considered moderate and strong.

According to the varimax rotation, 16 components with Eigen values greater than 1.0 were extracted. One of them was strong since it explained 38.9% of the variance. The other components explained from 1.5 to 5.9 % of the variance, hence they were considered weaker and the first component only was included in the study. A threshold of 0.5 factor loading was adopted to select the strongest indicators contributing to component 1. Consequently, 30 indicators were identified as strong contributors to achieving smart eco-cities. Table 4 shows the selected 30 indicators and their importance mean ratings to achieve smart eco-cities initiatives. Each indicator was coded with the initials of its category and given a serial number for better results reading.

Figure 6 demonstrates the mean ratings bar chart for the 30 indicators showing that safety and security (S07) has scored the highest importance rating (M=3.47). This indicates the importance of users' safety and data security as an outmost priority to establish smart eco-cities. On the other hand, the availability of digital land-use and building permits (EC01) scored the least importance for establishing smart eco-cities (M= 2.518).

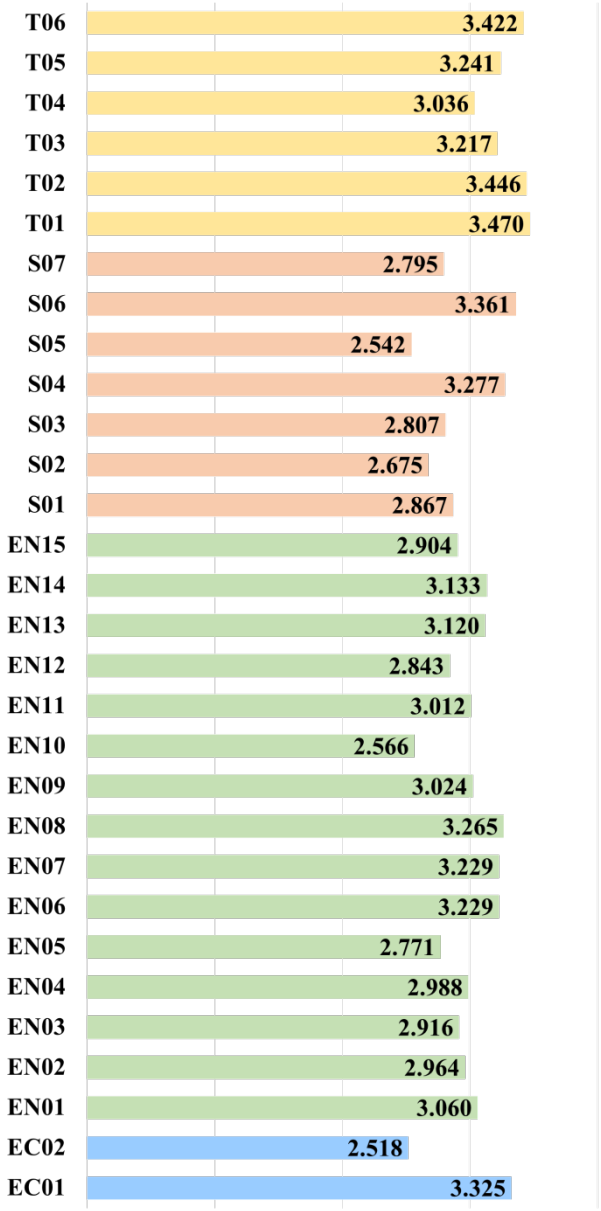

Figure 6. Indicators mean ratings

Table 4. Indicators Mean ratings, SD and Factor loadings (created by author using SPSS)

Indicators		Mean	SD	Factor loadings
Economic				
EC01	Digital land-use and building permits	2.518	0.7047	0.639
EC02	Business eco-systems	3.325	1.0372	0.825
Environmental				
EN01	Energy efficiency	3.060	0.9797	0.780
EN02	Energy demand	2.964	1.1629	0.797
EN03	Greenhouse gas emissions	2.916	1.2017	0.640
EN04	Green buildings	2.988	1.1315	0.783
EN05	Green areas and landscaped areas	2.771	1.1189	0.626
EN06	Renewable energy technology	3.229	1.1189	0.803
EN07	Sustainable waste management	3.229	1.1511	0.844
EN08	Sustainable materials	3.265	1.1271	0.879
EN09	Green-blue infrastructure	3.024	1.1580	0.795
EN10	Power consumption	2.566	1.0382	0.560
EN11	Passive houses	3.012	1.1842	0.737
EN12	Public spaces	2.843	1.1527	0.637
EN13	Eco-mobility	3.120	1.1624	0.878
EN14	Environment protection	3.133	1.2274	0.754
EN15	Clean technology	2.904	1.1854	0.513
Socio-cultural				
S01	Household and internet access	2.867	1.1345	0.714
S02	Public transport network	2.675	1.1274	0.765
S03	Health and healthy lifestyle	2.807	1.1419	0.626
S04	Residents ICT access	3.277	1.1078	0.859
S05	Citizen participation	2.542	1.0511	0.540
S06	Available digital learning devices	2.795	1.1451	0.711
S07	Safety and security	3.470	1.0041	0.879
Technological				
T01	Digitization	3.361	1.1324	0.891
T02	Connectivity	3.446	0.9403	0.580
T03	Smart waste systems	3.217	0.9246	0.564
T04	Real-time water quality monitoring station	3.036	0.8617	0.665
T05	Data privacy	3.241	0.9185	0.700
T06	Cybersecurity	3.422	1.0015	0.705

4.3. Smart Eco-Cities Conceptual Framework

Evidence from the survey results and bibliometric analysis proposes that the integration of three main dimensions (smart, ecology, and cities) is essential to achieve smart eco-cities, which merge sustainable and ecological urban strategies and novel smart solutions. Accordingly, Figure 7 presents the entities represented in the main dimensions for achieving smart-eco cities solutions for sustainable urban environments, which will help develop the proposed framework.

Furthermore, Figure 8 presents the conceptual framework for achieving smart eco-cities to achieve UN-SDGs encompassing the four thematic categories of indicators namely; economic, environmental, socio-cultural, and technological. The proposed framework could be used for both implementation and evaluation of smart ecological interventions in cities.

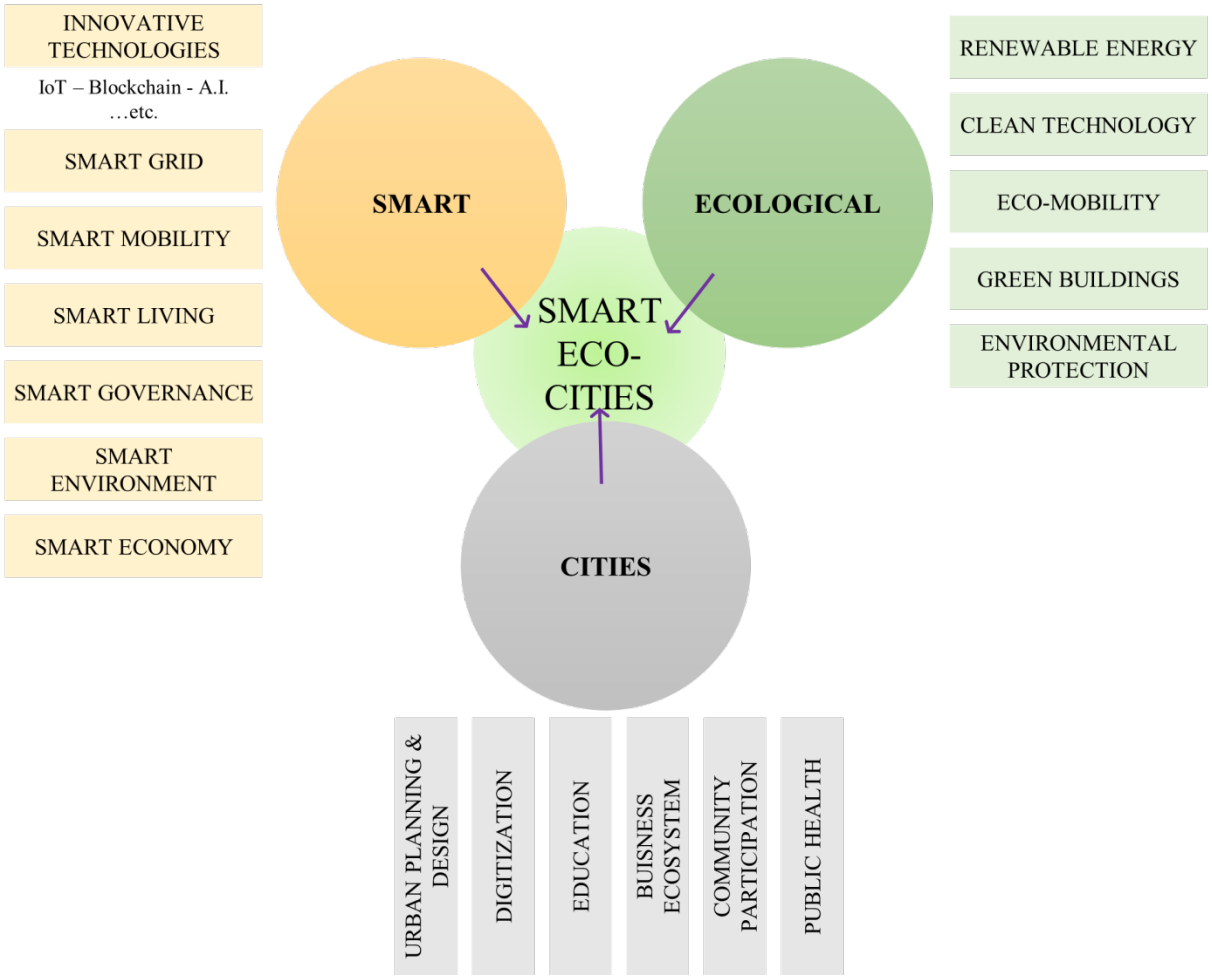

Figure 7. Achieving smart eco-cities - framework input (author).

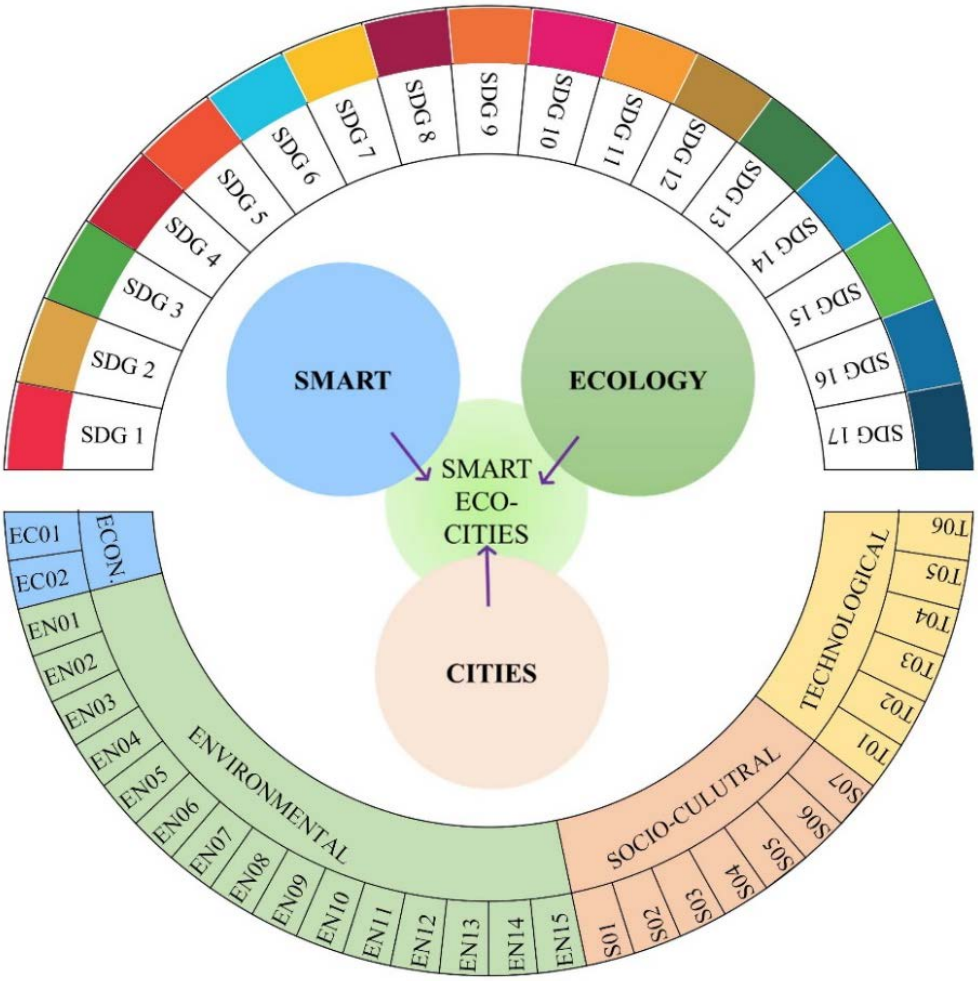

Figure 8. Smart eco-cities conceptual framework to attain UN SDGs (author)

4.4. Case Study Application: New Administrative Capital (NAC) – Egypt

The proposed conceptual framework is applied to a selected case study for better reading and understanding, and correspondingly, to highlight the potential of applying the smart eco-city concept in the Egyptian context. However, it is noticeable that NAC is still under construction therefore, the presented application of the framework is based on the initial design documents, recently published articles about NAC, and the initial executed infrastructure and buildings for the first phase of the construction work.

Table 5 shows the application and degree of existence for the 30 indicators in NAC. Seven indicators showed high existence; which are the existence of green areas and landscape areas (EN05), the existence and spread of public spaces (EN12), the existence of public transport network (S02), safety and security of people and the acquired data (S07), digitization of the city's aspects (T01), the connectivity (T02), and cyber security strategies (T06). However, five indicators are shown to be not applied in the proposed strategic plan for NAC namely; business eco-systems (EC02), green buildings (EN04), sustainable materials (EN08), environment protection (EN14), and real-time water quality monitoring station (T03).

Table 5. Application of Smart eco-city indicators in NAC

Indicators	Application	
EC01	Medium	✓ Digital records for land permits ✓ 30% of the city is business oriented ✓ Open platform integrating resource management and GIS information
EC02	N/A	
EN01	Medium	✓ Residential buildings according to preliminary studies are shown to have a strong potential for energy saving. ✓ R values and heat gain coefficients regarding the used materials in residential buildings are proven to promote energy saving. ✓ Buildings initial designs shown full compliance with energy codes. ✓ New capital power plants were established in 2016 encompassing natural gas and steam units.
EN02	Medium	✓ The plan is established that the demand and consumption will be 40% self-covered by the year 2035, depending on completely self-produced energy.
EN03	N/A	
EN04	Low	✓ Few buildings are designed following green buildings strategies.
EN05	High	✓ Green river as a central park. ✓ Gateway Park. ✓ Plants garden and heritage garden as major green spaces. ✓ Pocket parks distribution. o No ecology based gardens distributed all over the city. o No tree canopies or green utility corridors.
EN06	Medium	✓ Widespread usage of solar panels. ✓ Mainly NAC is established to be powered by renewable energy.
EN07	Low	✓ Sustainable solutions were provided for waste management in NAC, like municipal solid waste is going to be processed to generate fuels for cement industries. ✓ Sustainable waste management infrastructure was established.
EN08	N/A	
EN09	Medium	✓ Green river extended for 11 km to form a huge green park in the middle of the capital. ✓ Green areas distribution
EN10	Low	✓ Consumptions are planned to maintain operations without affecting energy needs.
EN11	Medium	✓ 70% of the building roofs covered with solar panels. ✓ Mainly NAC is established to be powered by renewable energy. ✓ Residential buildings according to preliminary studies are shown to have a strong potential for energy saving.
EN12	High	✓ 40% pedestrian paths.
EN13	Low	✓ Monorail and electric train are the only eco-mobility solutions applied.
EN14	Low	✓ Collecting sewage and storm water using main gravity pipelines for eventual discharge into the “New Capital Sewage Treatment Plant”. ✓ Integrated approach for waste management is established.
EN15	Medium	✓ Sustainable use of resources with negative environmental impact. ✓ Using solar energy and the spread of solar panels on buildings’ roofs. ✓ Expanding clean energy supplies.
S01	Low	✓ Internet is widely connected covering the entire city. ✓ Providing residential areas with high speed internet access.
S02	High	✓ Public transportation available on different levels.
S03	Medium	✓ Smart health records using online systems and databases

Table 5 Continued

S04	Medium	✓ Connected fiber infrastructure is implemented for all households. ✓ Smart services and payment systems is established for residents.
S05	Low	✓ Establishing online platforms for citizen participation. ✓ Offering lands to investors to participate in urban development.
S06	Medium	✓ Development of e-learning and online learning platforms. ✓ Smart schools and smart universities.
S07	High	✓ Advanced surveillance systems were established.
T01	High	✓ LTE mobility network ✓ Integrated digital infrastructure and network of smart facilities is developed and well planned to be implemented.
T02	High	✓ Shared mobile towers are established. ✓ Connected fiber infrastructures are implemented. ✓ Providing residential areas with high speed internet access.
T03	Low	✓ Advanced technology for waste management systems is planned to be implemented.
T04	Medium	✓ Advanced water treatment plants. ✓ Water quality monitors are available. ○ No active real-time water monitoring.
T05	Medium	✓ Data encryption and digital means are established for data privacy. ✓ Data privacy is activated through bylaws. ○ Still no open data available in all fields
T06	High	✓ National cyber security strategies were established in 2017. ✓ The creation of the Egyptian Supreme Cyber security.

✓ Points of strength in the application.

○ Points of weakness in the application.

N/A Not Applied

Figure 9 shows the framework application on NAC highlighting four sustainable development goals to be achieved by the opening of its final phase, namely; SDG 6 (clean water and sanitation), SDG 7 (affordable clean energy), SDG 9 (industry and innovation infrastructure), and SDG 11 (sustainable cities and community). Additionally, Table 6 shows a comparison between the existence of indicators in NAC and their degree of importance in the original model, where the values of the mean ratings less than 2 are considered low importance, meanwhile values between 2 and 3 are considered medium importance and values greater than 3 are considered high.

Therefore, green and landscape areas (EN05), public spaces' availability (EN12), and public transports network (S02) have a medium importance according to experts' ratings but it is highly applied in NAC. Meanwhile, business eco-systems (EC02), greenhouse gas emissions reduction (EN03), sustainable waste management (EN07), sustainable materials (EN08), Eco-mobility (EN13), Environment protection (EN14), and smart waste systems (T03) are highly important indicators according to the model and either applied in low interventions or not applied at all in NAC which is critical and needs action to be enhanced. However, digital land-use and building permits (EC01), energy demand (EN02), clean technology (EN15), Health and healthy lifestyle (S03), and available digital learning devices (S06) indicators shown medium importance according to experts and have medium existence in NAC.

In the light of the previous points, smart interventions in NAC include using digital technologies and applications to make the city more efficient, like providing digital records for residential buildings and land permits, and providing online platforms for resources management. It also involves providing more ecological and smart solutions for mobility and transportation, like encouraging waking, bike sharing, car sharing services and e-transport systems in addition to smart traffic systems. Energy efficient solutions to reduce energy consumption and reduce carbon footprint are also followed in NAC planning strategy. Also, more ecological interventions are comprised to enhance its urban quality of life as well as being more environmentally friendly mainly the wide provision of green spaces, the access of residential units to parks and the widespread usage of solar panels in addition to the energy efficient solutions adopted in the city. Additionally, enhancing the safety, attractiveness and business developments in NAC enhances its economic benefits, as well as using smart systems to enhance its public and business operations.

Accordingly, the previous results show mostly a need for deeper vision, regarding applying smart eco-city strategies. In addition to a need for understanding the dynamic relationship between the citizens and the smart built environment similar to the findings in [42].

Table 6. Comparing indicators existence in NAC to the framework ratings from experts' responses (author)

Indicators		Framework strength		Application strength in NAC
EC01	Digital land-use and building permits	2.518	M	M
EC02	Business eco-systems	3.325	H	N/A
EN01	Energy efficiency	3.060	H	M
EN02	Energy demand	2.964	M	M
EN03	Greenhouse gas emissions	2.916	M	N/A
EN04	Green buildings	2.988	M	L
EN05	Green areas and landscaped areas	2.771	M	H
EN06	Renewable energy technology	3.229	H	M
EN07	Sustainable waste management	3.229	H	L
EN08	Sustainable materials	3.265	H	N/A
EN09	Green-blue infrastructure	3.024	H	M
EN10	Power consumption	2.566	M	L
EN11	Energy efficiency	3.012	H	M
EN12	Public spaces	2.843	M	H
EN13	Eco-mobility	3.120	H	L
EN14	Environment protection	3.133	H	L
EN15	Clean technology	2.904	M	M
S01	Household and internet access	2.867	M	L
S02	Public transport network	2.675	M	H
S03	Health and healthy lifestyle	2.807	M	M
S04	Residents ICT access	3.277	H	M
S05	Citizen participation	2.542	M	L
S06	Available digital learning devices	2.795	M	M
S07	Safety and security	3.470	H	H
T01	Digitization	3.361	H	H
T02	Connectivity	3.446	H	H
T03	Smart waste systems	3.217	H	L
T04	Real-time water quality monitoring station	3.036	H	M
T05	Data privacy	3.241	H	M
T06	Cybersecurity	3.422	H	H

H = High M = Medium L = Low N/A = Not Applied

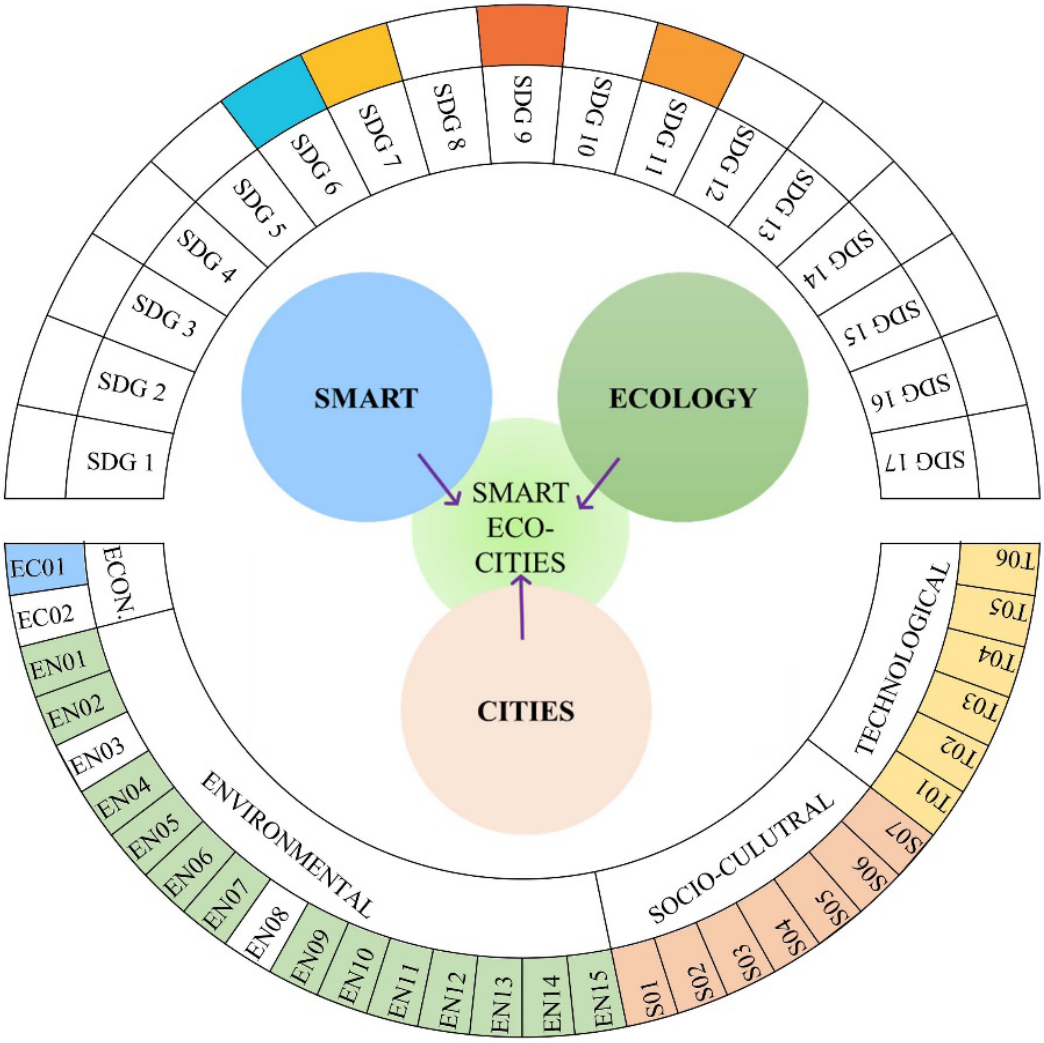

Figure 9. Applying Smart eco-cities conceptual framework on NAC (author)

5. Discussion

The study showed that smart eco-city interventions encompass technology and green solutions to achieve sustainability. This includes green areas provision, eco-efficiency, smart public transportation, clean technologies, and smart waste management systems. According to the critical literature analysis, the presented work synthesized the main dimensions and indicators of smart eco-cities, highlighting that it is an integration between economic, environmental, socio-cultural, and technological dimensions, this answers the first research question (RQ1) and this corresponds to the obtained results from prior studies [35], [42]. Furthermore, reviewing smart and eco-cities initiatives and their contribution to SDGs highlighted the role of both smart and ecological aspects that can play together to attain 2030 SDGs especially SDG 11 similar to other studies [13], [65], this answers the second research question (RQ2).

Based on the previous application and assessment of the smart eco-cities framework on New Administrative Capital (NAC) in Egypt, it is possible to point out the virtues and potentials of the proposed framework as an appropriate tool for managing the complexities of assessing smart ecological interventions in new and existing urban contexts. As well as assessing its contribution to UN-SDGs, this in turn answers the third research question (RQ3). Accordingly, the research highlights the importance played by technology and green solutions for achieving healthy and sustainable urban life, as well as efficient urban operations which highlighted the limitation of investigating smart ecological dimensions as mentioned in [5], [7]. Evidence of the previously illustrated results and findings recommends focusing on the low and non-existing indicators to make sure of contribution to UN-SDGs as a 2030 sustainable development plan through establishing fourth-generation cities (similar to [66], [67]). Furthermore, this will help achieve smart and ecological interventions in existing urban contexts, by ensuring flexibility in designing and retrofitting existing urban structures and upgrading the infrastructure.

The application of the proposed conceptual framework

on NAC as a selected case study highlights its potential as an appropriate tool in handling the complexities of applying smart eco-cities interventions in new cities. The framework allowed the evaluation of the existing strategies, and the implementation process for establishing the New Administrative Capital in Egypt. It analyzed the different indicators representing the four main dimensions; economic, environmental, socio-cultural, and technological. Throughout the application of the framework some recommendations regarding the application of smart eco-cities were elaborated, as follows:

- A public-private partnership should be established through new sets of smart and ecological models and financing resources, to help maintain and operate smart eco-cities (*contributing to indicators EC02 & S05*).
- Governance and operational management must integrate smart models like the ones adopted in smart management for smart cities [18]. In addition to smart business models and processes to support the offered smart services (*contributing to indicators EC02, EN14 & T04*).
- Local community participation at some levels in the decision-making process is an important aspect of the success of smart eco-cities implementation (*contributing to indicator S05*).
- Technology infrastructure shall be handled beyond traditional civic community [68]; it shall support new users like stakeholders, decision-makers, and value creators (*contributing to indicators S04, T01, T05 andT06*).
- Urban smart and ecological competencies should be developed at cities' level to maintain smart ecological development and sustainability (*contributing to all the indicators*).
- Smart eco-cities must simplify and enable information and data access, through open data initiatives, offering analytics services, and encouraging data sharing [46]. Meanwhile ensuring data privacy and security to protect the data gathering processes sustainability (*contributing to indicators S04, S05, T01, T05, and T06*).
- More strategies for energy reduction and adoption of renewable sources are needed [42] like wind energy biofuels, as well as applying smart grids as one of the applications of energy efficiency procedures (*contributing to indicators EN01 to EN06, EN10, EN14and EN15*).
- Connectivity and accessibility are important aspects of smart eco-cities development and should be handled as a high priority sustainability (*contributing to indicators S04 and T02*).
- Cyber security and secure connections are essential / vital to be included as smart eco-city aspects, to ensure information protection (*contributing to T06*).
- Performance of smart eco-cities measurements [20] and evaluation should be established through new metrics derived from smart eco-cities indices (*contributing to all the indicators*).

In general the interrelationship between smart interventions and ecological interventions should be strengthened during the application of smart eco-city strategies in sustainable urban development corresponding to what came in [42], [65]. More importantly, the development and application of smart eco-cities strategies depend mainly on the environmental and technological dimensions as shown in Table 1, Table 4 and figure 6 (similar to [65], [69]).

6. Conclusions

The future application of smart eco-city strategies is wide spreading; it encompasses different dimensions and indicators. Moreover, it is rapidly evolving due to the development of Digital technological applications and ICT, in addition to the affordability of sustainable solutions. The presented study identified the likely indicators to achieve smart and eco-cities by analyzing and reviewing the dimensions of implementing smart and ecological cities strategies. Then experts' survey was administered to identify the relative importance of the deduced indicators to achieve smart eco-cities. Furthermore, exploratory factor analysis was performed to identify the most effective indicators for implementing smart eco-cities to achieve SDGs. As a result, the indicators were reduced from 63 to become 30 effective indicators.

The present work synthesized the findings of the related literature into a conceptual framework for achieving smart eco-cities, this addressed the knowledge gap mentioned by [70] which recommended investigating different models regarding smart eco-cities implementation. The proposed framework encompasses the main dimensions for applying smart eco-city interventions along with the main indicators of smart and ecological cities.

The framework was applied to a case study in Egypt, the New Administrative Capital NAC as one of the fourth-generation cities in Egypt, which is characterized by adopting new smart and sustainable interventions. Consequently, the application of the proposed framework highlighted some potentials for applying smart eco-cities interventions in the Egyptian context, like the importance of the collaboration of public and private partnership; enhancing the digital infrastructure as the main key to this process's success; and developing evaluation process to monitor the establishment of smart eco-cities initiatives.

Based on the findings and outcomes of the presented work, it is clear that the concept of "smart eco-cities" is multidimensional, thus some recommendations for smart eco-cities' development strategies could be provided:

- Considering human and social aspects during the development process is essential for smart eco-strategies to be implemented efficiently as

mentioned in [8]. This could be achieved through providing high-quality education and health services to ensure smart people contribute to economic growth.

- Making and putting up smart and ecological plans through engaging research centers and universities as well as non-governmental organizations and different advisory boards. This will guarantee the efficiency and durability of ongoing smart eco-strategies and smart eco-cities projects that might face challenges or problems during their execution or processing.
- Backing up smart eco-cities initiatives with a supportive development outlook to ensure its contribution to UN-SDGs.
- Developing multi-level governance policies, including stakeholders, investors, civil society, and both public and private sectors.
- Proposing incentives for actors who contribute to sustainability challenges that face smart eco-cities development, and aid the process of achieving UN-SDGs.
- Raising competency in the fields like industry 4.0 and web 2.0 markets may enrich the smart eco-development process in community-based growth.
- Developing a socially inclusive framework to address the inequalities within a single community, may result from developing specific smart services for a specific income level or the elites only, such as smart banking, smart homes, or even more sophisticated digital platforms.
- Including innovation, investment, inclusion, and improvement actions during developing smart eco-cities development to enable their sustainability while facing different development challenges.

The presented research work addresses some limitations; first, the experts' sample size needs to be increased and more rotations for EFA need to be performed based on the increased sample size. Second, the New Administrative Capital is under construction, therefore the highlighted investigation is based on the initial design documents and executed infrastructures of phase 1. Third, the limited literature combines both notions of "smart" and "eco" for the development of cities. However, the presented study could be considered a starting point for studying smart eco-cities in Egypt and MENA region.

Findings and results of the presented work highlighted some core questions that would possibly extend the potential of applying smart eco-city interventions in relevance to the different dimensions, namely:

- How the dynamic system of citizens' partnership and sharing could be handled through?
- What are the available technologies that would make all data and information updated, private and secured?
- To what extent digital technologies have an influence on urban technologies integration with eco-systems in a way that enhances the performance of smart eco-cities?
- What are the potentials of technologies and smart systems in achieving sustainable green solutions and enhancing the urban structure for smart eco-cities?
- When should the dimensions for smart eco-cities development (economic, environmental, social and technological) should be balanced to achieve optimum solutions for achieving SDGs?

Furthermore, the study indicates further directions for future research, namely; developing decision-making models for implementing smart eco-cities strategies as a tool for urban planners and designers to implement such strategies aiming for sustainable development and achieving UN-SDGs. Applying system dynamics to the identified indicators and dimensions for smart eco-cities to understand the impact of indicators on each other. Moreover, smart green urbanism solutions and their different contribution could be investigated as interventions to achieve smart eco-cities strategies in different contexts.

Appendix A. Survey questions (author)

Personal information						
Area of experience	<5	6-10	11-15	16-20	>20	
Years of experience	Architecture	Urban design	Urban planning	Sustainability and environmental design	Other	
Please rate the following indicators from 1 to 5 according to their importance to achieve smart eco-cities strategies. (*1= low importance 5 = high importance*)						
1	Economic infrastructure	1	2	3	4	5
2	Integrated building management systems	1	2	3	4	5
3	Open-source cadastral data	1	2	3	4	5
4	Digital land-use and building permits	1	2	3	4	5
5	Public services	1	2	3	4	5
6	Smart mobility	1	2	3	4	5
7	Travel time index	1	2	3	4	5
8	Labour-related issues (employment)	1	2	3	4	5
9	Business eco-systems	1	2	3	4	5
10	Integrated planning	1	2	3	4	5
11	Mobility infrastructure provision	1	2	3	4	5
12	Public buildings	1	2	3	4	5
13	Energy efficiency	1	2	3	4	5
14	Energy demand	1	2	3	4	5
15	Greenhouse gas emissions	1	2	3	4	5
16	Building materials	1	2	3	4	5
17	Water management	1	2	3	4	5
18	Green buildings	1	2	3	4	5
19	Green areas and landscaped areas	1	2	3	4	5
20	Renewable energy technology	1	2	3	4	5
21	Sustainable waste management	1	2	3	4	5
22	Sustainable materials	1	2	3	4	5
23	Green-blue infrastructure	1	2	3	4	5
24	Power consumption	1	2	3	4	5
25	Passive houses	1	2	3	4	5
26	Building density	1	2	3	4	5
27	Mix of uses	1	2	3	4	5
28	Public spaces	1	2	3	4	5
29	Eco-mobility	1	2	3	4	5
30	Environment protection	1	2	3	4	5
31	Clean technology	1	2	3	4	5
32	Urban development and spatial planning	1	2	3	4	5
33	Noise exposure	1	2	3	4	5
34	Community involvement	1	2	3	4	5

Appendix A. Continued

35	Social infrastructure	1	2	3	4	5
36	Household and internet access	1	2	3	4	5
37	Public transport network	1	2	3	4	5
38	Health and healthy lifestyle	1	2	3	4	5
39	Residents ICT access	1	2	3	4	5
40	E-health records	1	2	3	4	5
41	Citizen participation	1	2	3	4	5
42	Access to e-learning platforms	1	2	3	4	5
43	Available digital learning devices	1	2	3	4	5
44	Population equipped with real-time alert systems	1	2	3	4	5
45	Safety and security	1	2	3	4	5
46	Pedestrian infrastructure	1	2	3	4	5
47	Provision of parking spaces	1	2	3	4	5
48	Accessibility	1	2	3	4	5
49	Digitization	1	2	3	4	5
50	Connectivity	1	2	3	4	5
51	Smart traffic lights	1	2	3	4	5
52	Households using digital applications	1	2	3	4	5
53	Available city services online	1	2	3	4	5
54	Buildings equipped with smart energy meters	1	2	3	4	5
55	Smart electricity lights	1	2	3	4	5
56	Smart waste systems	1	2	3	4	5
57	Real-time water quality monitoring station	1	2	3	4	5
58	Data privacy	1	2	3	4	5
59	Cyber security	1	2	3	4	5
60	Digital literacy	1	2	3	4	5
61	Open data	1	2	3	4	5
62	Public Wi-Fi	1	2	3	4	5
63	E-governance	1	2	3	4	5

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