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MODELLING A SUSTAINABILITY THRESHOLD-BASED ASSESSMENT AND ITS EXPERIMENTATION IN SUBURBAN ALGIERS

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Abstract:
This article examines the impact of growing urbanisation, with particular attention given to identifying thresholds that mark the onset of irreversible change and the associated risks when these thresholds are exceeded. The research presents a threshold-based tool for assessing sustainability – the Suburban Sustainability Systemic Thresholds Index (S^3-TI) – which uses a systemic approach with threshold modeling to evaluate urban sustainability. It identifies trigger factors and their development thresholds within the socio-ecological system. This tool was applied to the Bordj-El-Kiffan municipality in Algiers, where data was collected through indicators spanning five systems: social, managerial, economic, environmental, and the built environment. The results from these indicators were then benchmarked against a reference area: the central urban system area. The assessment categorises the development thresholds as acceptable, critical, or unacceptable, reflecting the system's proximity to sustainable or at-risk states. The results indicate that Bordj-El-Kiffan has surpassed critical to unacceptable thresholds in several domains, highlighting persistent deficiencies in essential services, limited citizen participation, difficulties in managing urban services and natural resources, unsustainable demographic patterns, and inadequate mobility infrastructure. The S^3-TI tool serves as an alert system and awareness-raising instrument, emphasizing the importance of defining and respecting development thresholds to support adaptive and sustainable territorial governance. By integrating the S^3-TI tool into future urban planning practices, sustainability in Algerian cities – and potentially in other Global South contexts – can be strengthened. The study emphasises qualitative aspects such as urban well-being and environmental equilibrium rather than solely focusing on quantitative indicators of growth, promoting a more holistic approach to urban sustainability.

***Key words*: sustainability, assessment, thresholds, modelling, Algiers.**

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1. INTRODUCTION AND THEORETICAL FRAMEWORK

In 2018, cities housed 55% of the world's population, and projections suggest this will rise to 68% by 2050 (UN DESA, 2018). However, rapid urbanisation in the Global South, particularly in Africa, has led to the proliferation of slums due to demographic pressures, poverty, infrastructure gaps, and limited resources (Agyemang *et al.*, 2022). For the Sustainable Development Goals, especially Goal 11, addressing these challenges

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is the central target, which aims to foster inclusive, safe, resilient, and sustainable urban environments by tackling social, economic, and environmental aspects of urban life (UN, 2017).

In Algerian cities such as Algiers, rural migration and continuing housing shortages drive unsustainable urbanisation, as evidenced by Riadh and Osman (2021). This phenomenon is characterised by a demographic and spatial dynamic. Here, the centripetal movement from rural to urban areas intensifies the scarcity of adequate housing in the receiving urban centers.

Rapid urbanisation frequently surpasses the capacity of urban planning, thereby undermining sustainable development efforts. The use of dedicated management tools allows for monitoring, controlling, and benchmarking urban growth. Ultimately, it leads to improved planning and greater awareness of growth limits. In crisis contexts, territorial management provides a flexible, adaptive framework for negotiation and planning, and for integrating managerial techniques to foster resilient, equitable, and sustainable local governance (Repetti and Desthieux, 2006; Zhang *et al*., 2016).

The integration of structured frameworks and advanced quantitative tools in benchmarking methods significantly advances sustainable suburban development. The use of robust and reliable indicators allows the effective comparison, evaluation, and prioritization of urban strategies, while also encouraging participatory governance and facilitating the adaptation of best practices to specific local contexts. This approach mitigates the negative impacts associated with traditional patterns of suburban growth and supports inclusive and resilient urban environments (Sáez *et al*., 2020).

A threshold is the point at which actions produce irreversible effects and result in permanent changes to the system (Randolph, 2004; Zhang *et al*., 2016). Within a spatio-temporal continuum, a threshold is the maximum or minimum value permitted before an event or process becomes irrevocable, after which it is no longer possible to reverse a decision (Hocine, 2021). Exceeding this limit signifies danger or the onset of significant transformation, marking the system's transition into a fundamentally altered state (Berezowska-Azzag, 2005).

This article investigates the effects of growing urbanisation, focusing on thresholds that go beyond conventional sustainability analyses. It proposes a threshold index as a problem-solving tool, particularly for suburban municipalities such as Bordj-El-Kiffan in the wilaya of Algiers, which frequently encounter eco-sociological challenges linked to urban development (Perrin and Nougaredes, 2022). Within Algeria's administrative structure, Algiers is one of 58 wilayas and constitutes a first-order administrative territorial division.

Although sustainability evaluation tools vary, those focused on identifying and governing thresholds in suburban areas are limited. Notable examples include Malisz (1972), Hughes and Kozlowski (1968), Kennett (2006), Stossel *et al*. (2015), and Hocine (2021). The tool was implemented in the Bordj-El-Kiffan municipality to examine sustainability challenges and to determine threshold conditions for transformative growth in social-ecological systems.

1.1 Urbanisation crisis and challenges in assessing sustainability

Davis (1965) noted that North American and European cities adopt sustainability assessments during crises. They have pioneered sustainable land use, containment, and growth boundary strategies (Valencia Torres *et al*., 2021), setting normative thresholds for economic output, resource use, and social accessibility. The Mediterranean, Middle Eastern, and North African regions are experiencing crises in their own cities, and the rapid growth in southern Mediterranean cities intensifies issues due to socioeconomic and management challenges (PLAN BLEU – Centre d'activités régionales du PNUE/PAM, 2013). These encompass limit thresholds, vulnerability to threats, resource availability, socioeconomic development, and territorial management.

Various theoretical frameworks address unsustainable environmental and urban development. These include the unsustainability related to the IPAT equation (Alcott, 2012; Ehrlich and Ehrlich, 2009); 'biophysical carrying capacity' and 'social carrying capacity' (Arrow *et al*., 1996); and the 'acceptable threshold' and 'limits of development' (Randolph, 2004; Hocine 2021).

Information on how to reach certain thresholds is intended to guide stakeholders through an open decision-making process. The tool is then formalised as a 'codified indicators system for thresholds', addressed to a forum of participatory members, which allows them to set up a dashboard, without the framework of an observatory (Martin *et al*., 2009). Acceptance will have to come from the community because any action of planning, developing, or preserving the various capitals, including natural capital and its carrying capacity, will depend on the consensus (Hegarty and Maubrey, 2020).

Benchmarking locally, and then in a broader context to experiment on evaluation made it possible to later consolidate the acceptable limit values and their threshold character. Theoretical methods for identifying thresholds between evolutionary states were compared. The methodology in this study involved bibliographic research to synthesize theoretical knowledge about sustainability assessment, impacts, factors, capacities, limitations, and thresholds.

The findings suggest that causality loops involving triggers and amplifying factors contribute to sustainability assessment issues and crises. As urban systems exceed their limits and their carrying capacities decline, they reach a critical state that could lead to collapse if not given prompt attention (Gudlaugsson *et al*., 2021; Hocine, 2021).

To assess sustainability, 'carrying capacity' is a central key, as it sets the limit beyond which environmental pressure becomes unsustainable. However, while this concept suits ecological systems, socio-spatial contexts require more nuanced, judgment-based approaches (Becker *et al*., 1984). The use of development thresholds, linked to drivers of imbalance and social-ecological systems, is advocated. These dynamic thresholds more effectively capture stabilising or destabilising changes, especially within holistic social-ecological frameworks in suburban areas. Carrying capacity is important for assessing sustainability because it marks the threshold where human pressure on natural resources becomes unsustainable. However, this concept fits ecological systems better than socio-spatial contexts, which need more judgment-based approaches (Becker et al., 1984). The use of development thresholds, connected to drivers of imbalance and to social-ecological systems, is proposed to characterise stabilising or destabilising trends, particularly in holistic suburban environments, i.e.:

- Factors of imbalance: according to the IPAT model, it is the multiplicative combination of factors – population, per capita consumption and technology – that determines human pressure on the environment, creating the main factors of imbalances that society must manage to achieve sustainability (Alcott, 2012; Ehrlich and Ehrlich, 2009);
- Social-ecological system: These hybrid systems, which combine artificial infrastructure and ecological processes, redefine the traditional boundaries between the city and nature. The socio-ecosystem emerges from the integration of human activities as a major ecological force, modifying energy flows and biogeochemical cycles (Barles, 2020);
- Development threshold: In social-ecological systems, accelerated and amplified processes within a vicious cycle can generate a snowball effect and ultimately destabilise the system. The perception of a threshold or a floor/ceiling level limit, and the intervention of a decision processor, can lead to a negative loop of reflex regulation. (Berezowska-Azzag, 2005; Hocine, 2021).

1.2 Systemic approach to extract trigger factors and their thresholds

Following the establishment of these fundamental concepts, the 'general system paradigm', 'systemic causality', and 'tree representation' are employed to depict the critical progression of a metropolitan social-ecological system. The methodology developed in earlier research was used as the basis for this study (Hocine, 2021). Three methodologies and tools related to thresholds in engineering design and land-use planning are also examined to deepen the understanding of limits in sustainability assessment.

As in the previous study (Hocine, 2021), the thresholds and limits of development in territorial sustainable suburban planning will be examined, with particular emphasis on the role of indicators, observatories, and threshold dashboards as essential components of strategic and intelligent planning for enhanced dynamic territorial management. Insights were drawn from systems developed by Repetti and Desthieux (2006), Berezowska-Azzag (2013), and Hocine (2021). The methodology is built on the general framework established in an earlier publication (Hocine, 2021) to model positive feedback mechanisms and threshold crossings within circular causal frameworks as defined by de Rosnay (1975), Morin (1981), and Le Moigne (1994).

In his book *Le Macroscope*, de Rosnay (1975, p.79) contrasts circular causality with linear causality, asking: "Does the cause precede the effect, or is it the opposite?" He argues that the question cannot be answered definitively, noting that cause and effect appear to be intertwined. They cannot be dissociated in time. Causality circulates throughout the loop and leads to vicissitudes. For systems scientists, the vicious circle can be transformed into a virtuous one through balancing. The most illustrative examples are: (1) the flow of materials and the explosion of waste quantities; balancing by recycling reverses the trend towards a new balance; and (2) the explosion of CO_2 emissions and the pursuit of balance by their mitigation at source or increasing carbon sinks.

Morin (1981) further develops this by emphasising feedback in closed systems, which create their own causality and autonomy. Le Moigne (1994) ranked the complexity of evolving system models from 1 to 9, with level 4 involving the information system and level 5 involving the decision-making system. The threshold then allows the emergence of level 6; the decision processor will have to plan actions for compensation and stabilisation, drawing on the reserves of its memory. Memory is important for decision-making systems, and can notably give rise to dashboards and urban observatories. As previously stated by Hocine (2021), this approach has been applied in medical science research (Falissard, 2005) and developmental psychology (Vernon *et al*., 2015). This study identifies strategies to address unstable conditions in territorial, urban and social-ecological systems resulting from threshold exceedance within these circular causalities.

Unsustainable urban development causes a crisis when the socio-ecological system reaches its limits. A virtuous negative feedback loop counteracts a vicious positive feedback loop to restore system integrity. A heuristic mapping method was used to identify stabilising and destabilising elements, as well as threshold indicators, representing multiple factors in arborescent shapes (Kumar *et al*., 2013).

2. METHODOLOGICAL FRAMEWORKS FOR ASSESSMENT

To perform urban sustainability, it is necessary to merge theoretical constructs, practical methodologies, and three crucial elements: modelling the threshold system, selecting an experimental territory, and creating the S^3-TI assessment tool.

2.1 Modelling threshold systems

A tree model of threshold systems is developed on the basis of previously identified driving factors and threshold indicators. Five auxiliary systems are incorporated into the model: social, managerial, economic, environmental, and built environment. Systems theory is employed to construct a modelling tool capable of representing complex interdependent thresholds and variables that contribute to system stabilisation.

2.2 Selection of experimental terrain

Algiers, the capital and largest metropolitan region of Algeria is administratively divided into 57 municipalities. The Master Plan for 2035 or PDAU-2035 (*Plan Directeur d'Aménagement et d'Urbanisme*) outlines a CUSA – Central Urban System Area composed of 27 municipalities and nine additional urban systems (PDAU, 2015). This study focuses on the municipality of Bordj-El-Kiffan (Figure 1), which is part of the suburban areas due to recent population growth and housing constructions that require a rapid sustainability assessment.

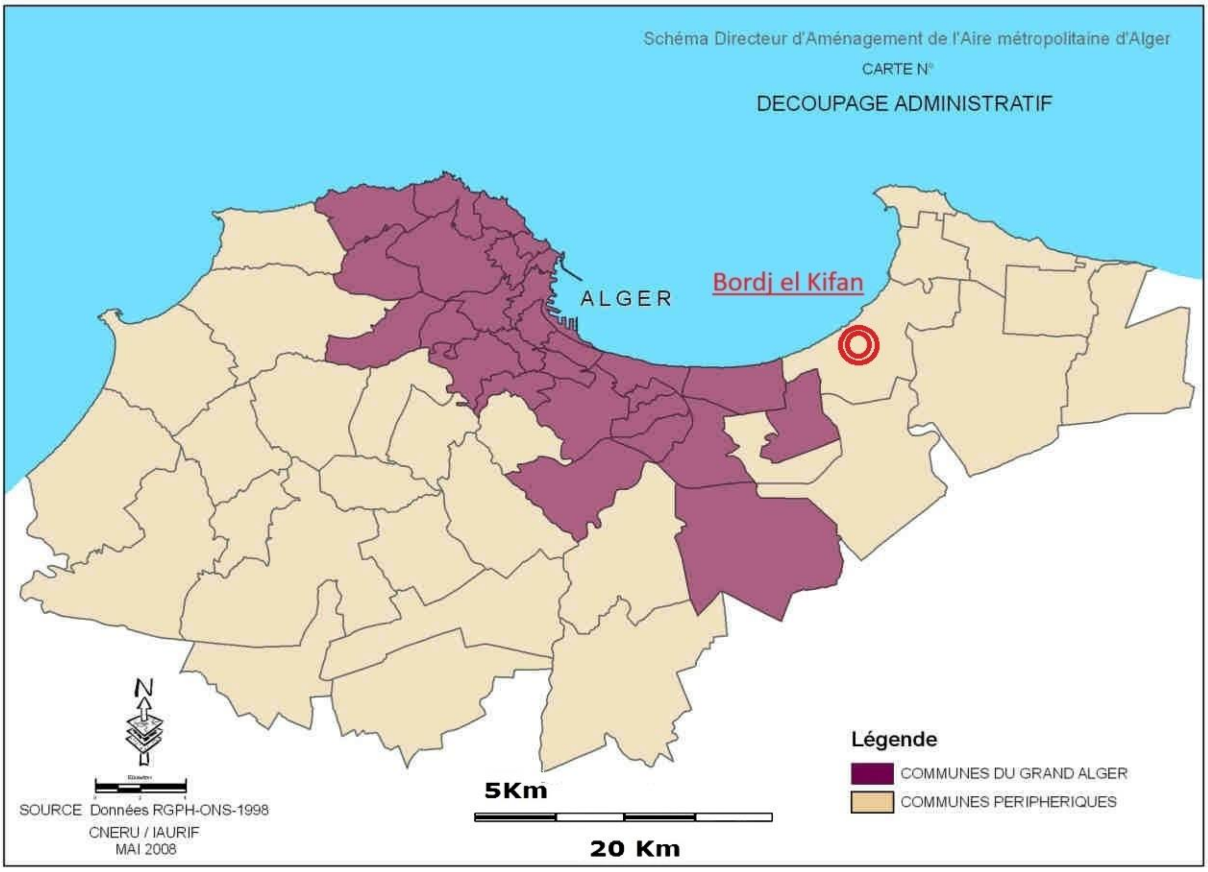

Figure1. Bordj-El-Kiffan municipality in suburban Algiers, East side of CUSA-central urban area system (Source: CNERU/IAURIF)

According to numerous studies, the development of the Algiers metropolis and its municipalities does not seem sustainable, demonstrated by:

- Ben-Hamouche and Medjitna (2020, p. 353) showed that "Algiers offers a striking example of the urbanisation trend and primacy observed in many African and Arab countries". From its origins, the city has been deeply shaped by the colonial era and by a capitalist economy largely rooted in rural–urban disparities.
- Tabti-Talamali and Baouni (2018) and Hocine (2021) have emphasised the redeployment of the population towards suburban areas in their research on residential mobility in Algiers. Within 50 km of the CUSA central urban system, an array of secondary cities has subsequently developed at a rapid pace.
- Semmoud (2003; 2015) examined how social inequality and mobility had contributed to maintaining the Bordj-El-Kiffan and other Algiers fringe municipalities in a state of uncontrolled development.

Bordj-El-Kiffan was also examined as part of the Algiers Bay development project study (Nouri-Boudiba *et al*., 2022). Bordj-El-Kiffan, originally a rural area containing 21.5 km^2, is located entirely on the fertile Mitidja plain, and bordered to the south by the hills of the Blida Atlas and to the north by the Mediterranean Sea. It features 8 km of beaches and tourist facilities. Because of the proximity to Algiers' industrial belt built in the

1970s, workers have taken over some abandoned fields and farmland to meet their need for affordable housing.

The 1990s, marked by terrorism, prevented the establishment of a sustainability assessment framework. The municipalities and the PDAU-2010 urban plan (approved in 1995) lack coherent development projects, and the rush to provide housing and facilities for residents and war refugees had a detrimental effect on the municipality's sustainability assessment (Baouni, 2016). Migration to the Algiers wilaya and its territory took on intensity during a period of anti-terrorism operations. Many inhabitants felt compelled, because of security threats in their regions, to move to denser, safer areas, hence Algiers. This situation affected a few poorly prepared municipalities in the Algiers wilaya, particularly Bordj-El-Kiffan. The resignations of the urban administration, the war on terrorism, and the expansion of uncontrolled urbanisation have worsened these problems (Hocine, 2021).

Bordj-El-Kiffan experienced major socioeconomic changes, urbanisation, and demographic increases between 1989 and 2015. Its population increased from 61,035 in 1987 to 147,715 in 2008. According to the prospective diagnosis of the PDAU-2035 urban plan, which includes a section on socio-economic aspects and scenarios projected a further rise to 191,144 inhabitants by 2015 (PDAU, 2015). The PDAU-2035 aims to analyse sustainability through 2035, integrating fringe territories into metropolitan dynamics. Semmoud (2015) highlighted the efforts made by the wilaya's administration to reduce disparities between central and suburban communities.

This resulted in infrastructure upgrades across three main categories: (1) local facilities and services (schools, health, post offices, etc.); (2) basic infrastructure (sanitation, water supply, and electricity); and (3) significant infrastructure developments, such as the east-west tramway line and coastal protection measures along an 8 km of BEK (Bordj-El-Kiffan) shoreline. Notable disparities between the BEK municipality and the CUSA underscore the importance of enhanced local sustainability assessments in the future (Figure 2).

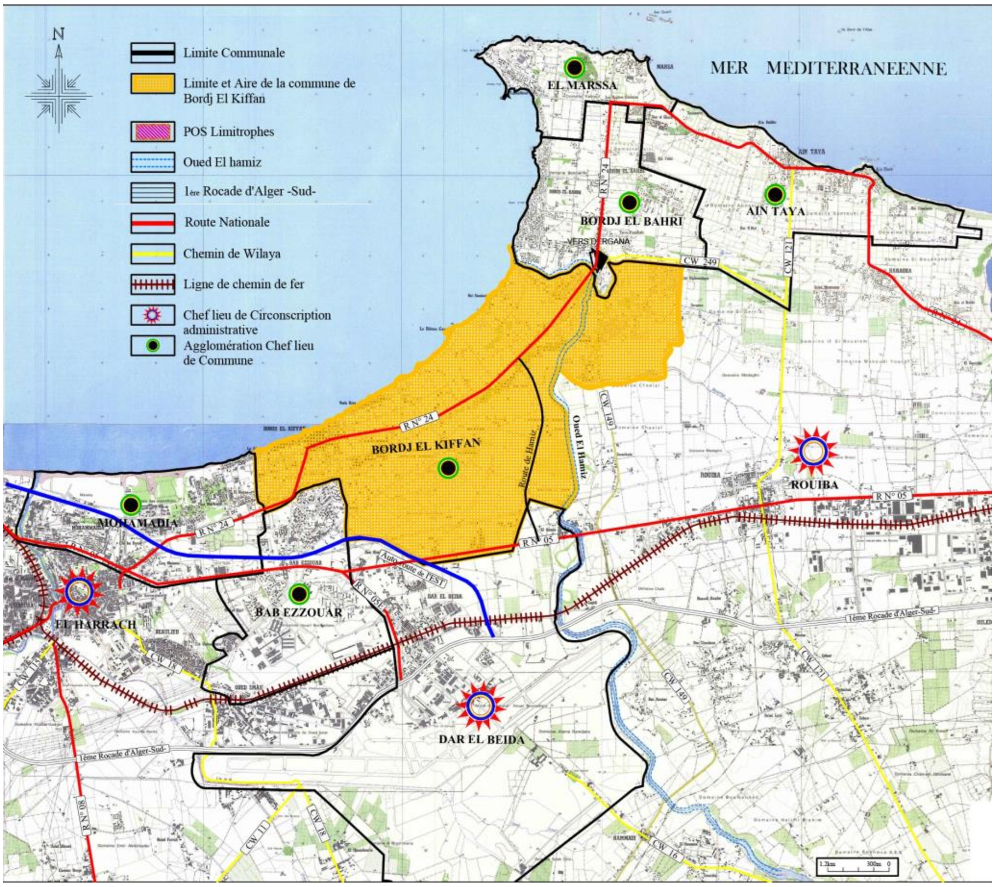

Figure 2. Bordj-El-Kiffan municipality along the Mediterranean coast and the national road n°24 (Source: PDAU, 2015, modified by Authors)

2.3 Proposing the S³-TI assessment tool

The threshold system was first modelled and subsequently tested in the suburban municipalities of Algiers, with Bordj-El-Kiffan selected as the case study. Before proceeding with the analysis, the municipality and its planning and management context are introduced, with emphasis on three key elements:

1. Gathering data on indicators and their accessibility in Bordj-El-Kiffan and Algiers wilaya and classifying them within preset subsystems;
2. Hypothetically assigning average points, referencing PDAU-2035 and the central urban system area (CUSA), composed of 27 Algiers municipalities; and
3. Providing comments on the findings and calculating and verifying achievement threshold levels.

This experimental method explains the reduction in urban quality in Algiers' fringes. The benchmark establishes a shared norm based on target indicators that preserves local urban system stability and prevents destabilisation. Internal, temporal, and spatial comparisons are employed by integrating territorial units; this is achieved by contrasting a suburban municipality with the central urban area of Algiers. The development of threshold indicators can be further refined by considering additional urban entities. Alternative benchmarking methods remain possible. The benchmark's ‘acceptable’ values align with the average values observed in the reference territory. Data is sourced mainly from PDAU-2035 (*PDAU*, 2015), governmental sources (DPAT, 2005; DPAT, 2015; ONS, 2011; ONS, 2012), and other researchers’ data (Berezowska-Azzag *et al*., 2015; Hocine, 2021).

3. RESULTS AND DISCUSSION

The benchmark was applied to a reference territory: the CUS (Central Urban System) area comprising (27 municipalities) as defined in PDAU-2035. It is an experimental assessment, based on the threshold values (floor and ceiling) derived from the CUS area by an aggregation procedure. The values and their weights were hypothesised to be acceptable. A participatory judgment of experts and/or citizens within the framework of an observatory or a dashboard could retain the threshold values.

As in the previous publication (Hocine, 2021), hypothetical average weights, a point-based weight scale, and a five-level colour code (1-acceptable, 2-critical low, 3-critical high, 4-unacceptable low and 5-unacceptable high) were set. Based on the average calculation formula (1) below, an acceptable threshold weight and a reasonable ideal constant were obtained, denoted as ‘What’ (hypothetical acceptable threshold weight):

$$What = \frac{1}{27} * \Sigma Wlci\left(i = 1, 2, 3, \ldots, 27\right) \qquad (1)$$

What: hypothetical acceptable threshold Weight
Wlc: locally collected Weight
i: central urban area 27 municipalities

The socio-ecological system is organised into five auxiliary systems. It is then followed by an experimental evaluation using 65 relevant and feasible threshold indicators specific to the township and municipal territory of Bordj-El-Kiffan. The assessment matrix is structured around the three core subsystems of sustainable development: economic, social, and environmental, with governance incorporated as a key enhancement to both the social and economic subsystems. Given its significance, the ecological aspect is divided into two subsystems: the natural environment and the built environment. The selection of the 65 indicators was guided by both their pressure attributes and data availability. The administration of the wilaya of Algiers validated all the data used. Tables 1-5 present the results:

- AS1: Social, 17 indicators (Table 1)
- AS2: Managerial, seven (7) indicators (Table 2)
- AS3: Economic, 16 indicators (Table 3)
- AS4: Environmental, 12 indicators (Table 4)
- AS5: Built-Environment, 13 indicators (Table 5)

The use of ratios and aggregation allows for the comparison between the BEK municipality and the CUS area without the results being skewed by their differences in size. Furthermore, as a suburban municipality, BEK is justified in seeking to evaluate the sustainability of its urban development. In the absence of an established system of indicators, internal benchmarking presents a viable approach. This method can use the central urban area as a reference for sustainable development and extend the analysis to suburban zones, enabling assessment even when standardised frameworks are lacking.

This represents an important milestone toward developing and refining a methodological framework for appraising urban sustainability at the local scale. The development of context-sensitive tools is part of this framework.

The calculated weight in the Bordj-El-Kiffan municipality is assigned a score, expressed in points according to formula (2) below (Hocine, 2021). The Acceptable Threshold weight – or the reference threshold for optimality – is set at a score of 100 points, fixed by the reference region.

$$Sl = \frac{Wlc}{What} \times 100\, points \qquad (2)$$

Sl: Local score In Bordj-El-Kiffan
Wlc: Locally Collected Weight
What = hypothetical acceptable threshold Weight
The optimal Score, in 27 CUSA municipalities is fixed at: 100 points

3.1 Assessment results

3.1.1 Thresholds indicators

The indicator's weight is always 100 points (Hocine, 2021), nevertheless, the weight of the threshold indicator can be expressed as follows:

– More (>) 100, the threshold is then called 'high' or,
– Less (<) 100, the threshold is then called 'low'

Table 1. Test assessment 'social' auxiliary system, acceptable threshold indicators (Source: Authors, according to: DPAT (2005), DPAT (2015), ONS (2011), ONS (2012), Berezowska Azzag et al. (2015), PDAU, (2015), Hocine, (2021))

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l **(point)**	S_{hat}	**High/low**
AS1.1: number of students by pedagogical division in primary education (No. /Div.)	35.0	29.5	**118.7**	**100**	(↑)
AS1.3: number of pupils per pedagogical division in secondary education (No. /Div.)	38.4	29.3	**131.0**		
AS1.14: public health care facilities capacity (U/10, 000 inhb.)	0.9	0.8	**112.5**		
AS1.16: capacity of hospitality facilities (U/ 10, 000 inhb.)	46.0	44.2	**103.3**		
AS1.2: availability educational places in high schools (No. /10,000 inhb.)	324.6	436.6	**74.3**		(↓)
AS1.4: vocational training centre density (U/ 10, 000 inhb.)	0.08	0.2	**40**		
AS1.5: ratio of trainees in vocational training centre (No. /10,000 inhb.)	17.5	31.0	**56.5**		
AS1.6: density of post office (U/10, 000 inhb.)	0.2	0.6	**33.3**		

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS1.7: telephone connection density (Con. No. /10,000 inhb.)	807	1781	**45.3**		
AS1.8: internet connection density (Con. No. /10,000 inhb.)	72.2	359.3	**20**		
AS1.9: publishing house density (U/10, 000 inhb.)	0.1	0.9	**11.1**		
AS1.10: density of listed heritage buildings (U/10, 000 inhb.)	0.1	0.4	**25**		
AS1.11: density of cultural facilities: public libraries, youth and cultural centres (U/10,000 inhb.)	0.2	0.6	**33**		
AS1.12: capacity in preschool places (No. /10,000 inhb.)	12.8	25.2	**50.8**		
AS1.13: capacity of sport facilities (U/10,000 inhb.)	0.6	1.1	**54.5**		
AS1.15: pharmacy capacity (U/10, 000 inhb.)	1.9	3.2	**59.3**		
AS1.17: Travel agency capacity (U /10,000 inhb.)	0.5	1.2	**41.6**		

Table 2. Test assessment 'Governance' auxiliary system, acceptable threshold indicators (Source: Authors, according to: DPAT (2005), DPAT (2015), ONS (2011), ONS (2012), Berezowska Azzag et al. (2015), PDAU (2015), Hocine, (2021))

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS2.1: Municipality (local government) provision (U /10,000 inhb.)	0.15	0.2	**75**	100	(↓)
AS2.2: Capacity of local government officer (No. /10,000 inhb.)	74.4	92.2	**80.7**		
AS2.3: Operating expenses per inhabitant (Dzd. / Inhabit)	3835	5141	**74.6**		
AS2.4: Capacity in neighbourhood association (No. /10,000 inhb.)	2.9	7.1	**40.8**		
AS2.5: Subsidy for local associations per inhabitant (Dzd. / Inhabit.)	158.4	473.4	**33.4**		
AS2.6: Civil defence station provision (U /10,000 inhb.)	0.10	0.11	**90.9**		
AS2.7: Capacity in sanitation worker (No. /10,000 inhb.)	8.9	21.2	**42.0**		

Table 3. Test assessment 'economic' auxiliary system, acceptable threshold indicators (Source: Authors, according to: DPAT (2005), DPAT (2015), ONS (2011), ONS (2012), Berezowska Azzag et al. (2015), PDAU (2015), Hocine, (2021))

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS3.1: annual population increase, 2008-2015 (%/ year)	5.2	1.2	**433.3**	**100**	(↑)
AS3.3: level of uneducated women in the total female population (%)	17.9	15.8	**113.3**		
AS3.16: number of industry economic entities (U /10,000 inhb.)	30.1	28.3	**106.3**		
AS3.2: level of the population over 65 (%)	6.5	10	**65**		(↓)
AS3.4: level of women with university education (%)	8.1	14.5	**55.9**		
AS3.5: level of working women in the female population (%)	16.2	25.1	**64.5**		
AS3.6: level of active male population in the male population (%)	72.9	74.5	**97.9**		
AS3.7: level of uneducated male population (in global male population) (%)	9.7	13.1	**74**		
AS3.8: inhabitants receiving social assistance (U /10,000 inhb.)	62.3	91.3	**68.2**		
AS3.9: household rate with a second home (%)	2.8	4.6	**60.9**		
AS3.10: households equipped with washing machines (%)	39.2	50.3	**77.9**		

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS3.11: households equipped with computers (%)	17.3	25.8	**67**		
AS3.12: level of household energy consumption (10^3 Kwh/annum)	33	60	**55**		
AS3.13: total economic entities (U /10,000 inhb.)	284.8	351.3	**81.1**		
AS3.14: number of service economic entities (U /10,000 inhb.)	78.7	115.3	**68.3**		
AS3.15: number of business economic entities (U /10,000 inhb.)	112.3	191.8	**58.6**		

Table 4. Test assessment 'environmental' auxiliary system, acceptable threshold indicators (Source: Authors, according to: DPAT (2005), DPAT (2015), ONS (2011), ONS (2012), Berezowska Azzag et al. (2015), PDAU (2015), Hocine, (2021))

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS4.1: Land area subject to landslide hazard (Ha)	4000	1400	**285.7**	**100**	(↑)
AS4.2: Land area subject to flood hazard (ha)	2500	1000	**250**		
AS4.3: Urban protected land against Urb. Dev. (ha /10,000 inhab.)	120	40	**300**		
AS4.7: Availability of LPG (liquefied petroleum gas) filling station (U /10,000 inhb.)	0.2	0.1	**200**		
AS4.10: Number of chronic respiratory patients (No. /10,000 inhb.)	2.7	2.6	**103.8**		
AS4.11: Number of water drilling sites per km^2 (No. /km^2)	1.5	0.4	**375**		
AS4.4: Availability of wooded (forest) land (ha /10,000 inhab.)	4.9	8.5	**57.6**		(↓)
AS4.5: Public parks and gardens (U /10,000 inhb.)	0.3	1.4	**21.4**		
AS4.6: Availability of urban green areas (m^2/ inhab.)	0.1	10.2	**1**		
AS4.8: Share of housing connected to gas (%)	41.8	69.9	**59.8**		
AS4.9: Number of households with a private car (%)	35.7	41.1	**86.9**		
AS4.12: Level of housing connection to the sewerage network (%)	75.7	88.8	**85.2**		

Table 5. Test assessment 'built-environment' auxiliary system, acceptable threshold indicators (Source: Authors, according to: DPAT (2005), DPAT (2015), ONS (2011), ONS (2012), Berezowska Azzag et al. (2015), PDAU (2015), Hocine, (2021))

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS5.1: Sustainability assessment area per inhabitant (m^2 / inhab.)	102	92.9	**109.8**	**100**	(↑)
AS5.3: Evolution rate of sustainability assessment area from 2011 to 2035 (% / year)	1.05	0.8	**131.3**		
AS5.4: Annual evolution rate of the housing stock, 1987-2015 (% / year)	15.1	6.4	**235.9**		
AS5.7: Annual evolution of new housing program for 2015-2035 period (% / year)	1.8	1.6	**112.5**		
AS5.2: Population density in sustainability assessment area (Inhab. / ha)	102	108	**94.4**		(↓)
AS5.5: collective housing rate in housing stock (%)	20.1	43.2	**46.5**		
AS5.6: Housing density in sustainability assessment area in 2015 (Houses / Ha)	18.2	23.1	**78.8**		
AS5.8: Business park surface area per inhabitant in 2015 (m^2 / inhab.)	1.3	4.5	**28.9**		
AS5.9: Number of households with a private vehicle (%)	35.7	41.1	**86.9**		

Threshold Indicator (code & unit)	W_{lc}	W_{hat}	S_l (point)	S_{hat}	High/low
AS5.10: Availability in 1st and/or 2nd order street linear (Km/ 10,000 inhab.)	1.0	3.5	**28.6**		
AS5.11: Availability of public transport (bus, tramway) lines (U. / 10,000 inhab.)	0.1	1.4	**7.1**		
AS5.12: Availability of public transport (bus, tramway) seats (U. / 10,000 inhab.)	340	550	**61.8**		
AS5.13: Availability of public transport stations: bus, train, metro, tramway (U. / 10,000 inhab.)	0.2	0.5	**40**		

3.1.2 Aggregate threshold indicators

Aggregations are essential to represent threshold indicators for each auxiliary system and the entire social ecological system. The Weighted Sum Method (WSM) is employed to aggregate the various trigger factors (causes and effects) arising from the multi-component and auxiliary systems. This method is renowned for its mathematical simplicity and is common to mathematical multi-criteria analysis. Employing a top-down method following a thematic approach, numerous criteria were combined, assuming transitive judgments (e.g., a > b, b > c, then a > c) (Hocine 2021). The total weight score is expressed in points and is obtained using the formula (3), below:

$$Slag = \left[\frac{\Sigma Sli}{\Sigma Shat}\right] * 100 \, (i = 1, 2, \ldots, n) \qquad (3)$$

Slag: Local aggregated weight score In Bordj-El-Kiffan, i: indicators and/or aggregated indicator
Sli: Local scores In Bordj-El-Kiffan (i=1,2,...,n)
Shat = hypothetical acceptable threshold Score, in 27 CUSA municipalities, fixed at 100 points

Next, threshold indicators were aggregate from the five auxiliary systems, distinguishing between default values (low) and excess values (high) in Table 6.

Table 6. Threshold indicators aggregated by auxiliary system and global (Source: Authors)

Auxiliary systems	***Sl*** (point)	***Shat*** (point)	***Slag*** (point)
AS1: Social	**116.3 (↑)**	**100**	**183.4 (↑)**
AS3: Economic	**217.6 (↑)**		
AS4: Environmental	**252.4 (↑)**		
AS5: Built-Environment	**147.4 (↑)**		
AS1: Social	**41.9 (↓)**		**54.2 (↓)**
AS2: Management	**62.5 (↓)**		
AS3: Economic	**67 (↓)**		
AS4: Environmental	**52 (↓)**		
AS5: Built-Environment	**47.4 (↓)**		

3.1.3 Threshold representations

The assessment objective is to inform a broad audience about the attainment of at least five threshold levels: acceptable, critical (low, high), and unacceptable (low, high). A result meter was created, based on the work of Stossel et al. (2015) and Hocine (2021), to display the score points for each threshold indicator and for the aggregated threshold indicator. The result meter shows both the measured (local) value and the optimal (threshold) value, along with the indicator weight (score in points) and the optimal weight (100 points). The three main situations of reaching threshold values, their points score, and cursor colour code are as follows:

- Acceptable: 75 < P.S. < 125 - ☺
- Critical, (2.1) Low value: 50 ≤ P.S. ≤ 75-😐, (2.1) High value: 125 ≤ P.S. ≤ 150-😐
- Unacceptable, (2.1) Low value: 0 ≤ P.S. ≤ 50-☹, (2.1) High value: P.S. > 150-☹

In the Result meter, the point index highlights three situations when thresholds exceed the floor or ceiling values. Hypothetically the levels were fixed. The colour code comprises three complementary colours: green, orange, and purple, representing the five states: acceptable, critical (low, high), and unacceptable (low, high), as defined earlier.

Threshold indicators can be depicted in the result meter (Figure 3), showing both high and low values, aggregated by the auxiliary system and globally for the entire social ecological system.

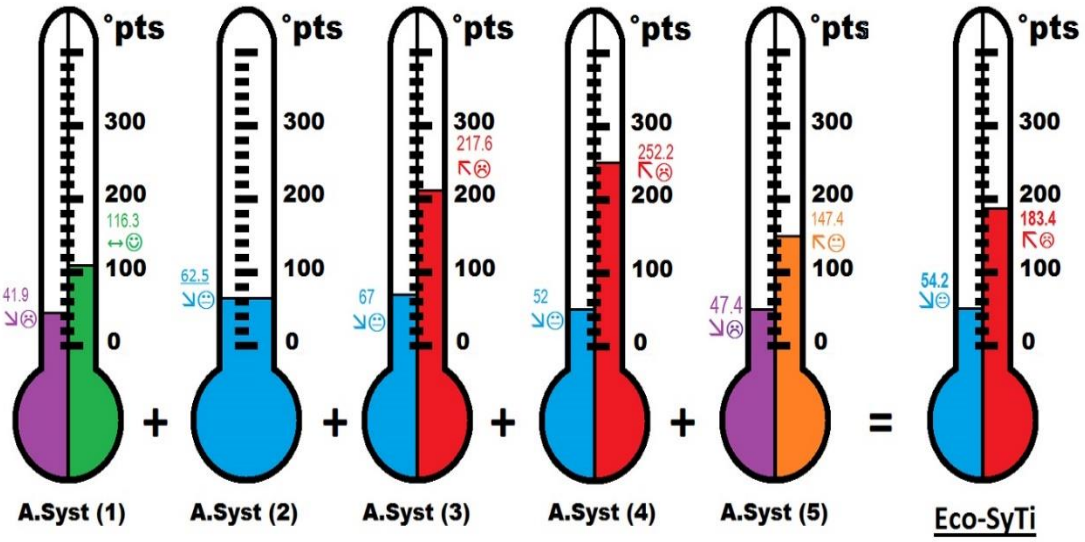

Figure 3: Systemic threshold index result meter aggregated by auxiliary system and globally for all the social ecological-system (Source: Authors)

3.2 Discussion of results

Urban development, particularly in major cities and metropolitan areas, should prioritise environmental sustainability. When urban growth exceeds critical or unacceptable thresholds, municipal management must assess and notify residents groups. Considering this assessment and the definition of critical or unacceptable thresholds, some strategies are presented for the sustainable and balanced development of Bordj-El-Kiffan.

3.2.1 Social auxiliary system

Multiple threshold indicators (AS1.3, AS1.6, AS1.7, AS1.8, AS1.11, AS1.12, and AS1.13) highlight substantial limitations in providing essential urban services at the neighbourhood level, including secondary education, sports, culture, youth, early childhood services, a postal service, and ICT services across social, physiological, and operational aspects.

For instance, the UN's Sustainable Development Goal 4 advocates for inclusive and equitable quality education throughout all primary and secondary schools. However, should secondary education be limited only to those in central districts? It is argued that the population of Bordj-El-Kiffan, as in other suburban municipalities, should have adequate access to educational opportunities. The educational facilities considered here are limited to the secondary level. Higher education institutions (universities, research centers) serving broader metropolitan and regional networks beyond municipal boundaries were not included in this evaluation.

This assessment highlights substantial shortfalls in the facilities and equipment available within Bordj-El-Kiffan's urban context, particularly evident in indicators AS1.9, AS1.10, and AS1.7, which point to a pronounced lack of cultural infrastructure.
To revitalise certain regions and reduce over-tourism in central areas, there is a greater focus placed on developing heritage initiatives, focusing more on rural, archaeological, and intangible resources. These approaches are labelling and developing new alternatives to traditional tourism by utilising local specialties, agricultural products, and landscapes.

3.2.2 Management auxiliary system

The assessment identifies states with threshold excesses as follows:

- Citizen involvement tends to be weak, especially when local organisations receive extra support from local authorities. (See threshold indicators AS2.4 and AS2.5);
- Weak management services, particularly in the collection of waste, as evidenced by the threshold indicator AS2.7.

Bordj-El-Kiffan residents and the local government must recognise the importance of smarter urban management. This involves the implementation of threshold dashboards, observatories, and indicators, followed by dynamic territorial management techniques such as monitoring, tracking, and benchmarking (Repetti and Desthieux, 2006; Hocine, 2021). Modern urban planning, as described by Berezowska-Azzag (2013), has evolved into a project with three key components: encompassing social justice, economic performance, and environmental sustainability (Hocine, 2021). Through participatory and collaborative means, these components have evolved into a local government. The responsible, efficient, and strategic shaping of the future of urban development necessitates engineering, innovation, and a vision of urban intelligence (Berezowska-Azzag, 2013). Intelligence and intelligent system control represent advanced levels of system complexity (Le Moigne, 1994).

3.2.3 Economic auxiliary system

The evaluation of this system has revealed unacceptable threshold crossings in terms of both the rate and magnitude of population growth, as indicated by AS3.1. Economic development inadequately engages women and the elderly, as reflected in indicators AS3.2, AS3.4, and AS3.5. Additionally, access to economic opportunities that would bring life on par with CUSA's 27 municipalities remains significantly challenging, as indicated by threshold indicators AS3.11 and AS3.12.
This unsustainable development scenario runs counter to the United Nations Sustainable Development Goals and 2030 Sustainable Development Goals. This specifically contradicts the definition of sustainable development in the Commission's 2017 report, which abolishes all forms of poverty internationally (UN, 2017).

3.2.4 Environmental auxiliary system

This assessment highlights the municipality of Bordj-El-Kiffan's challenges in protecting and upgrading its freshwater, groundwater, and green agricultural soil resources. Key components of the water cycle and territorial hydrogeology (such as watercourses and aquifers) face management limitations, as indicated by threshold indicators AS4.1, AS4.2, and AS4.11.

Threshold indicators AS4.4, AS4.5, and AS4.6 regarding population access to urban green spaces and wooded areas reveal critical circumstances. Although unused soil resources have potential for urban use, they are primarily employed in agriculture. Conversion of large-scale agricultural land is a widespread tendency in suburban areas, posing a danger to the stability of the eco-social system.
To fulfil the land requirements of the Bordj-El-Kiffan municipality, the PDAU-2035 established a 169 ha urban land reserve as one of its components. Additionally, a 533 ha restricted construction area was designated into three primary categories (PDAU, 2015; Hocine, 2021):

1. Agri-park: a perimeter aimed at stopping urbanisation, a kind of city-scale green belt (373 ha);
2. More major agricultural land is being protected and added to the Algiers wilaya's Agricultural Land Reserve: 73 ha; and
3. Natural area related to the wetland of the El Hamiz River (87 ha) and shoreline facing the Mediterranean Sea (41 ha)

Initiatives for natural areas, agri-parks and agricultural reserves have yet to begin, although urbanisation programs have generated considerable areas for housing operations. Long-term urbanisation schemes would divert prime agricultural soils from their intended use for urbanisation.

3.2.5 Built-environment auxiliary system

From a built-environment perspective, the threshold indicators signal high urban growth expected by 2035 within the new urban perimeter (PDAU, 2015; Hocine, 2021), with indicators AS5.3 and AS5.4 having already been at critical levels since 1987.

Mobility conditions in the area have seen little improvement, largely due to the absence of an integrated multimodal transport network to accommodate urban growth that is primarily housing-focused. Threshold indicators AS5.10, AS5.11, AS5.12, and AS5.13 underscore deficiencies in the road system, particularly regarding the development of first- and second-order roads, which signals a suboptimal transport network.

Urban sprawl and design constraints drive people to rely on private vehicles despite growing congestion (Newman and Kenworthy, 2006). The Bordj-El-Kiffan municipality has had a tramway in place since 2010. Given its population and urban growth, it stands to gain even more from this type of transportation. A densification process, as well as functional diversification and urban intensification along the corridor in line with Transit-Oriented Development (TOD) theory (Wood, 2021), can enhance the municipality's urbanisation model. This assessment highlights Bordj-El-Kiffan's challenges in establishing an independent sustainability model. Although PDAU-2035 aims to limit farmland conversion, it has still allocated a 169 ha land reserve for housing and amenities in the municipality (*PDAU*, 2015).

To preserve the natural urban growth potential and safeguard natural resources, especially land, the Bordj-El-Kiffan municipality must consider two key strategies: (1) densifying its urban fabric and (2) postponing urbanisation to other sites within the regional urban network where potential exists (Hocine, 2021).

The 'Systemic Thresholds Index' suburban sustainability assessment tool can be used to efficiently mobilise human, financial, and managerial resources, while also being an early warning system. Communities worldwide are continuously developing innovative approaches to sustainable development and resilience building. The Bordj-El-Kiffan municipality appears capable of implementing this strategy.

The S^3-TI assessment tool raises awareness of the importance of establishing and adhering to thresholds and facilitating arbitration and compromises. It enables effective management of climate change impacts, resource scarcity, and fulfillment of human and community development needs. As in the previous publication (Hocine, 2021), its integration is envisioned as part of an assessment and monitoring tool in future municipal land use and development plans, enhancing the quality of the planning process and promoting local sustainable development.

4. CONCLUSIONS

After conducting this study, the threshold-based assessment modelling revealed several limitations:

- The database used mainly reflects past conditions, which may not fully reflect the evolution over time of threshold exceeding processes.
- The evaluation model needs to be made stronger by performing sensitivity analyses and replacing the current list of sixty-five (65) indicators with equally relevant ones.
- The third limitation relates to the relationship between the five (5) threshold levels: acceptable, critical (low, high), and unacceptable (low, high), as well as their weight

(expressed in points), which represents an average value. Typically, these elements can be generated through focus groups and brainstorming sessions in an urban decision-makers' workshop or an urban/metropolitan observatory (Hocine, 2021). However, due to unavailability, an empirical simulation study was substituted.

– Internal benchmarking was selected to construct the evaluation database indicators. Specifically, this means spatial comparison by aggregating territorial entities (municipalities, wilaya averages, etc.). Further refining this comparison by incorporating sub-municipal urban organisations – such as homogeneous or structural units – could yield more detailed and nuanced findings.

Our development approach prioritises qualitative aspects, such as urban comfort, social well-being, and environmental balance, over quantitative growth alone. Sustainability assessment allows for effective decision-making and adaptability to stress and crises. Addressing negative human impacts is emphasised through impact assessment, which is essential for averting environmental crises while preserving resource availability. The impact magnitude depends on the factors exceeding the thresholds. The system's carrying capacity is directly linked to its acceptability. Evaluating thresholds by participatory members establishes acceptance, often via observations integrated into master plans (Ohnuma et al., 2022; Repetti and Desthieux, 2006).

The essential concept here is the threshold for sustainability and other social-ecological system components. At critical levels, their overruns can cause irreparable damage. Considering this, sustainability assessment planning tools should include a monitoring mechanism, informed by diagnoses and assessments, and a dashboard, to communicate potential development crises. The S^3-TI tool's development leads to sustainable and intelligent planning for suburban areas. The objective is to integrate the S^3-TI assessment tool into urban planning practice in Algerian cities. With the ongoing revision of the Algerian Act, university researchers are tasked with contributing to its enhancement. This addresses challenges in Algiers, potentially, other Algerian, African, and global south cities. Careful attention is essential, given the issue's sensitivity and limited human skills in planning suburban municipalities.

By the end of the 21st century, the global surface will cross the 1.5°C and 2°C warming thresholds. There are potential future developments of the S^3-TI assessment tool for mitigation and attenuation strategies. They are fundamental components of urban planning practice, helping to create more sustainable and resilient cities, in reference to the UN SDG Goal 13 "Climate Action" (UN, 2017).

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