IJEMS | SCIENTIFIC ARTICLE

Knowledge Management Index for Better Climate Change Management: A Case Study in the Egyptian Petroleum Sector

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Climate change presents significant challenges to organizations, requiring adaptation and mitigation strategies grounded in climate-related knowledge and technological innovation. The petroleum sector faces increasing regulatory and environmental pressures. In response, this study introduces the Climate Change Knowledge Management Index (CKI), a novel metric designed to assess climate knowledge preparedness by integrating energy, environmental, and knowledge management systems. The CKI provides a standardized framework for evaluating how petroleum organizations manage, formalize, and apply climate-relevant knowledge in strategic decision-making. The index was applied to two Egyptian petroleum companies with differing knowledge management approaches, revealing notable differences in climate resilience. The company with formal knowledge management practices scored 0.283, demonstrating stronger integration, lower emissions, and more informed climate decisions. In contrast, the comparison company scored 0.133. Both scores were benchmarked against an optimal value of 0.606. These findings highlight the role of structured knowledge management in strengthening climate resilience and supporting strategic choices across high-emission sectors. The CKI equips decision-makers with a practical tool to evaluate and improve knowledge governance, particularly in developing economies. Its diagnostic capacity offers valuable guidance for sectors transitioning toward sustainable operations.

Key Words: climate change management, knowledge management index, strategic decision-making, energy management systems, environmental management systems, petroleum sector https://doi.org/10.70908/2232-6022/18.53-82

INTRODUCTION

Applying a Knowledge Management System (KMS) is pivotal in enhancing organizational performance, particularly in the petroleum sector, which operates under complex environmental and operational constraints (Abdelwhab Ali et al. 2019). Organizations in this industry must comply with stringent environmental regulations while maintaining efficient and uninterrupted operations. To meet these dual demands, a KMS is essential for capturing, preserving, and sharing critical institutional knowledge (Orsato et al. 2017). Beyond protecting technical know-how, an effective KMS enhances adaptability by linking employee expertise with structured organizational systems (Yang et al. 2024). Previous research has emphasized the strategic role of KMS in improving climate change management and operational resilience (Ahmed and Elshazly 2021).

The Egyptian petroleum sector stands at a critical intersection between economic growth and environmental vulnerability. Beyond its economic significance, the sector's exposure to climate-induced disruptions, ranging from infrastructure damage due to sea-level rise to operational inefficiencies caused by temperature extremes, poses challenges beyond traditional risk management frameworks (Shaltout et al. 2015; Shaltout 2019). In response, there is a growing emphasis on aligning operational practices with international climate commitments, notably Egypt's ratification of the Paris Agreement (United Nations 2015) and its national efforts toward achieving Sustainable Development Goals (SDGS) 7 and 13 (United Nations 2015). Addressing these challenges demands a strategic shift: organizations must embed knowledge-driven resilience mechanisms that interlink environmental stewardship, energy management, and institutional learning within their core business models.

The Egyptian petroleum sector plays a strategic economic role, contributing approximately 24% of the national GDP while simultaneously facing acute climate risks, such as coastal flooding and rising sea temperatures (Shaltout et al. 2015). This dual vulnerability necessitates the adoption of integrated management systems that balance operational continuity with climate adaptation imperatives. However, existing frameworks often fail to adequately represent these unique sectoral challenges, reinforcing the need for more targeted climate knowledge management initiatives.

At the macroeconomic level, the Knowledge Economy Index (KEI), developed by the World Bank Institute, provides a benchmark for evaluating how countries utilize knowledge to drive innovation and sustainability (World Bank 2009). However, for industries exposed to climate-related risks, such as the petroleum sector, there is an increasing need to integrate KMS with Energy Management Systems (EnMS) and Environmental Management Systems (EMS). Janus (2016) emphasizes that embedding KMS within environmental strategies is vital for building long-term resilience.

The theoretical foundations of Knowledge Management (KM) in high-risk industries draw heavily from Nonaka's (1994) SECI model, which identifies four knowledge conversion processes: socialization, externalization, combination, and internalization. This model explains how frontline operational expertise (e.g., emission reduction techniques) becomes institutionalized through documentation and training in climate change contexts.

Recent global developments have further accelerated the integration of knowledge systems with sustainability efforts. The growing reliance on Environmental, Social, and Governance (ESG) reporting frameworks, such as those developed by the Global Reporting Initiative (2021) and the World Economic Forum's stakeholder capitalism metrics (World Economic Forum 2020), compels petroleum companies to demonstrate tangible knowledge management practices related to environmental stewardship. Furthermore, international financial institutions increasingly link credit ratings and investment decisions to demonstrated climate resilience, emphasizing the strategic importance of formalized climate knowledge systems within corporate governance structures (Global Reporting Initiative 2021; World Economic Forum 2020). International financial institutions increasingly link credit ratings and investment decisions to demonstrated climate resilience, further elevating the strategic importance of formalized climate knowledge systems within corporate governance structures.

This integration has been gaining attention in Egypt. Implementing ISO 50001 EnMS has led to measurable improvements in energy efficiency and reductions in greenhouse gas emissions. (Salaheldin et al. 2015). Complementing this, structured decision-making tools such as the Analytic Hierarchy Process (AHP) and Fuzzy AHP have proven valuable for prioritizing sustainability projects across environmental, economic, and social pillars (Galal and Moneim 2015; Salaheldin 2009; Salaheldin et al. 2015). While KEI and AHP-based tools exist, none integrate KMS, EnMS, and EMS into a unified framework for sector-specific climate resilience assessment, particularly within the petroleum sector. The CKI introduced in this study is the first diagnostic tool to combine these management systems into a unified, operationalized framework, enhancing climate resilience.

This study addresses this gap by introducing the Climate Change Knowledge Management Index (CKI), a novel framework designed to evaluate how organizations manage climate-related knowledge by integrating KMS, EnMS, and EMS practices. The CKI leverages international standards and structured methodologies, such as AHP, to provide a multi-criteria evaluation system tailored to the complexities of the petroleum sector.

Given its strategic economic role and growing vulnerability to climate-related risks, the Egyptian petroleum sector is a fitting context for this study. Cross-sectoral collaboration is vital in this landscape, as Penca et al. (2024) argue that building transdisciplinary competencies is essential for developing actionable solutions to sustainability challenges. Furthermore, the scientific contributions of Shaltout et al. (2015) and Shaltout's (2019) work, particularly on sea-level rise and sea surface temperature trends, underscore the urgent need to translate environmental data into operational strategies.

This research also builds upon broader regional initiatives to promote green transformation in industrial sectors across North Africa. Recent national strategies, such as Egypt's Integrated Sustainable Energy Strategy (ISES) 2035 (Ministry of Electricity and Renewable Energy 2016), emphasize the importance of coupling energy and environmental management systems with knowledge-based innovation as essential for advancing sustainable development. Thus, the Climate Change Knowledge Management Index (CKI) addresses immediate organizational needs and contributes to Egypt's broader national objectives toward achieving a greener, more resilient economy (Ministry of Electricity and Renewable Energy 2016; United Nations 2015).

Accordingly, this study aims to develop and validate the CKI as a practical, scalable tool for enhancing climate resilience in the Egyptian petroleum sector.

LITERATURE REVIEW: THEORETICAL AND METHODOLOGICAL FOUNDATIONS

While the introduction outlined the rationale for integrating KM into climate resilience efforts, this section comprehensively reviews the theoretical and methodological foundations supporting the CKI's development. KMS has long been recognized as a catalyst for innovation and adaptability, particularly in complex, high-risk industries like the petroleum sector (Abdelwhab Ali et al. 2019). The World Bank's Knowledge Economy Index (KEI) provides a foundational framework for assessing national knowledge infrastructures, highlighting how effective knowledge use contributes to long-term sustainability (World Bank 2009). However, the KEI lacks the operational granularity necessary to evaluate KM performance within individual organizations or specific sectors.

Building on this global perspective, national-level studies have increasingly emphasized the importance of formalized knowledge systems in specific sectors. Previous research emphasized KMS's strategic role in supporting climate change adaptation and operational continuity in Egypt's energy sector. Ahmed and Elshazly (2021) highlight the urgent need to formalize tacit knowledge flows into structured systems for resilience building. In parallel with knowledge management development, structured decision-making methodologies have emerged as critical tools for evaluating sustainability priorities.

Researchers and practitioners increasingly rely on structured decision-making methods to prioritize and assess complex environmental and operational criteria. Among these, the Analytic Hierarchy Process (AHP), developed by Saaty (1980), remains predominant. In the Egyptian context, Galal and Moneim (2015) applied AHP to develop a sustainability index that balances economic, environmental, and social considerations, an approach conceptually aligned with the CKI introduced in this study.

While AHP offers a solid foundation for prioritization, emerging hybrid models have further enhanced decision-making under uncertainty. However, while AHP provides a structured prioritization method, its reliance on subjective pairwise comparisons introduces potential bias. This study mitigates such risks by employing expert validation techniques and consistency ratio checks during the matrix development.

Hybrid models such as Fuzzy AHP (Salaheldin 2009) have gained traction in enhancing decision-making under uncertainty. Notably, Salaheldin (2009; Salahedin et al. 2015) applied both AHP and Fuzzy AHP to prioritize energy improvement projects and evaluate the performance of energy management systems in Egyptian industrial facilities. These studies illustrate how integrating KMS with structured frameworks such as EnMS and EMS can support more sustainable and efficient operations. Building on this foundation, the CKI extends these tools to evaluate knowledge management maturity in the context of climate resilience. However, operationalizing climate knowledge resilience also requires addressing fundamental challenges related to knowledge conversion processes.

Knowledge Conversion Challenges in Climate Resilience

The theoretical foundations of knowledge management in high-risk sectors, such as the petroleum sector, heavily rely on Nonaka's (1994) SECI model, which outlines four knowledge conversion processes: socialization, externalization, combination, and internalization. While socialization (informal tacit knowledge sharing) predominates frontline climate adaptation practices, formalizing this knowledge remains an ongoing challenge. The 'know-how paradox,' where critical safety or operational expertise resists documentation (Orsato et al. 2017), along with the knowledge attrition linked to aging workforces (Abdelwhab Ali et al. 2019), presents significant barriers.

Empirical studies reinforce this gap: ISO 30401-certified KMS implementations have been shown to improve climate resilience metrics by 18–22% in comparable sectors (Janus 2016). However, Salaheldin et al. (2015) found that approximately 63% of climate-related operational knowledge remains tacit in the Egyptian petrochemical sector, underscoring the critical need for structured knowledge conversion systems. These insights align with findings from Ahmed and Elshazly (2021), which emphasized KM maturity gaps in Egyptian energy firms and highlighted the necessity of integrated KM benchmarks to support sustainability transitions. External regulatory frameworks also shape climate knowledge management practices alongside internal knowledge dynamics.

Regulatory Context and Sectoral Imperatives

Egypt's national 2030 sustainability agenda mandates the integration of Environmental Management Systems (EMS) and Energy Management Systems (EnMS) across industrial sectors. However, as noted in Ahmed and Elshazly (2021), no standardized framework for benchmarking Knowledge Management System (KMS) maturity exists against these environmental standards. The CKI addresses this regulatory gap by offering a scalable diagnostic tool that aligns knowledge governance with broader sustainability mandates, enhancing compliance and organizational resilience. Beyond organizational and regulatory considerations, integrating ecological knowledge has become increasingly vital for comprehensive climate resilience.

Ecological Context for Climate Knowledge Integration

Beyond traditional organizational frameworks, recent studies highlight the ecological dimensions of climate knowledge integration. Mangrove ecosystems, for example, play a critical role in carbon sequestration, offering natural solutions to rising CO_2 levels (Awad et al. 2023). Integrating such environmental insights into CKM systems enables petroleum organizations to align operational strategies with environmental sustainability goals. The CKI encourages incorporating ecological data into strategic planning processes, supporting more holistic approaches to climate resilience.

In summary, existing literature lacks a sector-specific framework to assess how petroleum organizations structure, prioritize, and utilize climate-related knowledge. The CKI is designed to fill this gap by drawing on existing models like AHP, EnMS, and EMS and aligning them within a unified KMS-based evaluation framework. This innovative tool is both a diagnostic instrument and a strategic guide for organizations striving for knowledge-driven climate resilience.

METHODOLOGY

Methodology Description

The research methodology primarily relies on analyzing questionnaires using structured techniques. It begins with designing a draft questionnaire based on the study objectives. The draft was reviewed through structured interviews with field experts to enhance its accuracy.

After revisions, the finalized version was distributed online to reach the maximum number of targeted respondents. Additionally, to ensure the clarity and reliability of the survey, we followed three key validation steps: expert review, cognitive interviewing, and usability testing, as recommended by Beatty et al. (2020).

TABLE 1 Hierarchy of Key Performance Indicators

(1)	(2)	(3)	(4)	(5)	(6)
EnMS	IEN	E1	Percentage of employees having Awareness sessions of the EnMS	I_{11}	Max
		E2	Energy intensity	I_{12}	Min
		E3	Energy efficiency midterm target [%] (3–5 years)	I_{13}	Max
EMS	IEV	N1	Percentage of employees having Awareness sessions of EMS	I_{21}	Max
		N2	Percentage of direct and indirect GHG emissions from sources owned or controlled by the company and from the generation of acquired and consumed electricity, steam, heat, or cooling (collectively referred to as 'electricity') (Scope 1 & 2) [tons]	I_{22}	Min
		N3	Percentage of all indirect GHG emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions (Scope 3) [tons]	I_{23}	Min
KMS	IKM	K1	Percentage of employees having Awareness sessions of the KMS	I_{31}	Max
		K2	The percentage of climate–related ideas collected from employees	I_{32}	Max
		K3	Percentage of climate–related converted knowledge (implicit to explicit)	I_{33}	Max

NOTES Column headings are as follows: (1) main system, (2) pillar, (3) KPI, (4) KPI descriptions, (5) ID for each KPI, (6) the optimal directions. Appreciation of GHG refers to Greenhouse Gases.

The structured interviews involved asking all participants the same questions in a fixed order (Rashidi et al. 2014). These questions cover the level of importance of each Key Performance Indicator (KPI) in relation to the others in each pillar listed in table 1.

Structured interviews were employed to ensure consistency in data collection. This approach allowed for a standardized set of questions, facilitating comparability across responses and reducing potential biases in data interpretation (Rashidi et al. 2014).

The methodology was implemented through nine steps:

1. Initial design of the first questionnaire.
2. Structured interviews to adjust the first questionnaire.
3. Designing the first questionnaire and distributing it by using Google Forms.
4. Collect and analyze the results.

5 Calculate the weight of each pillar.
6 Define three KPIS for each pillar.
7 A second structured interview with only decision-makers to calculate the weight of KPIS.
8 Define the formula to calculate CKI.
9 Apply this formula to two different companies.

The CKI was applied to two companies within the Egyptian petroleum sector. One has implemented a KMS in compliance with ISO 30401, while the other has not, allowing for a clear comparison of the index's performance under different KM conditions. Both companies had previously adopted energy management systems, ensuring a fair basis for comparison. Access to performance data in this sector is typically restricted, which further shapes the scope of the application. Given these constraints, a focused two-company application was considered appropriate for the initial validation of the CKI. The goal at this stage was not to generalize findings, but to assess the index's practical relevance. Broader applications are recommended in future research to confirm its robustness across the sector.

The questionnaires include quality control questions to measure the respondents' seriousness and relevance to the field of research.

The first questionnaire was built to measure the weight of the three main pillars using 15 questions, as seen in Appendix 1. Then, a structured interview with six experts was conducted: an operations manager in a petrochemicals company, a quality manager of an oil refining company, an energy efficiency manager in a petrochemicals company, the exploration manager in an upstream company, and the head of the oceanography department at Alexandria University. This structured interview omits three questions, adds two new questions, and clarifies three of the existing questions. The final questionnaire consists of 14 questions, including personal information, nature of work, and technical information (Appendix 2).

The adjusted form of the first questionnaire was distributed using Google Forms and was valid for two weeks (from January 22, 2023 to February 5, 2023). This questionnaire was only distributed within the Egyptian petroleum sector and was valid for all its categories and disciplines. The quality control strategy accepts only the responses that complete their information and answers.

The second survey started with a structured interview technique designed only for organizational decision-makers. It was performed to identify the specific weight of each KPI inside each main pillar.

The questionnaire design strategy involved using the AHP, as described by Saaty (1980). This method was employed to calculate the
 weights of each pillar and all its corresponding KPIS.

In addition, the Inconsistency Index (ICI) was used as a quality control factor. First, a Consistency Ratio (CR) is used to measure how consistent the judgments have been relative to large samples of purely random judgments. If the CR is over 0.1, then the judgments should be considered untrustworthy, as explained by Salaheldin et al. (2015).

Analytical Hierarchy Process (AHP)

The AHP, developed by Thomas Saaty in 1980, is a widely used decision-making tool based on pairwise comparisons. It assigns relative weights to key factors, in this study, EnMS, EMS, and KMS, through a structured comparison process (Saaty 1980). Pairwise comparisons provide numerical values for the relative importance of each factor, helping determine the priority vector for further calculations.

This study used the first survey to evaluate the three main pillars, and the second survey was to assess the KPIS across three hierarchical levels. This approach ensures rational decision-making by comparing two elements at a time without external influence (Saaty 1990).

Weighting Criteria Using AHP

AHP was applied to determine the relative importance of criteria and sub-criteria, using a nine-point scale to rank their significance (Saaty 2008). Six pairwise comparison matrices were created to evaluate the main hierarchy (EnMS, EMS, and KMS) (Ramík 2020). This method is further supported by Salaheldin (2009), who utilized FAHP for bid evaluations in petrochemical projects, and Salaheldin et al. (2015), who applied AHP for energy efficiency optimization in the petrochemical sector.

The evaluation comparison scale used to assess the relative importance between factors follows Saaty's (1980) nine-point scale in the Analytic Hierarchy Process (AHP). Experts used Saaty's scale, where 1 indicates equal importance and 9 represents extreme importance. Intermediate values 3, 5, and 7 correspond to moderate, strong, and very strong importance, respectively. A detailed summary of the entire comparison scale is provided in Appendix 2.

TABLE 2 Pairwise Comparison Matrix for AHP Calculations

	A	B	C
A	1	a	a
B	1/a	1	1/b
C	1/a	c	1
Sum			

The pairwise comparison process adheres to Saaty's (1980) AHP methodology, wherein criteria are evaluated relative to one another to derive a consistent priority vector. Table 2 presents the structural form of the comparison matrix employed in this study.

The decision makers' judgment may be inconsistent; therefore, it was necessary to analyze the inconsistency of the pairwise comparison. This was achieved by calculating the ICI and Inconsistency Ratio (ICR). The preference ratings given by the decision-makers were considered consistent if the ICR was less than or equal to 0.1. The ICI and ICR were calculated using equations (1) and (2), respectively.

$$\text{ICR} = \frac{\lambda_{\max} - n}{n-1}, \tag{1}$$

$$\text{ICI} = \frac{\text{ICR}}{\text{RI}}. \tag{2}$$

Where n is the size of the comparison matrix, $\lambda_{\max}$ is the eigenvalue, and RI is the random index depending on the matrix size. The pairwise comparison is to be conducted by many decision-makers to arrive at the relative weight for each criterion. The weights obtained from the subjective judgment of each decision maker are aggregated using the geometric mean as per equations (3) and (4):

$$\boldsymbol{w}_{1ij}^{m} = \left(\prod_{m=1}^{n} \boldsymbol{w}_{1ij}^{m}\right)^{\frac{1}{n}} \text{ For all } i \text{ and } j, \tag{3}$$

$$\boldsymbol{w}_{kl}^{m} = \left(\prod_{m=1}^{n} \boldsymbol{w}_{kl}^{m}\right)^{\frac{1}{n}} \text{ For all } k \text{ and } l. \tag{4}$$

Where $\boldsymbol{w}_{1ij}^{m}$ indicates the weight $\boldsymbol{w}_{1ij}$ given by the m^{th} decision maker, and n represents the number of decision-makers involved in setting the criteria preferences.

In the current study, the geometric mean prioritizes all elements. The advantage of the geometric mean is that it gives equal weight to each number in the set, which can be helpful when calculating growth rates or rates of return. The disadvantage is that it cannot be used with negative numbers (Vogel 2022) which is not considered in our study.

The *t*-test is applied to measure the main differences between the geometric means. The *t*-test is a statistical test used to identify whether

the difference between two means is significant or not (Liang et al. 2019).

The CKI Hierarchy

The CKI is measured in terms of three main pillars represented: (a) EnMS, (b) EMS, and (c) KMS. To assess the degree of conformance concerning each pillar, several KPIS consider each pillar's main aspects. Thus, a hierarchy of KPIS is suggested as shown in table 1.

The first level of the hierarchy includes the three pillars of EnMS, EMS, and KMS.

The second Level in the hierarchy represents the KPIS' identification (ID), definition, and improvement direction, which are presented in table 1. All these indicators have one level of subcategories and are thus labelled I_{kl}. Two suffixes identify each indicator: the first (k) indicates the main pillar, and the second (l) indicates the KPIS.

The following criteria are considered in selecting the relevant indicators (Galal and Moneim 2015):

- Measurability: This can be measured using quantitative or qualitative data.
- Ease of access to data is based on readily available data in the facility; no extra effort is needed for data collection.
- Non-dimensionality: This is indicated as a ratio of the same units to facilitate the aggregation of all indicators into a single dimensionless value.
- Relevancy: relates directly to the dimensions of sustainability.

The definition and formula of each indicator will be discussed as follows.

The EnMS Pillar (IEN)

It measures the extent to which the organization controls its energy consumption, including promoting awareness and managing consumption practices. In addition, this pillar evaluates the organization's economic approach to managing its climate change knowledge.

The KPIS are:

- Percentage of employees having awareness sessions of EnMS:

$$I_{11} = \frac{\textit{no. of employees have energy management system awareness sessions}}{\textit{total number of employees}} \quad (5)$$

- Energy intensity

$$I_{12} = 1 - \frac{\textit{\$ value of eneregy consumption}}{\textit{\$ value of total inputs of production}} \quad (6)$$

- Energy efficiency midterm target [%] (3–5 years)

$$I_{13} = \frac{\textit{\$ value of eneregy consumption}}{\textit{\$ value of total inputs of production}} \quad (7)$$

The EMS Pillar (IEV)

It measures the extent to which emissions from any organizational process are controlled. This pillar also measures the number of employees aware of this system and its effect. The key performance indicators are:

- Percentage of employees having Awareness sessions of EMS:

$$I_{21} = \frac{\textit{no. of employees have environment management system awareness sessions}}{\textit{total number of employees}} \quad (8)$$

- Percentage of direct and indirect GHG emissions from sources owned or controlled by the company and from the generation of acquired and consumed electricity, steam, heat, or cooling (collectively referred to as 'electricity') (Scope 1 & 2) [tons]:

$$I_{22} = 1 - \frac{\textit{total direct and indirect emissions (Scope 1 \& 2)}}{\textit{weight of annual emissions quantity produced (All Scopes)}} \quad (9)$$

- Percentage of indirect GHG emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions (Scope 3) [tons]:

$$I_{23} = 1 - \frac{\textit{Total indirect emissions (Scope 3)}}{\textit{weight of annual emisions quantity produced (All Scopes)}} \quad (10)$$

The KMS Pillar (IKM)

It measures the value added by sharing knowledge and its efficiency. This represents the social effect of key performance indicators that reflect the well-being of the laborers and their development. The key performance indicators are:

- Percentage of employees having Awareness sessions of KMS:

$$I_{31} = \frac{\textit{no. of employees have knowledge management system awareness sessions}}{\textit{total number of employees}} \quad (11)$$

- Percentage of climate-related collected ideas from employees annually:

$$I_{32} = \frac{\textit{no. of climate related ideas}}{\textit{total number of ideas}} \quad (12)$$

- Percentage of climate-related converted knowledge (implicit to explicit):

$$I_{33} = \frac{\textit{no. of converted climate related knowledge}}{\textit{total number of converted knowledge}} \quad (13)$$

Calculating the CKI

The calculation of the CKI is achieved in two steps. First step, the KPIS within each of the three pillars are algebraically added using their respective weight to obtain a single measure for each. The three resulting measures are the IEN, IEV, and IKM, which are obtained using equations (14–16), respectively.

$$I_{EN} = \sum_{i=1}^{3} \boldsymbol{w}_{1i} I_{1i} \quad (14)$$

$$I_{EV} = \sum_{i=1}^{3} \boldsymbol{w}_{2i} I_{2i} \quad (15)$$

$$I_{KM} = \sum_{i=1}^{3} \boldsymbol{w}_{3i} I_{3i} \quad (16)$$

Second step, the three resulting pillars are considered as three components of a vector in a three-dimensional space to arrive at the CKI as per equation (17):

$$\mathrm{CKI} = \sqrt{I_{EN}^2 + I_{EV}^2 + I_{KM}^2} \quad (17)$$

RESULTS

The study initially collected 52 responses during the questionnaire's time frame. However, two responses were removed due to incomplete information, and an additional nine responses were excluded because they were not employed in the petroleum sector. Moreover, five responses were rejected based on the quality control criterion, specifically due to a high inconsistency ratio. As a result, 36 valid responses were retained for analysis.

First Questionnaire (Target Group Whose Occupation Is Related to the Petroleum Sector)

The survey of 36 Egyptian petroleum professionals revealed a significant operational disparity: downstream operations (oil refining, petrochemicals, gas processing plants) accounted for 86% of responses (n = 31), with representation from oil refining (42%, n = 13), petrochemicals (32%, n = 10), natural gas processing (13%, n = 4), and service providers in O&M, HSE, and maintenance (13%, n = 4). In contrast, (Oil & Gas Exploration and Production) represented only 14% (n = 5).

This distribution highlights the strong representation of processing/manufacturing roles and potentially lower engagement in upstream operations with climate change knowledge initiatives. The findings suggest:

- Upstream professionals may be less aware of or engaged with climate initiatives.
- Targeted awareness programs are needed for exploration/production teams.
- Further research should investigate specific knowledge gaps.

Notably, gender analysis showed no significant differences in response patterns across sectors.

The Upstream Category

The results indicate that, according to industry sectors and the upstream category, workers in this sector tend to place greater importance on awareness about energy management and climate change knowledge than on other drivers (EnMS, EMS, and KMS).

The upstream category has five responses:

- All participants are male, as women are rarely represented in upstream fields.
- 4 out of are 5 in the age range 35–45, 1 out of 5 is in the age range 45–55.
- All participants hold middle management positions.
- All participants work in operational fields.

TABLE 3 The Geometric Mean Values for the Upstream and Downstream Categories

Pillar	Upstream		Downstream	
	Geometric Mean	Normalized	Geometric Mean	Normalized
IEN	0.2659	0.3924	0.2459	0.3647
IEV	0.2830	0.4176	0.3038	0.4506
IKM	0.1288	0.1900	0.1246	0.1848

As shown in table 3, employees working in the upstream segment of the petroleum industry reported that EMS had the highest influence on their knowledge about climate change, with a share of 41.76%. The EnMS came next, accounting for 39.24% of the impact. Meanwhile, KMS was seen as having a minor role, contributing only 19.00% to their understanding. These results suggest that EMS and EnMS primarily shape climate-related knowledge in upstream operations, while KMS practices may still need further attention.

The Downstream Category

The downstream category is divided into refining, petrochemicals, natural gas, and services industries (table 3). The results indicate that workers in this sector tend to place greater importance on awareness about environmental management and climate change knowledge than on other drivers (EnMS, EMS, and KMS).

The downstream category has 31 responses:

- 2 out of 31 are female, and 29 out of 31 are male.
- 4 out of 31 are in the age range 25–35, 18 out of 31 are in the age range 35–45, 8 out of 31 are in the age range 45–55, and 1 out of 31 is in the age range above 55.
- 8 out of 31 are senior-level, 16 out of 31 are middle management level, and 7 out of 31 are top-level management.

According to the results presented in table 3, most workers in the downstream segment identified EnMS as the most influential factor in shaping their climate change knowledge, with a score of 45.05%. The EMS followed at 36.46%, while KMS had the least reported impact at 18.47%. These findings highlight the central role of energy and environmental systems in promoting climate awareness in downstream operations and suggest an opportunity to improve KMS's contribution in this area.

The segmentation of respondents based on their field of work, in-

TABLE 4 Fields of Work

Pillar	(1)	(2)	(3)	(4)	(5)	(6)	(7)
IEN	0.4175	0.1828	0.7480	0.6168	0.2087	0.2045	0.2024
IEV	0.4186	0.6543	0.1542	0.2622	0.4959	0.7379	0.4778
IKM	0.1639	0.1628	0.0979	0.1210	0.2954	0.0577	0.3198

NOTES Column headings indicate the geometric field of each field as follows: (1) Operations, (2) Maintenance, (3) Energy Management, (4) Quality Assurance, (5) Health, Safety and Environment (HSE), (6) Management, and (7) Administration.

cluding operations, maintenance, and management, reveals that the majority are from operations (50%), followed by maintenance and condition monitoring (8%), quality assurance (8%), health, safety, and environment (HSE) (8%), administration (8%), laboratory (3%), energy management (8%), and management (6%).

The responses from operations personnel indicate no significant difference between the impact of EnMS and EMS on climate change knowledge, as demonstrated in table 4. Responses from the maintenance field of work, HSE, management, and administration personnel were consistent with expectations, given that their work largely adheres to standards, and the only field with standardized regulations is environmental management. The responses from energy management professionals aligned with expectations, reflecting their focus on their specialized field. Quality assurance staff shared a similar perspective, with heightened concern for EMS.

Regarding the managerial level, middle management positions comprise 58.33% of the respondents, senior-level roles make up 22.22%, and top-level management constitutes 19.44%. Lastly, the geometric mean is normalized for the filtered data, and the analysis reveals that the EMS exerts the most significant influence on climate change awareness within the organization (43.92%), followed by the EnMS (37.43%). The KMS exhibits the least impact, contributing 18.64%.

Accordingly, the second questionnaire was conducted with decision-makers through a structured interview to determine the weights of indicators for each pillar mentioned above.

Second Questionnaire (Target Group: Decision-Makers Working in the Egyptian Petroleum Sector)

The second questionnaire was a structured interview conducted with 10 decision-makers working in the Egyptian petroleum sector to evaluate

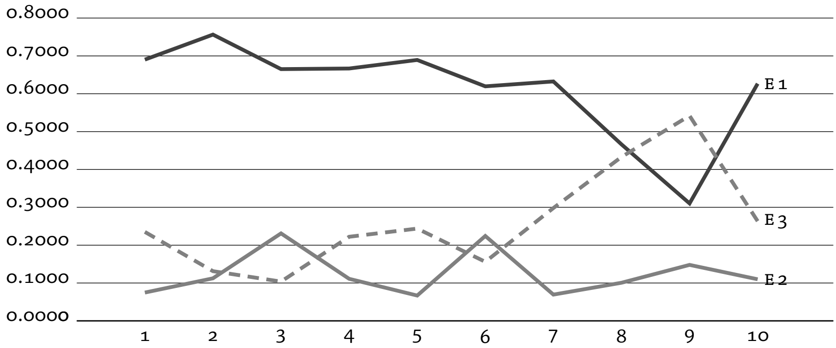

FIGURE 1 KPIS of EnMS

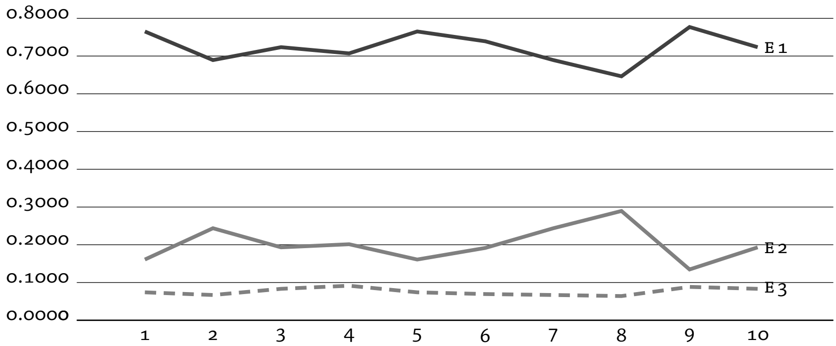

FIGURE 2 EMS's KPIS

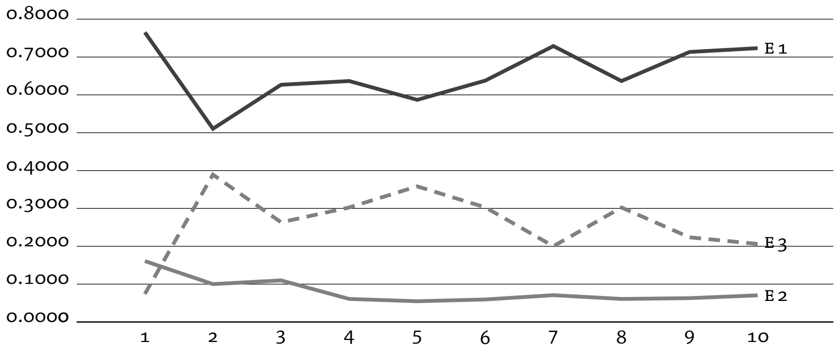

FIGURE 3 KMS's KPIS

the weight of the Key Performance Indicators (KPIS) that may affect the knowledge of each pillar in this study (table 1).

First, the main KPIS and their weights for the EnMS are listed in table 6 and shown in figure 1. The results highlight the greater significance of raising employee awareness compared to other KPIS. Secondly, for the EMS, table 6 lists the selected main KPIS and their weights. The results show the importance of raising employee awareness over the other KPIS as seen in figure 2.

Finally, the main selected KPIS and their weights for the KMS, as listed in table 6, show that raising awareness among employees is considered more important than the other KPIS, as illustrated in figure 3.

Final Weights

The final weights for each KPI (refer to table 1 for descriptions) were derived through AHP pairwise comparisons. For EnMS, employee awareness sessions (E1) received the highest weight (0.63), followed by energy intensity (E2) and midterm targets (E3) at 0.12 and 0.25, respectively. A similar weighting pattern emerged for EMS (N1 = 0.73) and KMS (K1 = 0.67), confirming the importance of awareness-building in climate knowledge governance (table 6).

FRAMEWORK IMPLEMENTATION

The proposed framework was implemented to evaluate the CKI of two petroleum sector companies in Alexandria, Egypt. Both companies are certified with four quality certificates: ISO 9001, ISO 14001, ISO 50001, and ISO 45001; however, Company 1 also holds ISO 30401. The companies employ between 1,000 and 3,000 staff members.

Selecting two companies with varying levels of KMS maturity enabled testing the framework under different real-world conditions. This diversity enhanced the validation process by demonstrating the CKI's ability to assess organizational readiness across different operational contexts. Moreover, this choice balanced methodological rigor with practical constraints, such as data accessibility within the petroleum sector.

Data Collection

The data required to calculate the various indicators were collected from the two companies and are presented in table 5. Notably, the data needed for calculating the indicators does not require special data collection, as they are part of the standard data recorded for any plant. These align with other information typically required for different quality systems in use, meaning there is no additional burden associated with the sustainability assessment.

TABLE 5 Data Collected from the Two Companies

Data description	1	2
Number of employees who attended EnMS awareness sessions	850	100
Total number of employees	1100	2200
Dollar value of energy consumption ($)	320	500
Dollar value of total inputs of production ($)	1450	1700
Number of employees who attended EMS awareness sessions	400	350
Weight of annual emissions quantity produced (All Scopes)	560	1300
Total direct and indirect emissions (Scope 1 & 2)	450	700
Total indirect emissions (Scope 3)	300	450
Number of employees who attended KMS awareness sessions	200	10
Total number of ideas collected from employees annually for devel.	185	20
Number of climate-related ideas collected from employees annually	45	10
Total number of converted knowledge (implicit to explicit)	60	15
Number of climate-related knowledge conversions.	12	2

NOTES The (Dollar value $) indicates the financial value of the data.

Calculations

Utilizing multiple existing data sources – such as ISO 50001 audit reports, ISO 14001 compliance documentation, and internal training records – enabled effective data triangulation. This cross-verification enhanced both the reliability and validity of the collected information, reducing the potential for bias and ensuring that KPI evaluations accurately reflected actual operational practices rather than isolated documents or individual reports.

All quantitative indicators (e.g., energy consumption, emissions data) were validated against the companies' ISO 50001 and 14001 audit reports to ensure reliability. For employee awareness metrics (KPIS K1, N1, E1), data were cross-checked with training attendance records to ensure consistency. However, Scope 3 (indirect emissions, KPI N3) relies on supplier self-reports, which is a known limitation in the petroleum sector (Galal and Moneim 2015). This potential bias was mitigated by averaging the responses of multiple decision-makers, thereby enhancing data reliability.

Despite the structured approach, specific challenges were encountered during data collection. Access to detailed operational data was sometimes restricted due to confidentiality concerns. Additionally, inconsistencies were observed in how different departments documented their environmental or energy-related knowledge practices. These challenges required careful clarification through follow-up interviews and reinforced the need to triangulate findings across multiple sources.

The verified data were systematically mapped to the corresponding KPIS. Where discrepancies existed among documents, interviews, and observations, expert judgment and consensus validation techniques were employed to adjust scoring. This ensured that the final CKI values accurately reflected documented practices and operational behaviors within each organization.

While the CKI framework was successfully applied, several operational challenges emerged that warrant discussion. First, variations in departmental awareness of knowledge management protocols complicated the aggregation of accurate data, especially regarding tacit-to-explicit knowledge conversions. Second, resistance to sharing sensitive environmental and energy information delayed parts of the validation process, highlighting an underlying cultural barrier to open knowledge exchange in petroleum organizations.

Despite these challenges, the implementation demonstrated the framework's flexibility and adaptability. Utilizing pre-existing ISO-related data significantly reduced the burden of new data collection, proving that the CKI can be integrated with existing quality management systems without requiring major procedural overhauls. This characteristic is critical for encouraging adoption within resource-constrained or operationally conservative sectors.

Furthermore, the cross-functional involvement of operational, HSE, energy, and management personnel enriched the quality of the collected insights. This suggests that CKI assessments are most effective when designed as multidisciplinary exercises rather than siloed technical evaluations. Future applications could benefit from formalizing this cross-functional collaboration early in the assessment process to streamline data collection and enhance diagnostic accuracy.

Table 6 shows that the CKI was calculated for the companies under study using the methodology described in equations (1) through (16), based on the data from table 5. The Climate Change Knowledge Management Index (CKI) was mathematically computed according to equation (17), where the summation includes all selected KPIS. This approach ensures that indicators with higher strategic importance, as determined by expert judgment, have a greater influence on the final CKI score.

A benchmark value of 0.606 was established based on evaluations

TABLE 6 Final Calculations

KPI	w	Company 1		Company 2		Ideal	
		I	$w \times I$	I	$w \times I$	I	$w \times I$
I_{11} (E1)	0.6313	0.7727	0.4878	0.0455	0.0287	1.0000	0.6313
I_{12} (E2)	0.1206	0.7793	0.0940	0.7059	0.0851	1.0000	0.1206
I_{13} (E3)	0.2481	0.2207	0.0548	0.2941	0.0730	1.0000	0.2481
I_{21} (N1)	0.7260	0.3636	0.2640	0.1591	0.1155	1.0000	0.7260
I_{22} (N2)	0.1979	0.1964	0.0389	0.4615	0.0913	1.0000	0.1979
I_{23} (N3)	0.0761	0.4643	0.0353	0.6539	0.0498	1.0000	0.0761
I_{31} (K1)	0.6719	0.1818	0.1222	0.0046	0.0031	1.0000	0.6719
I_{32} (K2)	0.0786	0.2432	0.0191	0.5000	0.0393	1.0000	0.0786
I_{33} (K3)	0.2495	0.2000	0.0499	0.1333	0.0333	1.0000	0.2495
IEN	0.3743	0.1826		0.0107		0.2363	
		0.0352		0.0319		0.0451	
		0.0205		0.0271		0.0929	
		0.2383		0.0699		0.3743	
IEV	0.4392	0.1160		0.0507		0.3190	
		0.0171		0.0401		0.0870	
		0.0155		0.0219		0.0334	
		0.1485		0.1127		0.4392	
IKM	0.1864	0.0228		0.0006		0.1252	
		0.0036		0.0073		0.0147	
		0.0093		0.0062		0.0465	
		0.0356		0.0141		0.1864	
	CKI	0.2830		0.1334		0.6064	
	CKI/Ideal	46.67%		21.99%			

by an expert panel. This value reflects a realistic upper limit for mature organizations operating within the petroleum sector and represents the expected integration level of knowledge, energy, and environmental management systems under current best practices.

The CKI score for the evaluated company that applies the KMS was 0.208, equivalent to 46.67% of the theoretical maximum (0.208 ÷ 0.606 × 100). In contrast, the CKI score for the other company was 0.133, representing 21.99% of the theoretical maximum.

The first company's higher CKI score indicates stronger formalization and integration of climate knowledge within its operational strategies. Conversely, the second company's lower score suggests fragmented or informal practices, particularly regarding knowledge sharing and environmental sustainability initiatives.

This dimensionless index serves multiple purposes: it functions as a performance benchmark, a tool for tracking longitudinal improvement, and a comparative metric within the sector. Beyond the aggregate CKI scores, a deeper analysis of individual KPI trends provides additional insights into each organization's specific focus areas and strategic behaviors.

The resulting scores indicate a considerable opportunity to improve the organization's climate knowledge management practices and progress toward alignment with best-practice standards. The results reveal a clear pattern: companies place greater emphasis on training employees about climate issues (awareness sessions) than on technical indicators like energy use or emissions. They prioritize these training programs three to nine times more than technical objectives.

This behavior aligns with knowledge management theories that emphasize externalization and socialization phases (Nonaka 1994), where cultivating awareness and shared understanding precedes technical system optimization.

The results indicate that Egyptian petroleum companies prioritize culturally preparing their teams for climate action rather than merely setting strict targets. This finding is consistent with Salaheldin et al.'s (2015) conclusion that changing workplace habits is often more complicated than achieving technical goals.

FUTURE WORK

Future research could examine the applicability of this framework in other sectors, particularly those that are resource-intensive or heavily reliant on knowledge management. Tracking the CKI over time could provide valuable insights into how organizations mature in managing climate-related knowledge. Moreover, raising awareness about the strategic value of KM, not just as a tool for documentation but as a key driver of resilience, should be prioritized.

Future studies could also explore the potential for sectoral benchmarking by applying the CKI across industries such as mining, chemical manufacturing, or logistics, where climate resilience is increasingly vital. Conducting cross-sector comparisons would validate the index's adaptability and help refine its weighting structures to accommodate sector-specific challenges.

In addition, future researchers may investigate the integration of digital technologies, such as artificial intelligence and blockchain, into CKI assessments. Leveraging digital tools could enhance data collection accuracy, real-time monitoring, and transparency in climate knowledge governance.

Furthermore, integrating Geographic Information Systems (GIS) into future CKI assessments could provide critical spatial insights into climate vulnerabilities, resource allocation, and operational risks. Companies could develop geographically targeted knowledge management strategies by mapping organizational facilities against climate exposure data, such as flood zones, heat stress indices, or coastal erosion maps. This spatial integration would enhance the CKI's ability to guide location-specific adaptation planning, operational risk mitigation, and informed decision-making.

CONCLUSION

The CKI represents a novel contribution to climate action by systematically quantifying the role of KM in organizational resilience. Its validation across two Egyptian petroleum companies, one with an ISO 30401-compliant KMS and one without, demonstrated strong diagnostic utility. The company's significantly higher CKI score (0.283 vs. 0.133) with formalized KMS implementation underscores the framework's practical value for assessing climate knowledge maturity. While this initial study focused on a limited sample, the contrast in outcomes offers a robust foundation for future scalability testing across diverse organizational contexts.

The CKI's integrative framework bridges critical gaps between Energy Management System (EnMS), Environment Management System (EMS), and Knowledge Management System (KMS), offering a standardized approach to measure climate-related knowledge governance. By translating technical practices into quantifiable metrics, the index aligns with global climate resilience priorities, particularly in high-impact sectors like petroleum.

Its application within the Egyptian petroleum sector yielded operationally meaningful results, suggesting the CKI's promise as a sector-specific benchmarking tool. Though not yet generalizable, the framework's adaptability supports its use in assessments and cross-industry replication.

Finally, the study revealed structural insights: downstream operations showed greater engagement with environmental systems than upstream segments, and middle managers, who accounted for 58% of respondents, emerged as critical actors in climate knowledge dissemination. These findings point to two strategic imperatives: enhancing climate awareness in upstream operations and continuing investment in middle management development programs to sustain progress in knowledge-driven climate adaptation.

ACKNOWLEDGMENTS

The authors sincerely thank the organizers and contributors of the Climate Change Management through Mitigation and Adaptation (ADAP-TM) project under Erasmus+. We would also like to thank our mentors, colleagues, and the participating organizations in the Egyptian petroleum sector for their valuable contributions and insights, which were instrumental in the completion of this study.

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APPENDIX 1: SURVEY 1

In the field of climate change and the development of plans of managing its impacts, a lot of scientific research and international institutions have emphasized the importance of having a knowledge management system to ensure increased awareness of the implementation of the best dally practices at work to ensure reducing the impacts of climate change as much as possible. In order to achieve the best value for a system for knowledge of climate change, I propose that it is important to think it to the existing management and quality systems. such as:

- Energy Management System (ENMS). ISO 50001 (Economic Pillar of Knowledge)
- Environmental Management System (ENVMS). ISO 14001 (Environmental Pillar of Knowledge)
- Knowledge Management System (KMS). ISO 30401 (Social Pillar of Knowledge)

So it is important to know your valuable opinion to compare between the importance between these systems to the knowledge management of climate change (* indicates required question).

1 Email* ____________________
2 Name* ____________________
3 Gender* Male Female
4 Age range* <25 25–35 35–45 45–55 >55
5 Company* ____________________
6 Position* Top Management Middle Management
Section Head Other ____________________
7 Country* ____________________
8 Industry* Refining Petrochemicals Natural Gas
Other ____________________

9 Field of Work* Quality Assurance Operations
Energy Management Health Safety and Environment
Sustainable Development Other ____________

10 (1) Regarding to Energy and Environment fields. Which system is more important to the knowledge of climate change?*
Energy Management System
Environmental Management System

11 In question 1, what is the degree of importance of your chosen system?*
1 2 3 4 5 6 7 8 9

12 (2) If you compare between Energy and Knowledge management fields. Which system is more important to the knowledge of climate change?*
Energy Management System
Environmental Management System

13 In question 2, what is the degree of importance of your chosen system?*
1 2 3 4 5 6 7 8 9

14 (3) Finally, which system is more important to the knowledge of climate change?*
Energy Management System
Environmental Management System

15 In question 3, what is the degree of importance of your chosen system?*
1 2 3 4 5 6 7 8 9

APPENDIX 2: SURVEY 2

Energy	Percentage of employees having awareness sessions of Environment Management System	E1	The ratio of employees aware of the energy management system to the total number of employees.
	Energy intensity	E2	Amount of energy used to produce a given level of output or activity
	Energy efficiency midterm target [%] (3–5 years)	E3	How the company aims to achieve its emissions reduction targets and capture the company's ambition to use energy more efficiently can reduce its energy costs and lower GHG emissions.

Environment	Percentage of employees having awareness sessions of Environment Management System	N1	The ratio of employees aware of the environmental management system to the total number of employees
	Direct and indirect GHG emissions from sources owned or controlled by the company and from the generation of acquired and consumed electricity, steam, heat, or cooling (collectively referred to as 'electricity') (Scope 1 & 2) [tons]	N2	Measuring carbon footprints from direct emissions & emissions from purchased or acquired electricity, steam, heat, and cooling
	All indirect GHG emissions (not included in Scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions (Scope 3) [tons]	N3	Capturing the thoroughness of companies' accounting processes and understanding how companies analyze their emissions footprints. For most companies, the majority of emissions occur indirectly from value-chain activities
Knowledge	Percentage of employees having Awareness sessions of knowledge Management System	K1	The ratio of employees aware of the Knowledge management system to the total number of employees
	Percentage of climate-related collected ideas from employees	K2	The ratio of climate-related ideas to the total number of collected ideas
	Percentage of climate-related converted knowledge (implicit to explicit)	K3	The ratio of climate-related converted knowledge to the total number of c

Name
Company
Managerial level
Work field

E1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	E2
E1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	E3
E2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	E3
N1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N2
N1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N3
N2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N3
K1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	K2
K1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	K3
K2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	K3