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Prospective construction of carcinogenic risk scenarios using MICMAC and Régnier Abacus: an approach for health decision-making..

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ABSTRACT

Introduction: Cancer can be considered a complex phenomenon with interactions among environmental, occupational, social, and political factors. Understanding the nature of these links requires models that transcend traditional causal analysis and allow for the prediction of future risk structures. This work develops a prospective structural approach to carcinogenic risks, combining structural analysis methods as instruments for health decision-making based on anticipation.

Methods: A prospective, structural, exploratory, and descriptive study was conducted in three phases. First, documentary and bibliometric reviews were carried out to identify associated variables, with the most relevant variables being selected through expert consensus. Next, the MICMAC structural analysis (Multiplication Cross-Impact Matrix Applied to a Classification) was used to determine the hierarchy of influence or dependence among variables. Finally, the Régnier Abacus was used to assess the probability and desirability of evolutionary hypotheses, constructing plausible scenarios for the period 2024–2034.

Results: The predominance of institutional factors over biological ones was evident. Environmental governance, regulatory compliance, and coverage shaped the context of carcinogenic risk. Coherence analysis showed a correlation between social desire and institutional feasibility, allowing for the definition of three contrasting scenarios. The results also indicate that it is necessary to strengthen anticipation and coordination by health systems in the face of risks of a multi-causal nature.

Conclusions: The integrated use of the MICMAC technique and Régnier Abacus demonstrated that structural risk anticipation can become a tool for health governance. Reducing carcinogenic risk depends more on policy coherence, regulatory compliance, and public perception of risk than on technological interventions. Applied prospective allows for translating complexity into strategies and guide decisions toward more resilient, equitable, and sustainable scenarios

Keywords: Complex systems; health governance; structural prevention; prospective analysis; institutional sustainability; environmental vulnerability; regulatory policy; public resilience

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1. INTRODUCTION

Cancer is one of the leading causes of morbidity and mortality worldwide, according to the International Agency for Research on Cancer (IARC), nearly 20 million new cases of cancer were diagnosed in 2022, along with 9.7 million deaths from the disease (WHO, 2022). It is a disease with a multifactorial etiology, involving biological, environmental, occupational, and behavioral determinants, which complicates the definition and planning of prevention policies (Mahmood & Srivastava, 2022). In this context, prospective models are responsible for anticipating the evolution of cancer risks and informing public health policies under conditions of uncertainty. Hence the importance of risk scenarios, which allow for a representation of the interaction between causal factors and contexts, thus promoting evidence-based decision-making and future perspectives.

Carcinogenic risk assessment has thus far been understood primarily through quantitative methodologies, in line with exposure-response models and probabilistic simulations (Hernández & Tsatsakis, 2017; Gupta & Gupta, 2023). However, these approaches have limitations in incorporating qualitative or social variables that influence exposure to or mitigation of risk. Authors such as Godet (2001) and Vineis and Wild (2014) introduce structural prospective as an analytical complement to explore possible futures and alternative risk scenarios.

In the healthcare sector, the use of the MICMAC method (Multiplication Cross-Impact Matrix Applied to a Classification) has allowed for the identification of driving and dependent variables in complex public health systems (Morocho et al., 2020). In turn, Régnier Abacus facilitates the translation of these interrelations into participatory scenarios, integrating expert perspectives. Several studies have demonstrated the usefulness of these tools: Contreras (2014) applied MICMAC to analyze urban environmental risks with an impact on health; and Calva et al. (2020) used structural prospective in hospital management. However, a gap exists in the integrated application of MICMAC and Régnier Abacus specifically focused on carcinogenic risk, despite its growing relevance given the increase in cancers associated with environmental and occupational exposures (IARC, 2023).

Despite advances in cancer epidemiology, there remains insufficient integration of structured prospective methods for anticipating carcinogenic risk scenarios in healthcare planning. The central problem addressed by this research can be formulated as follows: How to build prospective carcinogenic risk scenarios that integrate epidemiological, environmental, and social variables, using structural methods (MICMAC and Régnier Abacus) to strengthen health decision-making?

In this sense, the present study is justified because healthcare management faces the need to anticipate emerging risks and prioritize resources in the face of the growing burden of cancer. The application of structural prospective methodologies allows for the identification of critical variables and dependency relations that determine the evolution of carcinogenic risk in different territorial or population contexts.

The combined use of the MICMAC method and Régnier Abacus allows for a systemic view of a health problem, as well as a health governance tool that integrates science, policy, and interdisciplinary participation. This approach strengthens institutional capacities for public health planning, aligning with the Millennium Development Goals (MDG 3: Good Health and Well-being). Therefore, the objective of this research was to develop a prospective methodology for constructing carcinogenic risk scenarios using the MICMAC method and Régnier Abacus, with the aim of supporting evidence-based public health decision-making and expert participation.

This study represents a methodological innovation by integrating these two methods into the analysis of carcinogenic risk, which is typically addressed solely using statistical and toxicological methods. Among the contributions of the study are: the identification of carcinogenic risk variables, participatory simulation of future scenarios for prevention, and the development of a replicable model for carcinogenic risk management environments that links research, planning, and health governance. In this way, it contributes to consolidating a forward-looking and strategic perspective on cancer control, strengthening public health planning capacities.

2. MATERIALS AND METHODS

This prospective structural, exploratory, and descriptive study employed two complementary prospective analysis tools: MICMAC and Régnier Abacus. These tools were used to identify key variables (Arcade et al., 2014), analyze their interrelations, and construct possible scenarios for the evolution of carcinogenic risk (Godet, 2001). The methodological design was developed in four sequential phases: Identification of carcinogenic risk variables; Structural analysis using MICMAC; Scenario building with Régnier Abacus; and Synthesis of strategic guidelines for healthcare decision-making.

Phase 1 (Identification of Carcinogenic Risk Variables): The first phase consisted of a documentary and bibliometric review of indexed literature (Scopus, PubMed, ScienceDirect, Redalyc, IARC) to identify the main factors associated with carcinogenic risk. Sources from 2010 to 2023 were considered, prioritizing epidemiological, environmental, and toxicological studies. From this review, an initial set of 40 variables was defined, grouped into five dimensions: Environmental, Occupational, Biological and Genetic, Behavioral, and Sociopolitical. These variables were validated by a panel of 12 experts (epidemiologists, toxicologists, public health professionals, and health planners) using the Delphi technique in two rounds.

Phase 2 (Structural Analysis using MICMAC): The MICMAC method, proposed by Michel Godet (1986), was applied to determine the degree of influence and dependence between the variables. The procedure was structured as follows: (1) Construction of the cross-influence matrix, where experts assigned scores between 0 (no influence) and 3 (strong influence) to each relation between variables; (2) Calculation of the matrix of direct and matrix impacts, using the LIPSOR-EPITA MICMAC software, which allowed the identification of: Driving variables (highly influential), Dependent variables (highly affected), Autonomous variables (low interaction), and Critical variables (unstable and uncertain); and (3) Structural interpretation, identifying the determining factors of the carcinogenic risk system.

Phase 3 (Scenario Building using Régnier Abacus): Régnier Abacus was used to construct prospective carcinogenic risk scenarios based on the identified variables (Godet, 1986). Participatory workshops were conducted with the same panel of experts, who assigned qualitative values to each variable according to its expected future behavior (positive, neutral, or negative). This process allowed for the construction of three scenarios: Optimistic Scenario (E1), Trend Scenario (E2), and Pessimistic Scenario (E3). The scenarios were analyzed according to the criteria of coherence, plausibility, and impact, following the prospective methodology of Godet and Durance (2011).

Phase 4 (Integration and Strategic Synthesis): Based on the scenarios obtained, strategic recommendations were developed for healthcare decision-making in carcinogenic risk contexts. The strategies were validated through expert review.

The study did not involve any intervention on humans or animals. The information used came from secondary sources and expert consultations. The confidentiality of participants and adherence to the principles of research ethics established by the Declaration of Helsinki (2014) were guaranteed.

3. RESULTS

This chapter details the results obtained from the methodological development of the study. It presents the findings derived from the phases of variable identification, selection and structural analysis of the variables, scenario building, and the synthesis of strategic guidelines for healthcare decision-making.

Phase 1: Identification of carcinogenic risk variables

The first phase of the investigation consisted of the identification and classification of the variables that determine carcinogenic risk, based on a documentary review and a bibliometric analysis carried out on literature indexed in Scopus, PubMed, ScienceDirect, Redalyc, and IARC Monographs, between 2010 and 2023. A total of 312 scientific articles and 18 technical reports related to the environmental, occupational, biological, behavioral, and sociopolitical exposure of cancer were analyzed.

Bibliometric processing allowed for the identification of co-occurring terms and key variables through frequency analysis and co-authorship networks, complemented by qualitative expert evaluation (Delphi technique in two rounds). This resulted in the definition of 40 carcinogenic risk variables, classified into five dimensions: Environmental, Occupational, Biological and Genetic, Behavioral, and Sociopolitical and Governance. Table 1 below shows the 40 identified risk variables, with their respective technical descriptions.

Table 1. Carcinogenic risk variables identified (2010–2023)

Number	Variable	Technical description
1	Urban air pollution	Prolonged exposure to PM2.5, ozone, and polycyclic aromatic compounds (Loomis et al., 2013).
2	Exposure to heavy metals	Presence of arsenic, cadmium, lead, and nickel in water or food (Tchounwou et al., 2012).
3	Water pollution	Contact with nitrites, trihalomethanes, pesticides, and industrial byproducts (Villanueva et al., 2007).
4	Soil pollution	Bioaccumulation of hydrocarbons, dioxins, and mining waste (Rodríguez-Eugenio et al., 2018).
5	Ultraviolet radiation	Prolonged sun exposure without protection, associated with skin cancer (Armstrong & Kricker, 2001).
6	Ionizing radiation	Medical, occupational, or accidental exposure to X-rays or gamma rays (Rühm et al., 2022).

7	Exposure to pesticides	Direct or indirect contact with organophosphates and carbamates (Mostafalou & Abdollahi, 2013).
8	Carcinogenic industrial emissions	Release of volatile organic compounds, benzene, toluene, and formaldehyde (Lee et al., 2022).
9	Exposure to smoke from domestic combustion	Use of biomass or coal for cooking or heating (Balakrishnan et al., 2014).
10	Occupational chemical exposure	Occupational exposure to solvents, dyes, asbestos, or heavy metals (Rushton et al., 2012).
11	Physical occupational exposure	Ionizing or non-ionizing radiation in industrial or hospital settings (Pearce et al., 2013).
12	Poor workplace safety	Lack of personal protective equipment or exposure controls in the workplace (Ahmad et al., 2016).
13	Exposure in mining and metallurgy	Chronic inhalation of silica, arsenic, chromium, and metal dust (IARC, 2012).
14	Hereditary genetic predisposition	Mutations in BRCA1/2, APC, TP53, and DNA repair genes (Kuchenbaecker et al., 2017).
15	Acquired somatic mutations	Genomic alterations induced by external carcinogenic agents (Alexandrov et al., 2013).
16	Genetic polymorphisms	Variations in metabolism genes (CYP1A1, GSTM1, NAT2) (Houlston, 2000).
17	Chronic inflammatory response	Sustained cytokine activation and oxidative stress (Candido & Hagemann, 2013).
18	Oncogenic viral infections	HPV, HBV, HCV, Epstein-Barr, and Helicobacter pylori (de Martel et al., 2020).
19	Hormonal imbalances	Exposure to endocrine disruptors or prolonged treatments (Diamanti-Kandarakis et al., 2009).
20	Tobacco	Active or passive consumption of cigarettes and tobacco products (Islami et al., 2015).
21	Alcohol	Chronic intake that potentiates mutagenic and oxidative effects (Bagnardi et al., 2015).
22	Diet rich in fats and processed foods	High consumption of red meat, nitrosamines, and ultra-processed foods (Micha et al., 2017).
23	Fruit and antioxidant deficiency	Low intake of vitamins A, C, E, and protective polyphenols (Kocyigit et al., 2017).
24	Sedentary lifestyle	Reduced energy expenditure and increased abdominal adiposity (Schmid & Leitzmann, 2014).
25	Obesity	Inflammatory and dysmetabolic state associated with breast, colon, and pancreatic cancer (Lauby-Secretan et al., 2016).
26	Chronic stress	Immunological alteration and increased free radicals (Chida et al., 2008).
27	Use of carcinogenic drugs	Prolonged exposure to certain cytotoxic agents, hormones, or immunosuppressants (Crestan et al., 2020).
28	Insufficient health coverage	Limited access to prevention and early detection programs (Prüss-Üstün et al., 2016).
29	Social inequality and poverty	Structural determinants that amplify exposure and vulnerability (Vineis & Wild, 2014).

30	Poor health education	Lack of knowledge about risk factors and self-care (Sørensen et al., 2012).
31	Weak environmental governance	Lack of control and monitoring of pollutants and waste (Li & de Oliveira, 2021).
32	Insufficient regulatory compliance	Insufficient enforcement of health and environmental laws (Brawley, 2017).
33	Unplanned urbanization	Urban growth associated with pollution and industrial exposure (Rashed, 2023).
34	Deregulated industrial expansion	Increase in industries operating without environmental impact studies (Rockström et al., 2009).
35	Climate change	Increased UV exposure, pollution, heat stress, and pollutant migration (Watts et al., 2018).
36	Fragmented health policies	Lack of inter-institutional coordination among the health, environment, and labor sectors (Mladovsky et al., 2012).
37	Public perception of risk	Social underestimation of cancer as an environmental problem (Slovic, 2016).
38	Limited institutional capacity	Lack of technical and human resources for health monitoring (Haines & Ebi, 2019).
39	Intersectoral cooperation	Level of coordination among health, environment, and industry agencies (Kickbusch & Gleicher, 2011).
40	Technological innovation in monitoring	Availability of biomonitoring, sensors, and early warning systems (Nieuwenhuijsen, 2015).

Source: Prepared by the author based on bibliometric analysis and consultation with experts

Bibliometric analysis revealed that environmental (1–9) and sociopolitical (28–40) variables are the most frequently cited and associated with the emergence of carcinogenic risk over the past 15 years, particularly in urban and industrial contexts of emerging economies. Behavioral and biological variables, while maintaining a high epidemiological incidence, also depend on structural and regulatory factors.

Following the initial identification of 40 variables, a prioritization and reduction process was carried out using a Delphi panel composed of 12 specialists (epidemiologists, toxicologists, health planners, and public policy experts). Each expert evaluated the variables based on three criteria: degree of potential influence on carcinogenic risk, degree of dependence on other variables, and strategic relevance for health management. Scores were assigned on a Likert scale from 1 (low) to 5 (high), and a weighted average was applied.

The result was the selection of 12 key variables, presented in Table 2, considered structurally determinant of the carcinogenic risk system. As can be seen, each variable was assigned an identifier code (V1-V12) for organizational, traceability, and analytical purposes within the study, as well as to justify its relevance. This coding allowed for the systematic structuring of the relations matrix, facilitated processing in MICMAC, and ensured a clear and consistent interpretation of the interdependencies among the selected variables.

Table 2. Key variables selected for the MICMAC structural analysis

Code	Variable	Justification of relevance
V1	Urban air pollution	It is one of the main environmental determinants of lung and systemic cancer; strong cross-cutting influence.
V2	Exposure to heavy metals	High toxicity and persistence; linked to skin, bladder, and lung cancer.
V3	Ionizing radiation	Key physical variable; interacts with health policies and labor regulations.
V4	Exposure to pesticides	Relevant in rural areas; high epidemiological and environmental impact.
V5	Occupational chemical exposure	Determinant of occupational health; links economic structure and incidence.

V6	Hereditary genetic predisposition	Structural biological factor; interacts with environmental exposures.
V7	Tobacco	Main behavioral risk factor for global carcinogenicity.
V8	Diet rich in fats and processed foods	Metabolic modifier and promoter of colorectal and gastric cancer.
V9	Insufficient health coverage	Structural determinant of social and health vulnerability.
V10	Weak environmental governance	Driving variable of a political and regulatory nature.
V11	Insufficient regulatory compliance	Amplifies the effect of all environmental and occupational variables.
V12	Public perception of risk	Key social variable that influences the adoption of preventive policies and habits.

Source: Prepared by the authors based on bibliometric analysis and consultation with experts

Phase 2. Structural analysis using MICMAC

Phase 2 consisted of structural analysis using MICMAC. The purpose of this phase was to determine the structure of causal relations and interdependencies among the variables that make up the carcinogenic risk system. MICMAC analysis allowed for identifying which variables are drivers (of structural influence), dependent, critical, or autonomous. To achieve this, the Matrix of Direct Influence (MDI) shown in Figure 1 was first constructed. In this matrix, the 12 experts on the panel assigned influence values among variables on a scale of 0 to 3 (0 = no influence, 3 = strong influence). As can be seen, variables such as V1, V2, V4, and V5, among others, show high values in their rows, indicating that they have a high influence.

Figure 1. MDI

	1 : V1	2 : V2	3 : V3	4 : V4	5 : V5	6 : V6	7 : V7	8 : V8	9 : V9	10 : V10	11 : V11	12 : V12
1 : V1	0	3	2	3	2	3	3	3	2	2	3	3
2 : V2	2	0	3	2	2	3	1	3	2	2	2	3
3 : V3	1	2	0	1	2	2	1	1	0	0	1	2
4 : V4	3	2	3	0	2	3	2	3	3	2	2	3
5 : V5	3	1	2	3	0	3	3	2	3	1	1	2
6 : V6	1	1	1	2	3	0	3	1	2	1	0	1
7 : V7	1	1	0	3	3	3	0	1	2	0	1	3
8 : V8	1	0	1	2	2	1	3	0	3	1	1	2
9 : V9	2	1	2	3	3	3	3	2	0	2	3	3
10 : V10	2	2	1	3	2	3	3	3	2	0	1	2
11 : V11	1	1	1	2	2	2	3	3	3	1	0	3
12 : V12	3	2	2	3	2	3	2	3	2	2	2	0

Source: Prepared by the author based on expert consultation

Subsequently, successive matrix multiplication was applied until stability was achieved in the influence and dependence indices, following the methodology of Godet (1986), using the LIPSOR-EPITA's MICMAC software, which allowed the variables to be classified in the four-quadrant plane (Dependence on the X-axis, Influence on the Y-axis), determining their relative position and their structural role in the system, as shown in Figure 2.

a) Driving variables (upper left quadrant)

Variables V1 (Urban air pollution) and V2 (Exposure to heavy metals) are the main structural environmental factors, as they determine the physical basis of carcinogenic risk. Meanwhile, V10 (Weak environmental governance) and V11

(Insufficient regulatory compliance) represent driving institutional factors that condition the capacity for control or mitigation. These variables together form the structural core of the system, since changes in these variables generate multiplier effects on the rest of the risk system.

b) Critical variables (upper right quadrant)

Variables V4, V5, V9, and V12 show a high degree of interaction between environmental, occupational, social, and communicative dimensions. V4 (Pesticide Exposure) and V5 (Chemical Occupational Exposure) depend on the level of environmental governance, but at the same time, they influence the incidence of occupational cancer. V9 (Insufficient Health Coverage) acts as a bridge between the social and health dimensions. V12 (Public Perception of Risk) emerges as an uncertainty variable: an increase in perception can generate rapid political or behavioral changes. These variables are sensitive to political intervention and determine the stability of the health system in the face of carcinogenic exposure.

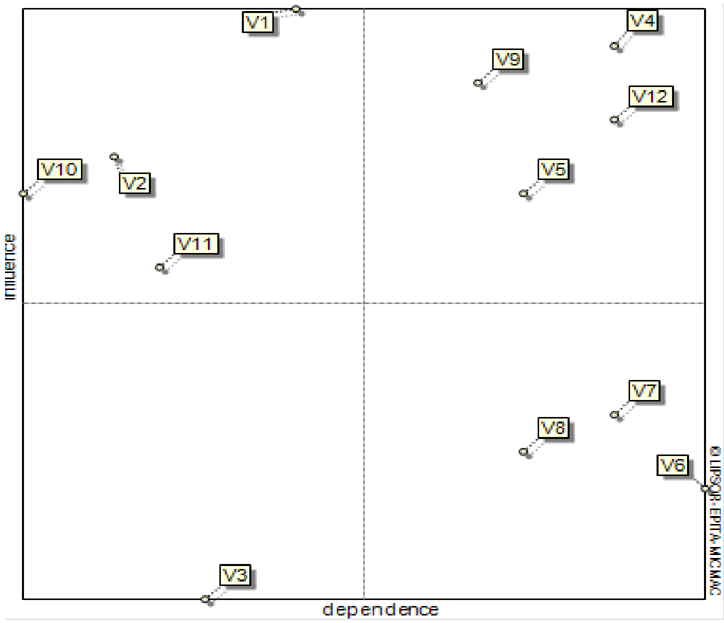
c) Dependent variables (lower right quadrant)

Variables V6 (Hereditary genetic predisposition), V7 (Tobacco), and V8 (Diet high in fat and processed foods) are primarily biological and behavioral in nature. Although they are highly dependent on certain factors, they have low structural influence. Nevertheless, their epidemiological behavior reflects the cumulative effect of preventive policies, lifestyles, and environmental exposure.

d) Autonomous variable (lower left quadrant)

Ionizing radiation (V3) acts autonomously, as it is internationally regulated and depends on natural or controlled sources. It has low interaction with other variables, but can become relevant in emergency scenarios or failures in medical and nuclear regulation.

Figure 2. Map of direct influence/dependence



Source: Prepared by the author based on expert consultation

Table 3 shows a synthesis of the classification of variables obtained through MICMAC, which revealed a system predominantly driven by environmental and political determinants, where governance and regulatory compliance play the most influential role in shaping carcinogenic risk.

The combination of critical variables (V4, V5, V9, V12) indicates that the system is highly sensitive to public policies, citizen perception, and occupational health controls. These findings support the need for a comprehensive preventive approach, where environmental regulations and health management work synergistically.

Table 3. General classification of variables

Variable type	Code	Name	Characterization and role within the system
Driving	V1, V2,	Urban air pollution; Exposure to heavy metals;	They have high influence and low dependence. They act as structural drivers of

	V10, V11	Weak environmental governance; Insufficient regulatory compliance	the system, determining the magnitude and distribution of carcinogenic risk. Environmental and regulatory policies are the primary causal core
Critical	V4, V5, V9, V12	Exposure to pesticides; Occupational chemical exposure; Insufficient health coverage; Public perception of risk	They exhibit high influence and high dependency, with unstable behavior. They represent points of vulnerability where small variations can drastically amplify or reduce risk.
Dependent	V6, V7, V8	Hereditary genetic predisposition; Tobacco; Diet rich in fats and processed foods	Low influence, high dependence. These are outcome variables, modulated by environmental and political conditions; they reflect the cumulative impact of driving factors.
Autonomous	V3	Ionizing radiation	It exhibits low influence and low dependence. Its behavior is relatively exogenous to the system, controlled by international protocols and natural exposure.

Source: Prepared by the author based on expert consultation

Phase 3. Construction of prospective scenarios using Régnier Abacus

The purpose of this phase was to anticipate possible trajectories of the carcinogenic risk system in the time horizon 2024–2034, based on the systemic interactions identified by the MICMAC method.

For this purpose, the Régnier Abacus was applied, a qualitative prospective analysis tool that facilitates the construction of plausible scenarios by evaluating the probability of occurrence and the degree of desirability of the hypotheses associated with each key variable. To carry out this phase, the experts formulated three evolution hypotheses (A = favorable, B = trend, C = unfavorable), evaluated according to their probability (P) and desirability (D), considering scientific information and trends observed between 2010 and 2023. Subsequently, the experts assigned probability (P) and desirability (D) scores on a scale of 1 to 5, thus expressing the internal consistency of the system. The results are presented in Table 4.

Table 4. Results of the Régnier Abacus (P-D Matrix of prospective hypotheses)

Code	Hypothesis A (favorable)	P	D	Hypothesis B (trend)	P	D	Hypothesis C (unfavorable)	P	D
V1	Significant reduction through clean policies	3.8	4.9	Stagnation at moderate levels	4.6	3.7	Increase due to urban expansion	4.0	2.1
V2	Regulatory control and environmental remediation	3.5	4.8	Persistence in industrial areas	4.8	3.4	Increase due to informal mining	3.9	2.0
V3	Strengthening of occupational controls	4.2	4.7	Partial compliance with regulations	4.6	3.9	Relaxation of regulations	3.4	2.2
V4	Comprehensive regulation and bioalternatives	3.7	5.0	Partial reduction in use	4.5	3.6	Uncontrolled intensive use	3.8	1.8
V5	Progressive substitution of toxic substances	3.6	4.8	Persistence with minimal controls	4.8	3.5	Increased exposure in informal sectors	3.7	2.0
V6	Integration of genetic screening into public health	3.4	4.0	Limited access to genetic diagnosis	4.2	3.8	Absence of systematic genetic programs	4.1	2.2

V7	Reduction in consumption through fiscal policies	3.9	4.9	Stability of consumption	4.5	3.5	Increase among young people	4.2	1.9
V8	Decrease through nutritional education	3.7	4.7	Moderate trend without structural change	4.7	3.4	Increase due to the expansion of ultra-processed foods	4.1	2.0
V9	Universal expansion of healthcare access	3.5	5.0	Partial coverage with persistent inequities	4.8	3.7	Reduced coverage and segmentation	4.6	1.9
V10	Strengthened intersectoral governance	3.8	5.0	Maintenance of the status quo with limited progress	4.7	2.8	Institutional fragmentation	4.0	2.1
V11	Effective monitoring and enforcement of sanctions	2.6	4.9	Partial and reactive compliance	4.8	3.5	Widespread regulatory relaxation	4.1	1.9
V12	High social awareness and citizen action	3.9	5.0	Partial awareness among educated groups	4.6	3.8	Low social perception of risk	4.0	2.1

Source: Prepared by the author based on expert consultation

The analysis of prospective hypotheses using the Régnier Abacus allowed the identification of differentiated patterns of evolution among the structural variables of the carcinogenic risk system.

The collective probability (P) and desirability (D) evaluations, issued by the panel of experts, revealed a distribution that reflects the tension between the possible and the desirable within the health and environmental trajectories towards the 2034 horizon.

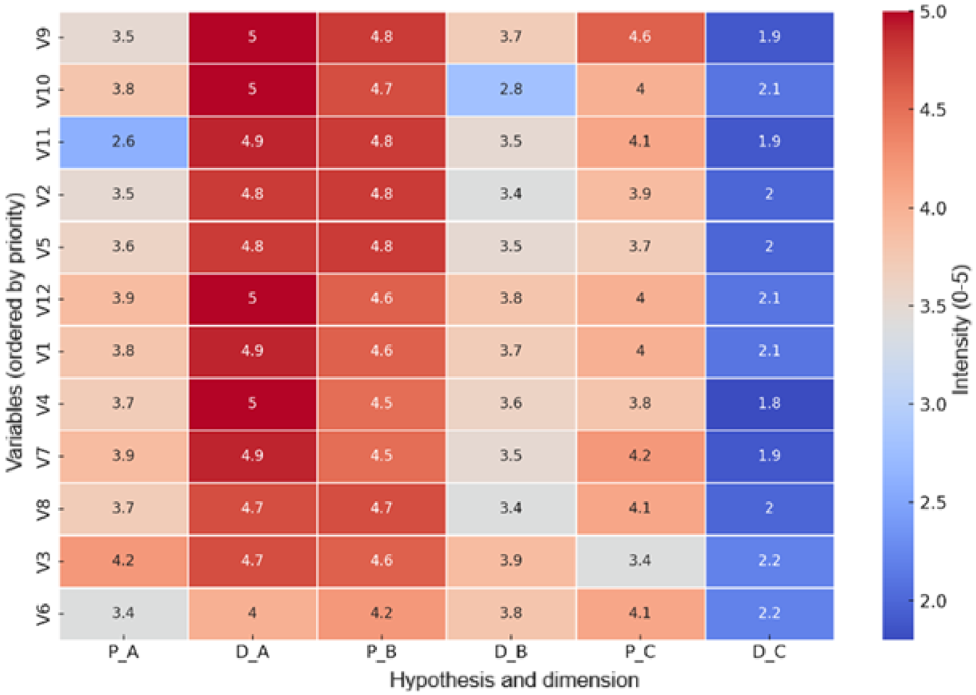
The heat map in Figure 3 synthetically illustrates the relations between probability (P) and desirability (D) of the three prospective hypotheses (A, B, and C) applied to the twelve variables analyzed using the Régnier Abacus. The "cold-warm" color scale allows visualization of the rating gradients assigned by the experts, where red and orange tones represent high values (≥4.5), and bluish tones correspond to low values (≤2.5), associated with unfavorable or undesirable scenarios.

As can be seen, variables V9 (Insufficient health coverage), V10 (Weak environmental governance), and V11 (Insufficient regulatory compliance) stand out at the top of the map, exhibiting intense red tones in both Hypothesis A (favorable) and Hypothesis B (trend), reflecting high desirability (4.8–5.0) and a high probability of occurrence (4.6–4.8). This suggests that improvements in health coverage, environmental governance, and regulatory compliance are considered strategic priorities with maximum influence on reducing carcinogenic risk.

Likewise, variables V2 (Exposure to heavy metals) and V5 (Occupational chemical exposure) also maintain high values in the favorable and trend quadrants, indicating a high sensitivity of the system to environmental and labor regulations, but also a realistic opportunity for mitigation through effective public policies. Together, these five variables form the driving force of the optimal scenario, which combines high desirability with institutional viability. In contrast, the blue tones that predominate in the column corresponding to hypothesis C (unfavorable), especially in cells D_C, demonstrate that regressive trajectories (such as increased pollutants, institutional weakening, or regulatory fragmentation) are perceived as undesirable and of low feasibility, reinforcing the consistency of the prospective system toward sustainability.

The overall observation of the color gradient shows a progressive decrease in intensity toward the lower variables (V7, V8, V3, V6), reflecting a lower relative strategic priority. In these cases, although hypotheses A maintain acceptable desirability values, the probability of their implementation tends to be lower (3.4–4.2), suggesting that they require longer-term innovation processes or institutional strengthening.

Figure 3. Heat map of the results of the Régnier Abacus (Probability and Desirability by Hypothesis)



Source: Prepared by the author based on expert consultation

The heat map reveals a high degree of internal consistency between probability and desirability in scenarios A and B. It also facilitates the identification of a strategic core of governance and regulation (V9, V10, V11, V2, V5) as the basis for the optimistic scenario and, finally, allows for a systematic decrease in desirability in scenario C, consistent with the expanded carcinogenic risk scenarios. This visual representation confirms that public health and environmental governance strategies are the essential levers for transitioning to scenarios with lower carcinogenic risk and greater health resilience.

Final synthesis of the prospective scenarios

The prospective exercise allowed for the construction of three contrasting scenarios for the evolution of carcinogenic risk based on the twelve variables selected and analyzed using MICMAC and Régnier Abacus. This methodological triangulation enabled a comprehensive understanding of the causal structure of the system and its possible medium-term development trajectories (2024-2034).

Scenario 1. Optimistic or integrated health governance prospective

This scenario arises from the predominance of Hypothesis A, associated with the most intense shades of red on the heat map, reflecting high desirability and probability values. It is characterized by the consolidation of robust intersectoral environmental governance (V10), accompanied by a strengthening of regulatory compliance mechanisms (V11) and an effective expansion of health coverage (V9). The control of critical pollutants (e.g., exposure to heavy metals (V2) or the substitution of occupational chemicals (V5)) acts as a catalyst for sustained improvement in public health.

The optimistic scenario represents a context in which environmental policy, labor regulation, and health planning converge, resulting in a significant population decrease. Its constitution is determined by strong political will, a reliable scientific and technological system, and a civil society with a high perception of risk (V12). From a structural perspective, it is a stable system with high positive momentum and low dependence, oriented toward sustainability.

Scenario 2. Trend or unstable equilibrium prospective

Scenario 2, comprised of Hypothesis B, represents the trend scenario in which the corresponding heat map tends toward orange. This scenario shows an intermediate level of probability and desirability, representing a context in which control and surveillance policies are only partially effective and do not achieve profound structural transformations. In this scenario, variables such as pesticide exposure (V4), a diet rich in processed foods (V8), and genetic predisposition (V6) retain a moderate effect on cancer incidence, due to uneven implementation of preventive measures and the persistence of territorial and social inequalities. Environmental governance is operational, albeit fragmented, and public health improvements are concentrated in areas with greater institutional capacity.

This state of circumstances tends to further widen the gap between regulatory design and its effective implementation, where a moderate, and indeed worrying, level of carcinogenic risk persists. From a structural perspective, it appears as a system of dynamic equilibrium, where influence and dependence counteract each other, but without reaching a breaking point, although it does show vulnerability to setbacks.

Scenario 3. Critical or health regression prospective

The critical scenario corresponds to hypothesis C, where the bluish tones of the heat map predominate, reflecting a low level of desirability and a low probability of success for preventive actions. This critical scenario is characterized by weakened environmental regulations (V11), institutional fragmentation (V10), and decreased healthcare coverage (V9), leading to an escalation of carcinogenic risk. Environmental and occupational exposures increase, especially those related to pesticides (V4), heavy metals (V2), and urban air pollution (V1), without effective control or compensation mechanisms. Low public perception of risk (V12) and decreased investment in public health amplify the negative impact.

The structure of this scenario exhibits high dependency and low autonomy, suggesting a fragile, reactive system with weak adaptive capacity. It is associated with contexts of socioeconomic crisis or political instability, where the deterioration of environmental and health governance generates a downward spiral of vulnerability and disease burden.

Taken together, the integrated results of MICMAC and Régnier Abacus allow for concluding that the optimistic scenario is structurally possible if environmental governance strategies, regulatory frameworks, and expanded access to healthcare are prioritized. The trend scenario represents the continuation of the status quo, while the critical scenario highlights the effects of institutional fragmentation and the loss of environmental control on public health.

4. DISCUSSIONS

The results of this study confirm the usefulness of structural prospective approaches (MICMAC and Régnier Abacus) as analytical and participatory tools for understanding the systemic complexity of carcinogenic risk. The interrelation between environmental, occupational, social, and political factors allows for moving beyond the traditional epidemiological paradigm toward an anticipatory, interdisciplinary vision oriented toward health governance.

Comparison with international evidence

The identification of driving variables (V1, V2, V10, V11) aligns with the findings reported by the International Agency for Research on Cancer IARC (2023), which identifies urban air pollution and exposure to heavy metals as the main exogenous determinants of cancer in industrialized and urban regions. Furthermore, global studies on environmental exposure, such as those by Vineis and Wild (2014) and Hassan et al. (2022), emphasize that political and institutional determinants, such as environmental governance and regulatory effectiveness, act as factors that amplify or modulate carcinogenic risk, beyond purely biological factors.

The results of the MICMAC analysis in this research demonstrate that the system's structure is subject to environmental and governance determinants, whose influence outweighs that of individual or genetic factors. This pattern has also been observed in research on environmental health policies in Europe and Latin America (Godet & Durance, 2011; Contreras, 2014; Calva et al., 2020), which concur that the level of regulatory compliance and intersectoral coordination determine the direction and speed of change in public health scenarios.

The Régnier Abacus phase confirmed this causal hierarchy, showing a high probability and desirability concentration in the variables of health policy (V9), governance (V10), and regulatory compliance (V11). This finding is consistent with the action frameworks proposed by the United Nations Environment Programme (UNEP, 2023), which state that controlling environmental and occupational cancer requires multi-level governance based on data, effective regulation, and social participation.

Coherence and systemic structure

The system modeled using the MICMAC method exhibited a high degree of institutional drive, where political and regulatory decisions can trigger cascading effects on the environmental, occupational, and behavioral dimensions. This pattern is consistent with the notion of “adaptive health systems” proposed by Kickbusch and Gleicher (2012), according to which health resilience depends on the capacity for anticipation and intersectoral coordination. The critical variables (V4, V5, V9, V12) represent vulnerability nodes, as their position in the upper right quadrant indicates high interdependence and unstable behavior, which aligns with the findings of Lugten et al. (2023) on fragility points in chronic disease management systems.

The resulting classification reinforces the argument that carcinogenic risk cannot be understood unidimensionally. As Loomis et al. (2013) point out, environmental and social factors interact synergistically, and omitting these relations creates biases in prevention policies. The use of MICMAC made it possible to overcome precisely this limitation, highlighting the hierarchical structure of risk and allowing efforts to be focused on high-impact variables with the capacity for strategic leverage.

Prospective evaluation of scenarios

The three prospective scenarios constructed (optimistic, trend, and critical) are consistent with the trajectories observed in the global literature on health transitions. The optimistic scenario coincides with the one presented by Vineis and Fecht (2018), who state that the implementation of integrated environmental policies and universal health coverage significantly reduce the incidence of cancer associated with pollution and industrial occupation. The trend scenario reflects the current reality in many middle-income countries, where regulatory capacity is limited and preventive action is unevenly distributed across different regions (Vineis & Wild, 2014). The critical scenario, meanwhile, resembles the deteriorating trajectories documented by UNEP (2023) in contexts of fragmented governance, where the relaxation of environmental regulations leads to increased carcinogenic exposure.

The compatibility between the scenarios and international evidence corroborates that the prospective methodology used possesses structural and contextual validity, which can reflect real dynamics in health policy. Specifically, the tendency for hypotheses A and B to exhibit a positive correlation between desirability and probability (Figure 4) reveals a certain technical consensus that allows for concluding that moving towards sustainable scenarios may be possible if policies aimed at governance, regulation, and health coverage are prioritized.

Strategic and scientific implications

The results of this study have significant implications for health policy planning from an evidence-based and prospective perspective. First, they show how carcinogenic risk can be mitigated based on the institutional capacity to manage intersectoral policies by integrating health, environment, and labor. Second, the structural approach demonstrates how public risk perception (V12) and environmental governance (V10) are strategic control variables, as their alteration can influence the response of the entire system, thus corroborating the findings of Galea et al. (2010) regarding the importance of risk communication as a determinant of health policies.

In methodological terms, the combination of the MICMAC and Régnier Abacus procedures represents an innovation compared to conventional cancer risk evaluation methods, which typically base their analysis on probability estimates or exposure estimates. This additional dimension that feeds this model focuses on the social, organizational, and interpretative dimensions, similar to the prevention proposals of the Lancet Commission (Coles et al., 2022).

From a scientific perspective, this work supports the need to further consolidate health prospective as a practical discipline, anticipating emerging risks and providing a framework for guiding investments in monitoring, regulation, and public education. The proposed framework is adaptable to other situations, such as chronic environmental diseases or multiple exposures. Consequently, it can be recognized as an adaptable tool for health governance in highly uncertain scenarios.

5. CONCLUSIONS

Prospective analysis revealed that carcinogenic risk is not solely a phenomenon resulting from biological or environmental exposures, but also the product of systemic interactions among structural, institutional, and social factors. Environmental governance, regulatory compliance, and healthcare are strategic aspects that affect the healthcare system's capacity to anticipate or mitigate the carcinogenic effects of the environment.

The combined application of the methods used allowed for the generation of expert judgments in prospective intelligence, visualization of the system's internal dynamics, and anticipation of its possible trajectories. Beyond identifying the variables in question, the model enabled an understanding of how political decisions and the social perception of risk shape the sustainability of healthcare decisions.

The scenarios developed show that reducing carcinogenic risk depends not only on advances in technology, biomedicine, or diagnostic centers, but also on adaptive governance processes, intersubjective coordination among stakeholders, and strengthened regulation. Consequently, transitioning from a trend-based to a preventative approach requires institutional capacity to guarantee regulatory continuity, policy coherence, and active public participation.

From a conceptual perspective, the study suggests that structural prospective can be a suitable tool for forward healthcare planning, as it can incorporate technical, social, and political dimensions into risk evaluation. Furthermore, the periodic application of prospective can increase the coherence of public policies in the face of new challenges, as well as strengthen the understanding of health as a complex, dynamic, and prospectively manageable system.

Finally, the study calls for a reconsideration of cancer as a socio-environmental reality rather than a purely biological event. Anticipating risk, and not just treating it, is the clearest path toward sustainable and resilient health systems in contexts of increasing carcinogenic exposure.

Strategic recommendations

The creation of permanent intersectoral coordination mechanisms between the ministries of health, environment, and work is recommended, employing the health approach in all policies. Institutional strengthening must go hand in hand with monitoring and evaluation systems based on carcinogenic risk indicators. The results also highlight the need to review and update regulations regarding exposure to environmental and occupational contaminants, and to ensure their enforcement through independent inspections and effective sanctions.

Universal access to cancer prevention, early diagnosis, and treatment must be consolidated as a strategic priority. Therefore, it is proposed to integrate environmental cancer monitoring into national public health programs. Furthermore, public perception of carcinogenic risk has demonstrated a significant influence on the effectiveness of preventive policies; hence, it is recommended to implement evidence-based programs for science communication, health education, and citizen participation.

Furthermore, it is suggested that the regular application of structural prospective tools be institutionalized in the health planning process. The MICMAC-Régnier Abacus methodology can be applied periodically to anticipate trends and evaluate the impact of environmental health policies. Finally, given the cross-cutting nature of carcinogenic pollutants, it would be desirable to promote academic and technical cooperation networks, for example, with the WHO, IARC, UNEP, universities, research centers, and activist groups, leading to the strengthening of monitoring and research.

Final implications

The findings of this study demonstrate that structural prospective can be a tool for managing highly sensitive strategic health governance, capable of integrating the complexity of carcinogenic risk into reproducible analytical models. If applied regularly, it can contribute to the formulation of public policies consistent with the real determinants of disease and with the Sustainable Development Goals (SDG 3 and SDG 13). Furthermore, prospective scenario building emerges as an innovative methodological alternative for anticipatory health decision-making, promoting a shift from reacting to disease to anticipating risk and implementing structural cancer prevention in the 21st century

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