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Coupling GIS and Multi-criteria Modelling to support post-accident nuclear risk evaluation: an application in the southern France region

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1. Introduction: nuclear risk management and the PRIME project context

Preparing for how to manage the consequences of a major nuclear accident necessarily involves the consideration of multiple criteria in order to ensure sustainable development in areas that might be affected. This often requires a multidisciplinary approach to produce a sustainable response to the environmental, economic and social problems linked to the various local intricacies. Moreover, the multiplicity of stakeholders produces multiple, often contradictory, objectives, which need to be taken into account and prioritised in order to facilitate decision-making. So that the decision-making process is transparent, properly recorded and reproducible, systems need to be developed to aid the process.

In concert with experts, decision-makers and local authorities, the objective of the PRIME project is to develop a multi-criteria method of analysis for use in characterising an area contaminated after an industrial accident involving radioactive substances (Mercat-Rommens *et al.* 2008). The main basis of the method used is the ranking of the vulnerability factors to a radioactive pollution. The ranking is established jointly by the various PRIME project participants in order to arrive at a shared vision, an essential prerequisite in devising an appropriate management strategy. This method is intended for the use of those managing risks. It should therefore meet two objectives: one being the protection of individual inhabitants, their personal property and their living conditions, and the other its general acceptability to people affected by living in a contaminated area.

The concept behind PRIME's research – which is participative, involving experts and also leading local figures – is to anticipate in a wide study area what the consequences of a nuclear accident will be. The aim is ambitious as it involves a large range of concerns which, moreover, are subject to local stakeholders' widely varying perceptions and interests, but the subject necessitates that these complexities are tackled head on. This requires, therefore, assembling as wide a cross-sectional panel of interests as possible to be able to appreciate the full range of consequences on the one hand and, on the other, engaging in a jointly agreed process with the panel to develop a rigorous method of classifying risks in the areas.

The study zone covers a radius of some fifty kilometres around three nuclear sites in the lower Rhone valley (the Cruas, Tricastin-Pierrelatte and Marcoule sites) (Figure 1a). To the south, the zone extends along the Rhone to the Mediterranean coastal area in order to take into account the possibility of radioactivity being carried into catchments basins.

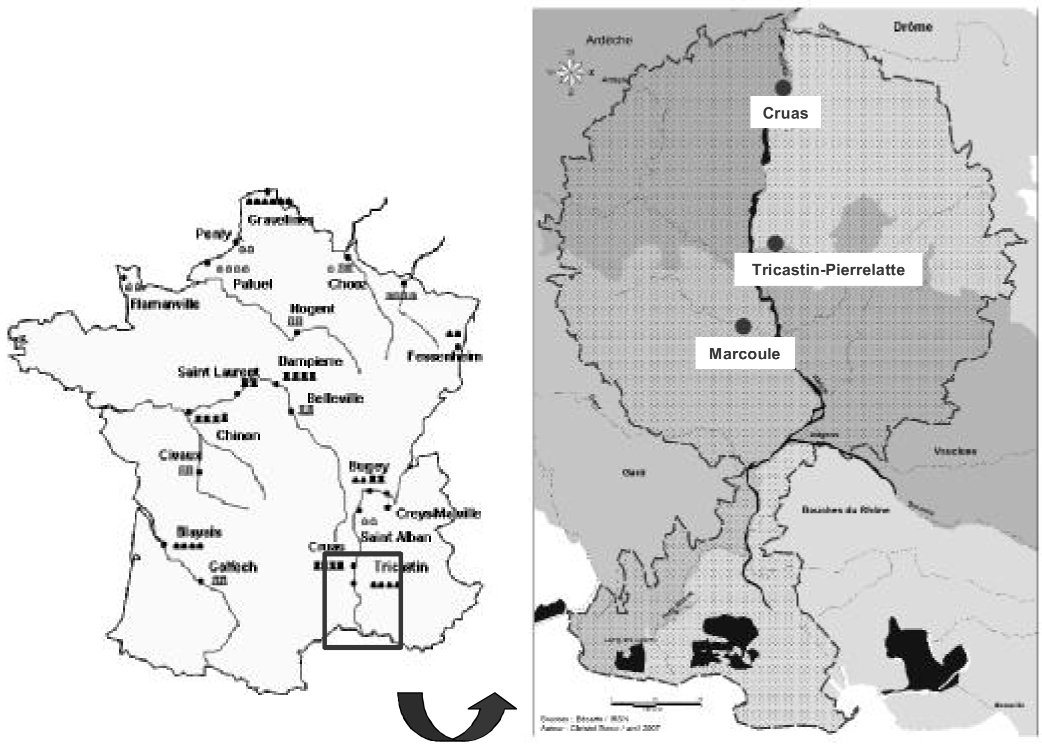

Figure 1a: The study zone

The choice of this vast zone corresponds to a scenario where a major accident involves the release of radioactivity into the atmosphere. Such a choice means taking into account a large number of factors: high population density along the Rhone corridor, very diverse environments (natural, agricultural, built-up areas, river and coastal zones), demographic, economic and tourist factors, and wealth (personal and environmental) and property issues. With such a multiplicity of factors, it would seem to be potentially worth exploring the tools that can result from a multi-criteria analysis for use in the preparation of decision-making aids.

To carry out this research with multiple participants, a group of mainly local stakeholders was approached to make up the PRIME working group (PRIME WG). The participants, in chronological order of becoming involved in the project) are:

- IRSN (French Institute for Radioprotection and Nuclear Safety),
- the Gard CLI (local information committee),
- ASN (Nuclear Safety Authority), Lyon Division,
- Paris-Dauphine University/LAMSADE (Laboratory for Analysing and Modelling Decision-Aid Systems),
- INERIS, a public research institute on industrial chemical risks,
- the Prefecture of the Drôme and related government services (such as DDAF – local agriculture and forest services, DDASS – local social and health services, and DDSV – local veterinary control services),

- AREVA NC (state energy transmission and distribution company) - Pierrelatte site
- a local wine producer from the Gard area,
- the Chairman of the Scientific Council of the Committee of the Bay of Toulon ,
- the Director of "Another Provence",
- the Chairman of the Development Agency for the “Gard rhodanien”,
- two representatives of CODIRPA, the French steering committee on post-accident management (ASN/Paris – the French Nuclear Safety Authority, and the Ministry of Agriculture’s CGAAER – the general council for agriculture, food and rural areas),
- CRIIRAD[1], the committee for research and independent information on radioactivity,
- EDF, the electrical services company – Tricastin site,
- CIGEET – the committee for information on major energy equipment, and the Cruas CLI – the nuclear safety authority, do not currently participate in GT PRIME meetings but they do receive meeting documents and are kept regularly informed of project developments.

A large panel of stakeholders and participants, whilst desirable, did complicate working arrangements, as did the need to deal with varying degrees of expertise and technical know-how. This concerted approach brought an additional constraint which is the need to integrate the developing methodology into a software prototype linking multi-criteria analysis algorithms and geographic information systems software (Chakhar *et al.* 2008).

The PRIME project was chosen for support in July 2006 by the Provence-Alpes-Côte d’Azur project agency on risks labelled “pôle de compétitivité Risques” and also receives research funding under MEEDDAT’s (the French environment ministry) Risk-Decision-Territory programme (convention n°0000771).

2. Methodology of evaluating the post-accident impact on the area

Three phases are usually identified during the process of a nuclear accident (Niel & Godet 2008):

- the urgent phase,
- the short-term post-accident phase termed the “transitional phase”,
- the long-term post-accident phase.

The urgent phase covers the risk phase, when it exists, which precedes the occurrence of the first releases into the environment, and the accidental release phase which produces a radioactive plume dispersing into the environment. It ceases when there are no further deposits, when the installation at the origin of the accident is made safe with no subsequent risk of producing fresh radioactive releases into the environment. The work of PRIME WG is not concerned with this first phase but needs to take into account the action taken during this phase for reasons of continuity and consistency.
The post-accident phase is that of the treatment of the consequences resulting from the event, especially those that result from the deposit of radioactive substances. It starts from

[1] CRIIRAD participates in GT PRIME’s work as a consultant in order to express its vision of the contaminated areas and what needs to be protected. However CRIRAD’s participation does not include approving the methodological software that implements the results of this consultation.

the termination of deposits with what is called the “transitional phase”, which involves a survey of urgent protective action needed, the characterising of the contamination and the introduction of the first protective measures in contaminated areas, as well as the preparation of long-term action. The post-accident phase may last for several months or years, depending on the extent and the persistence of the radioactive contamination in the area. The phase managing the long-term consequences is then begun, which leads to the implementation of a management plan for the long-lasting consequences of the event, worked out with all those involved in the transition phase. The PRIME project is concerned with a transitional phase that lasts for about one year and that takes into account local factors during this period, especially agricultural timetables.

The consequences of an accident on an area are reflected in the negative impact, shorter/ longer-lasting and minor/major on people, assets and the economy in general. The classification of the geographical districts in an area affected by the fall-out from an accident means being able to take account of the radiological consequences on inhabitants as well as negative economic and environmental impacts. The problem lies in finding a method of classification, resting on characterising the state of the area, which is shared by the various stakeholders. The approach taken within the PRIME project to construct a method is based on the successive stages described below. Through this approach, each district can be classified according to the degree to which it is at risk of a nuclear accident resulting in releases into the atmosphere. The scale adopted under the PRIME project has six levels, from 0 for a situation described as normal to 5 in the event of a major and long-lasting negative impact.

2.1. Identifying the stakes involved

The first stage aims to identify, in a concerted manner, the stakes involved, meaning everything that is of fundamental importance to an area and which can be adversely affected by an accident (such as zones that are densely inhabited, business activities, and cultural and environmental assets). This stage requires as accurate a knowledge of the area as possible, provided both by local stakeholders and also by researching all the information available from those holding local data, such as INSEE, (the French National Institute for Statistics and Economic Studies), Agreste (which produces Ministry of Agriculture statistics) and CCI (the Chamber of Commerce and Industry). Then one or more adverse effects (such as radiological contamination, destruction or drop in sales of agricultural products, a drop in company turnover, and the impact on asset values or on tourist numbers) has to be linked to each stake so that they represent the consequences of an accident in various sectors.

2.2. Choosing representative criteria for the various stakes

Once the various factors and adverse effects have been selected, the criteria that characterise them have to be identified. The radiological impact on people can be characterised by the dosage expressed in millisievert (mSv). The economic impact can

be characterised by the loss (in euros) linked to the destruction or a drop in product sales, or again by the percentage drop in a company's turnover.
Specific benchmark values are assigned for each criterion. They correspond to the threshold values that make up the degrees of scale of gravity of the event. For example, below 10 µSv (microsievert = 10^{-6} Sievert) the negative impact is minor (below 1 on the scale), above 10 mSv, the impact can be major (up to 5 on the scale).

2.3. Quantifying the criteria representing the stakes

Once the first two steps have permitted the construction of a scale of gravity to measure the various detrimental impacts, how they work and how consistent they are can be tested in a trial run. For a simulated accident, this therefore involves evaluating the consequences on each district, that means how the criterion or criteria for each negative impact is measured, in order to position them on the scales of gravity (Figure 2.3a).
This stage is completed when the evaluation matrix is achieved, i.e. when a table of data is available, in which the lines represent the districts within the study zone and the columns represent the classification criteria. Each box then contains the corresponding value of the criterion for the district in question.

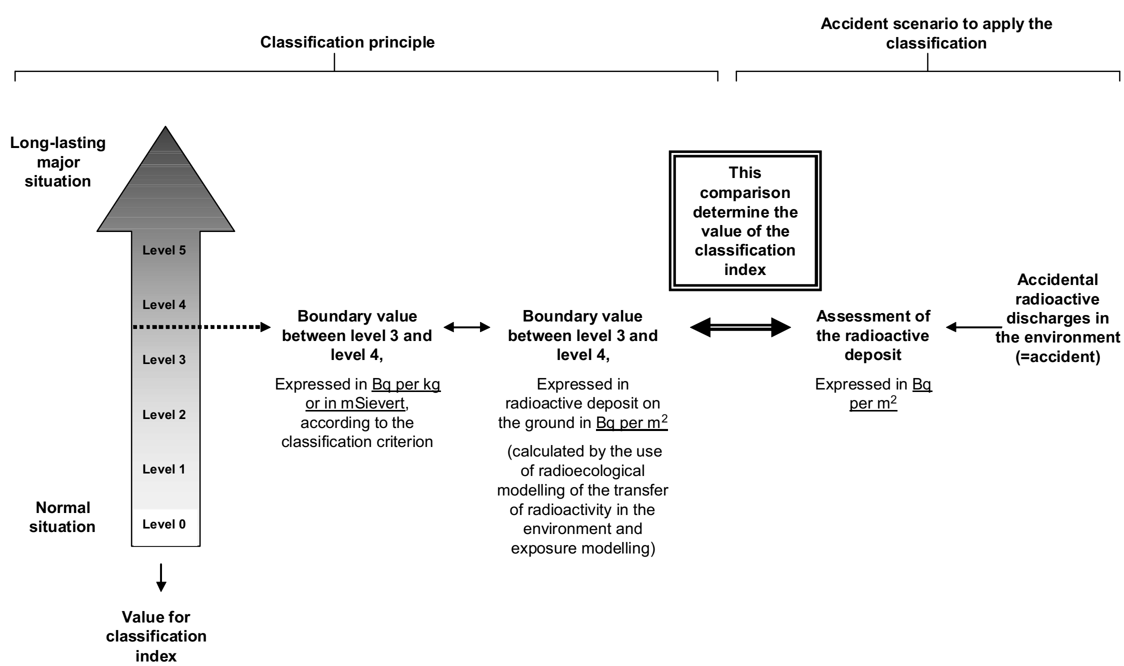

Figure 2.3a: The PRIME method classification principle

2.4. Ranking of criteria and classifications

Once the multi-criteria evaluation matrix is designed, the information for a specific district then has to be aggregated in order to obtain a global indicator of the gravity for the district according to an accident scenario. The ranking criterion is inevitably seen differently from various stakeholders' points of view. It was therefore necessary to develop software able to capture the differences and to represent them. Multi-criteria tools were explored within the PRIME project and the development of software coupling GIS functions and multi-criteria modelling made it possible to draw up maps showing the gravity of a nuclear accident and the importance of each criterion for the various stakeholders.

3. Application and results: using the data and results obtained

The PRIME project's success depends on completing two successive phases:

1. the collection and organisation of relevant databases to show the state of an area contaminated by a nuclear accident,

2. the use of this database in one or more possible scenarios corresponding to nuclear accidents, to rank the most affected districts and, in these districts, to identify the areas most affected by the accident.

3.1. Forming the multi-criteria evaluation matrix

In the first phase of the project, a database was developed for the PRIME study zone, gathering information *a priori* useful in a post-accident context. It is felt that this ad-hoc database can be relevant for decision-making processes if it gathers all the information necessary for classifying the area, in integrating the points of view of all the area's stakeholders. The database's architecture was therefore designed so that area stakes, as expressed by the panel of local representatives (PRIME WG) independently of administrative barriers, were taken into account, in order to permit the construction of classification criteria shared by everyone in the study zone. Moreover, the database structure allows easy access to data and will later facilitate its updating.

In the PRIME project, by taking into account the stakes identified by PRIME WG and/or expressed by other local stakeholders (local diagnostic phase - Barde *et al.* 2007), various kinds of data are collected and analysed: radioecological (linked to radioactive contamination in the area), economic and social (Figure 3.1a).

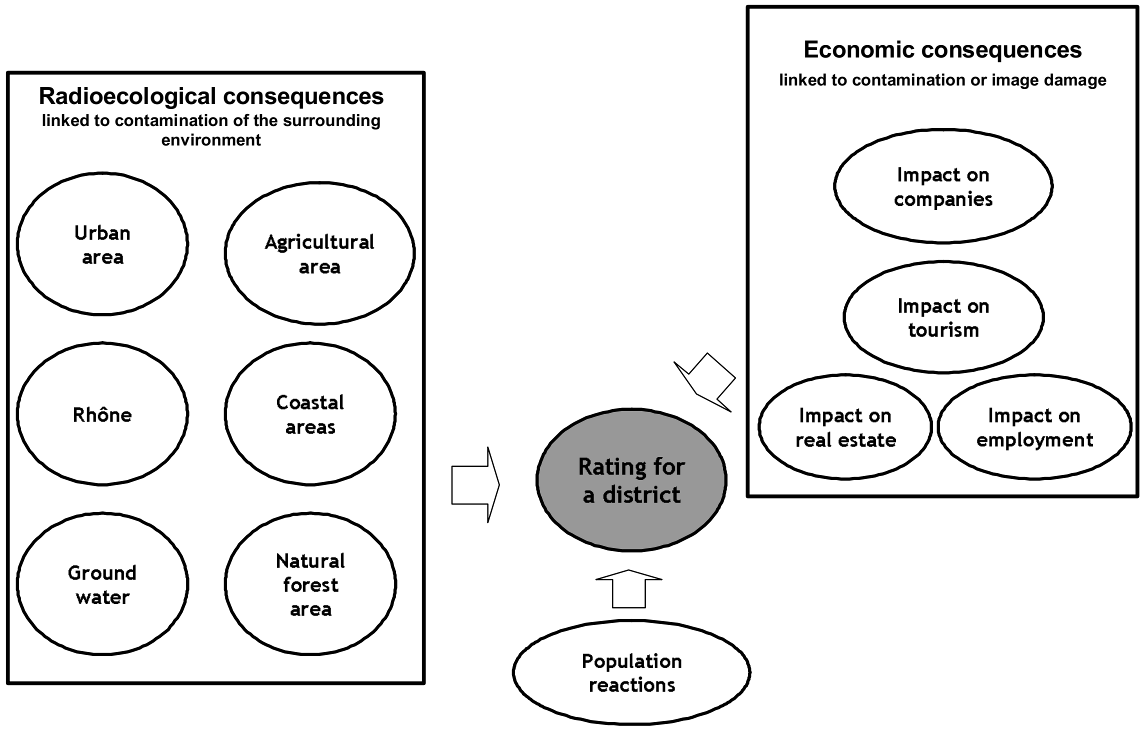

Figure 3. Selected stakes

3.1.1. Radioecological stakes

In the case of radioecological stakes, it has been possible through detailed analysis to propose indicators for the state of the area (known as radioecological criteria) and to link them to a classification system representing the scale of damage to a contaminated area.
Six levels of classification have been decided on, to indicate the radioecological vulnerability of the various media, with the following significance for each point on the scale:

- 0: “Normal situation”. The view will be that, for districts at this level, no particular surveillance or remedial works will be necessary.
- 1: “Very minor”. Typically this will be districts where there is only very slight contamination, difficult to measure with current means of assessment. For such districts, light monitoring measures could be proposed.
- 2: “Minor”. A sector where there is measurable contamination but still slight. There will be stronger monitoring measures than for level 1.
- 3: “Moderate”. Preventive action may be recommended (for example, a ban on the sale of agricultural produce, a ban on using food from the wild or a ban on certain foodstuffs).

- 4: "Major". The contamination of a sector has reached a predetermined normative value (NMA[2] for agricultural produce, for example).
- 5: "Major and long-lasting". Contamination in a medium exceeds a predetermined normative value with effects lasting for more than one year.

The terms proposed for the radioecological classification scale were discussed at length by those who took part in the second PRIME WG meeting and were reviewed in subsequent meetings, as the choice of terms is of great importance in communication terms. Thus the term "negligible", originally suggested for level 1, was felt by a number of participants to be problematic. Because of this, it was decided to use the term "very minor". Similarly, the initial choice of the term "serious" for level 4 was questioned during the project, because it might suggest an impact on health, whereas this point on the scale is reached when a specific normative value for food contamination is exceeded, which does not necessarily imply a health risk for people consuming such food.
In choosing terms for the scale, the aim is both to be easily understood by people but also to be precise, so that the reasons for this or that classification decision made by the authorities can be explained. This is a difficult aim and it is probable that, at the end of the project, the choice of terms may have to be further adapted for communication purposes. It is also worth noting that the choice of terms is linked to the action strategies implicit at each point on the scale (monitoring or remedial strategies). The relationship between classifications and action strategies has particular relevance as a research field, with a view to the practical implementation of the PRIME approach.

There are two types of radioecological criteria used: food contamination criteria (such as agricultural produce, produce gathered from the wild, groundwater, river water, and seafood) and dosage of radiation criteria linked to the varying exposure of people by sector. These criteria are defined by the 6 sectors that make up the study area: the agricultural sector, built-up areas, natural forest areas, water tables, the River Rhone and the coastal zone. Moreover, the process of evaluating radioecological criteria was debated at PRIME WG and in particular the calibration of radioecological calculation formulae which make it possible to evaluate the dispersion and movement of radioactive contaminants within the various sectors of the environment.

The agricultural medium was particularly closely studied as it will be affected in the very short term after an accident and the associated economic factors could very rapidly become of major importance. For this sector, 15 agricultural products, specific to the study zone, have been considered – tomatoes, melons, apricots and peaches, wine, cherries, olives, aromatic plants, early new potatoes, hard wheat, rice, goat's milk, chicken, chicken egg production and lamb. These products were chosen to represent a cross-section of how radioactivity is spread in relation to time of year and farming techniques. This was not an attempt to include all forms of agricultural production (as would be in preparing an impact study) but to put together a group of agricultural products that would indicate a variety of effects.

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[2] Niveau Maximum Admissible *(maximum permitted level)* (Euratom regulation n° 3954/87 of 22 December 1987 and CEE n° 2219/89 of 18 July 1989)

For a given district, therefore, 15 classification ratings were obtained corresponding to each agricultural product. The 15 ratings, to which a sixteenth is fields, therefore make up the classification criteria for the agricultural medium.

For the agricultural medium (through ingesting foodstuffs) the classification scale is defined as in Figure 3.1b below.

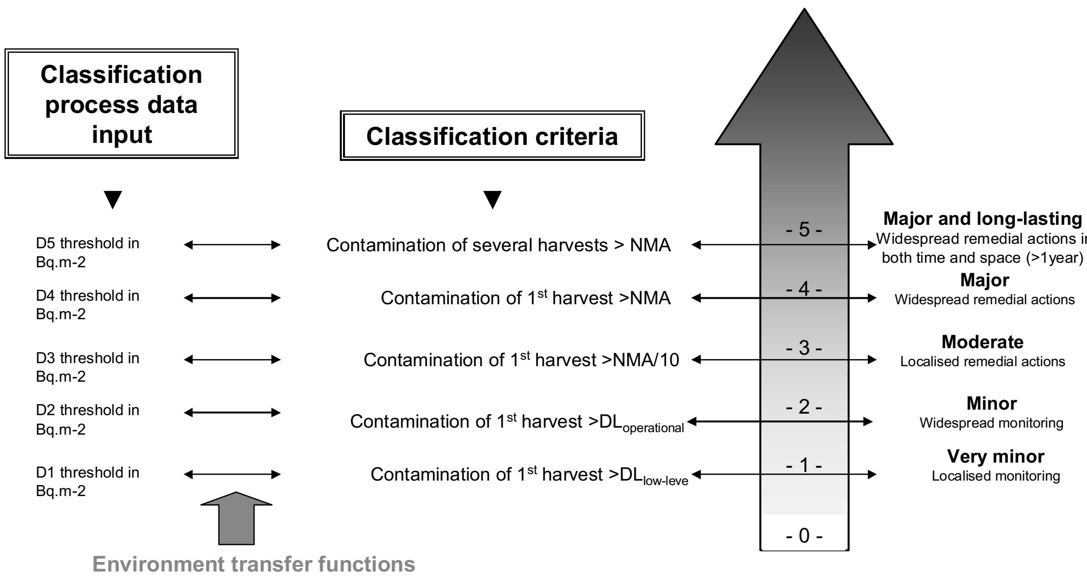

Figure 3.1b: Example of how the radioecological criteria on the agricultural medium are structured.

Two kinds of criteria have been proposed to define the thresholds between 0 and 5. For the levels of greater gravity (3 to 5), the proposal is to use the current norms for the sale of agricultural produce, the “NMA”. For slighter levels (0 to 2), the proposal is to use the minimum detectable amounts (DL = detection limits) and the differentiation made between low-level metrology instrument DL readings (measured in becquerels) and DL using actual regular metrology instruments. These choices come from an analysis of the elements in current regulations concerning foodstuff. This means that there could be debatable elements in the current set of guidelines but, in the context of the PRIME project, the approach was to imagine how the regulation values would be used in post-accident management and not to discuss the precise amounts.

3.1.2. Economic stakes

In taking into account, using the PRIME project method, the consequences of a nuclear accident on economic activity, the concept used is that of the damage function. It is an instrument taken from socio-economic assessments and used for flood purposes (MEDAD 2007). A variety of thinking has been expressed on how to assess these functions for flood-related damage and which can be transposed to a context of radioactive contamination: a damage chart for a given physical asset relating to the level of surface contamination and the percentage of damage to a given business activity, a damage function by homogeneous zone (a principle equating to the previous

one but applied to a space and not a physical asset) and an approach based on average cost. So far as flooding is concerned, damage functions are calculated either in line with expert opinion or based on using statistics from observations gathered after actual disasters. In the nuclear field, there has been no major nuclear disaster in France which allows for an empirical approach and therefore the approach used by the PRIME project is an approach using expertise, whilst remaining conscious of the limits of this type of approach.
However, these limits are reduced within the PRIME project by the fact that, as for radiological consequences, the object of economic analysis for PRIME is not to quantify all the damage, but to provide overall simple and consistent economic criteria to show all the economic stakes in the area.

The economic stakes chosen for PRIME's classification approach are linked to companies' vulnerability, real estate vulnerability, employment vulnerability and the vulnerability of tourist activity. A theoretical study undertaken by one of the PRIME project's partners (Genty & Brignon 2008) has made it possible to propose representative criteria for each of these four kinds of stakes. The financial vulnerability of companies is represented by the damage (called afterwards economic damage) to the added value that each business economic category produces. Real estate vulnerability is represented by the loss in value of surfaces according to their kind of use (built-up, agricultural or natural/forest area). Employment vulnerability is represented by the tendency to relocate jobs according to business category. Finally, the vulnerability of tourism activity is represented by the negative impact on tourism room capacity/occupancy in each district (Barde 2008).

To evaluate the economic impact, PRIME WG considered that knowledge about the consequences of a nuclear accident on activities is not sufficiently precise to justify many classes of effect. The classification of consequences has therefore been simplified and these simplifications have been made in various ways depending on whether or not the business consequences are linked to the contamination of a specific medium in the area. For example, for agricultural activities, the economic impact will be linked to the degree of contamination of the agricultural medium and the simplification proposed is consistent with the fact that the effects on image will increase the consequences of contamination, even when the level is minor, and thus lead to serious consequences from an economic point of view. The number of classes has therefore been reduced from 5 (major and long-lasting, major, moderate, minor and very minor) to 3 (major and long-lasting, major and minor), and the economic impact corresponding to each category has been determined through consultation. Thus, if after an accident, radioactive contamination in a district's agricultural medium reaches level 2, the loss to the added value of businesses in the agricultural sector and agricultural land values are rated as major and can have a total (100%) effect on the values before the accident.
This *modus operandi* (figure 3.1c), valid in the case of agricultural activity, is also used in the case of forestry in connection with contamination of the forest environment, for fishing in connection with the contamination of the River Rhone, for sea fishing in connection with contamination of the marine environment, for food in connection with contamination of the agricultural environment and for water distribution activity in

connection with the Rhone and underground water sources (whichever is more contaminated).

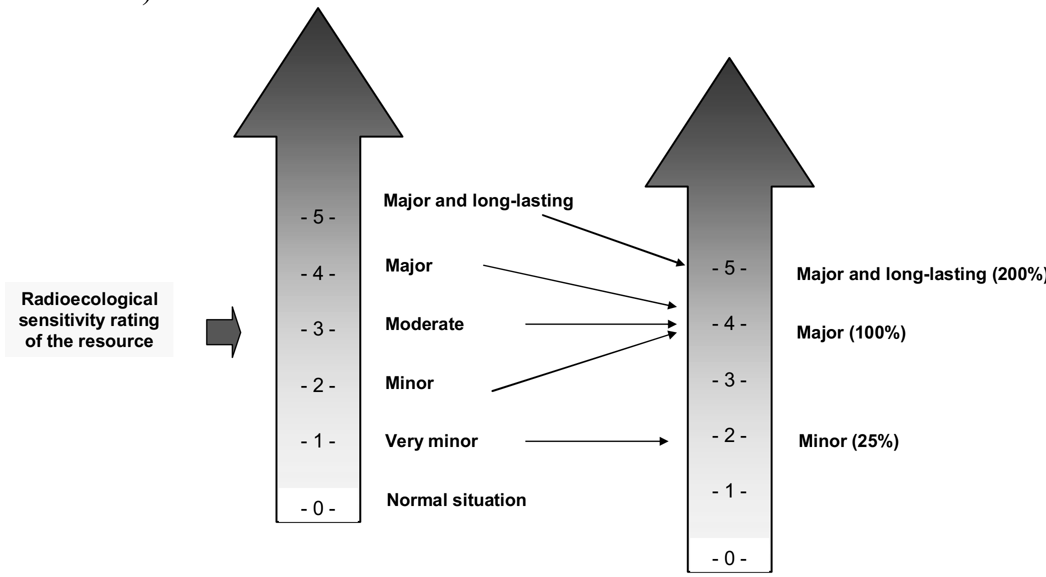

Figure 3.1c: Example of the relationship between radioecological and economic criteria for activities linked to the various media.

In the case of economic activity not directly concerned with the radioactive contamination of a specific medium (trades, the construction sector and industries other than the food industry), it was felt that the overall economic consequences would be of minor importance and therefore the proposed simplification retains only the first points on the scale (figure 3.1d).

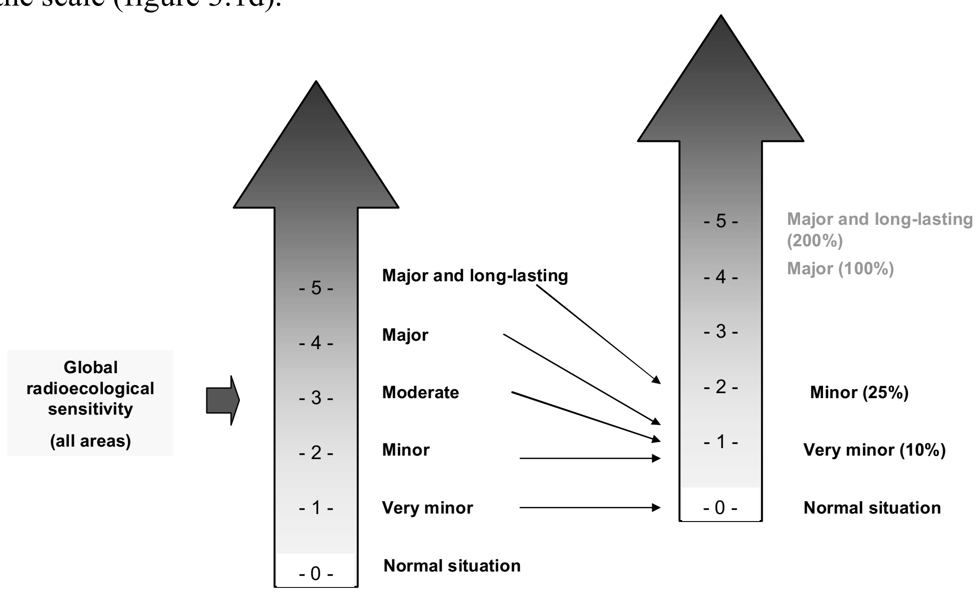

Figure 3.1d: Example of the relationships between radioecological and economic criteria in sectors not linked to a specific medium.

3.1.3. Societal stakes

In the PRIME project, the approach to social aspects of post-accident management is based on the concept of resilience. Determining resilience criteria thus means assessing the capacity of a district's population to react following an accident. This is a relatively innovative subject which is currently an area for research.
The variability criteria of this type of trauma are numerous. Research on risk perception (IRSN 2007) reveals criteria linked to the individual faced with risk: accustomed to risk, incomprehension, uncertainty, tacit acceptance, controllability, ethics... The French are particularly reticent in trusting the authorities with respect to pollution risks since they consider that risk management in this area is not easy to monitor. Certain other criteria with an influence on risk perception are linked to the social management of risk: identifying victims, trusting institutions, media coverage, advantage, equity. Other surveys show that in the population at large, different groups are characterised by their differences in approach to life (everyone has a perception of the world, imagining how best to make his way through life along paths defined by the values, beliefs and social networks which contribute to making a person who he or she is). And so resilience capacities will depend on social fabric, customs, experience and factors linked to collective behaviour. Depending on the group, the people who count will be different: influence of celebrities, imitation, influence of prominent citizens, of those close to us, influence of experts and administrators...
Depending on the geographical district, the average age, depending on the weight of associations and their activeness, the reactions will be different. Even though the existing bibliography has been studied in depth, current knowledge of societal reaction following a nuclear crisis is not sufficient to identify sound theoretical criteria for ranking the resilience capacities of populations.

3.1.4. Summary of PRIME method classification criteria

Figure 3.1e summarises all the criteria for vulnerability assessment recommended for assessing a district's global vulnerability to the consequences of radioactive contamination of the environment. All the information necessary for computing these criteria for each of the 491 geographical districts in the zone under study has been collected in a software prototype displaying the criteria values as a map and processing them using multi-criteria aggregation algorithms.

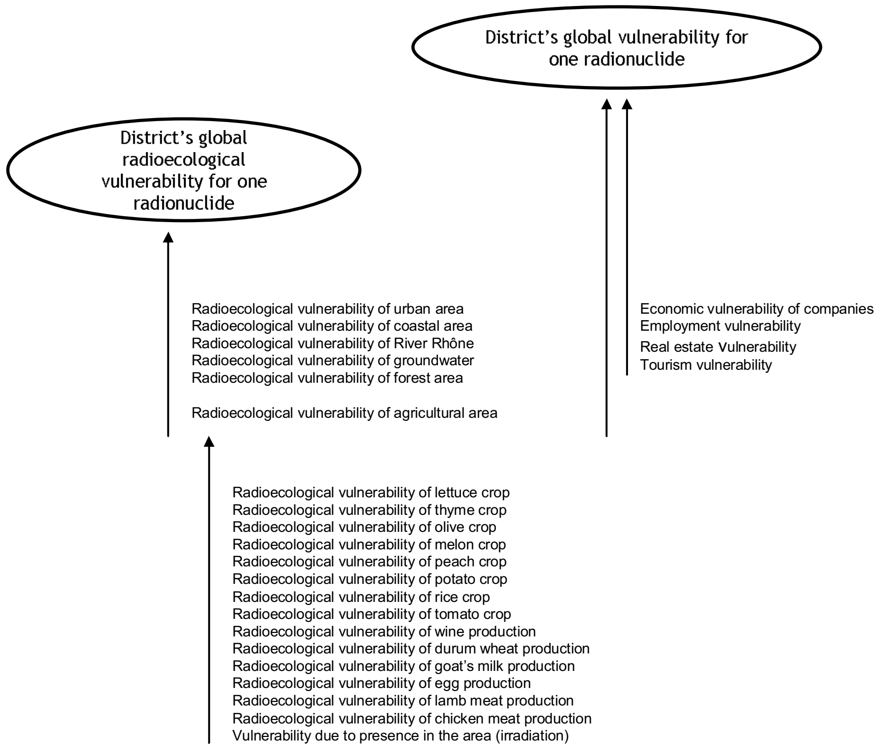

Figure 3.1e: Tree diagram of PRIME method vulnerability criteria

3.2. Implementing the multicriteria analysis core

Once the regional database has been completed (this being the matrix for the multi-criteria assessment), it is then a question of understanding how each stakeholder uses this information to prioritise, from his perspective, the global gravity of the impact on each district in addition to the districts with respect to each other. This phase of assembling the ratings is done together with the various members of the PRIME WG in order to validate the coherence of the resulting database and also to note similarities or differences in the way the stakeholders prioritise elements. To support this second phase of the PRIME project, the GIS/multi-criteria prototype tool was used both for obtaining a map representation of criteria assessment and collecting stakeholders' various points of view and to illustrate in real time any substantial modifications to this or that criterion.

Stakeholders' preferences were collected during one-to-one interviews between the project team and each stakeholder. The idea was to place each stakeholder in an imaginary post-accident management situation in a given region after providing them with the keys to understanding obtained by the PRIME method. The points tested during these working sessions concerned use of the vulnerability criteria set up by the PRIME WG to establish priorities. Are these criteria sufficient? What's missing? Based on this information, how are vulnerabilities prioritised?
These sessions lasted for about three hours. When stakeholders gave their permission, they were recorded to facilitate digital processing of the information they each

provided. Interview guidelines were established to organise the dialogue so that overall homogeneity of the different interviews was ensured. The points addressed consecutively during the interview are:

1. The goal of the work session. The aim is to rank each geographical district in the zone surveyed in the context of PRIME on a vulnerability scale from level 0 to level 5, for an imaginary accident scenario. This ranking is done twice during the interview (figure 3.2a): the first time on the basis of the contamination criteria of the district's various environments and the second time, integrating the economic consequences resulting from contamination of these environments.

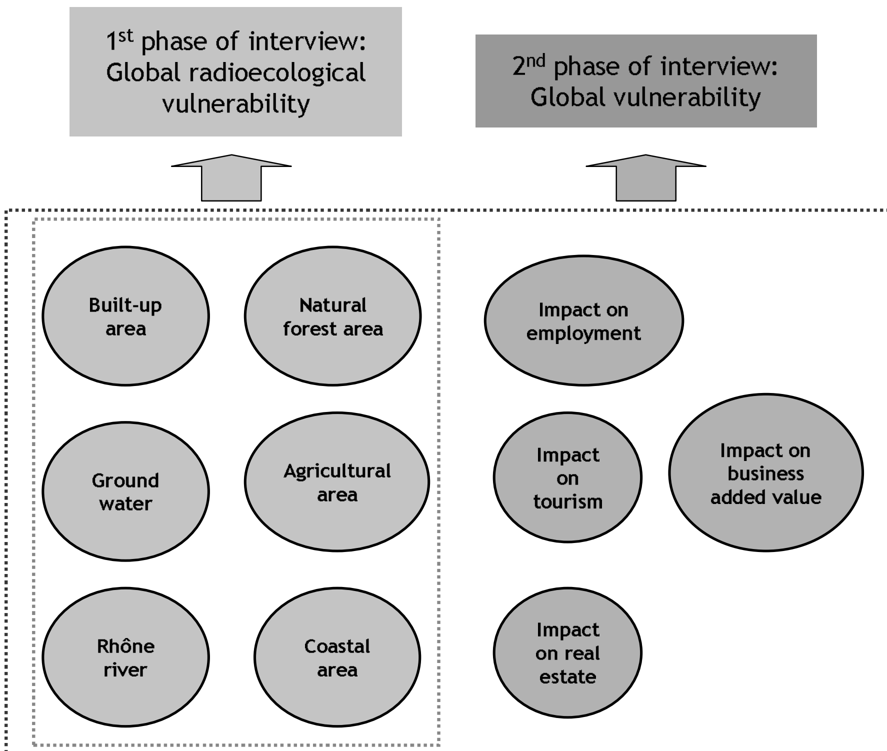

Figure 3.2a: Classification process presented during interviews

2. General presentation of the surveyed zone (figure 2a).

3. The classification scale and its interpretation (figure 3.2b).

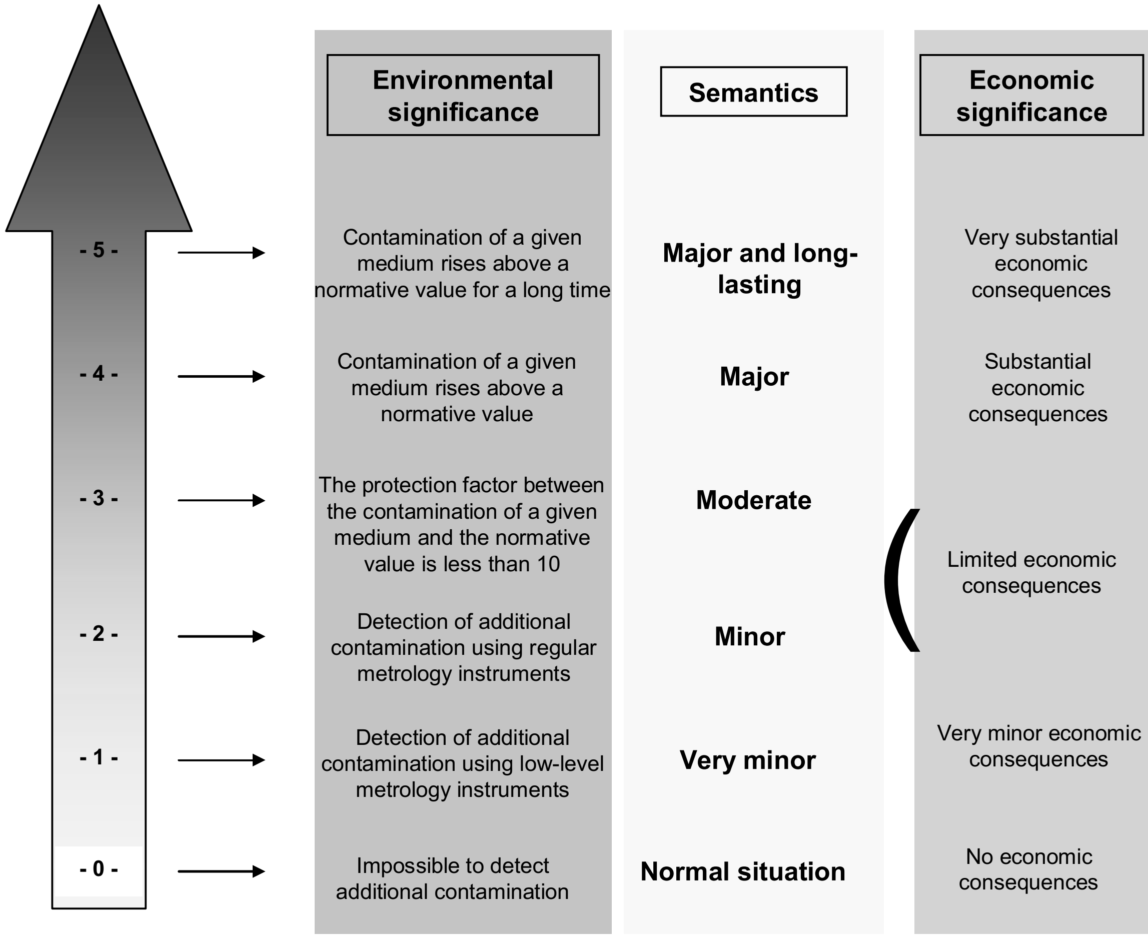

Figure 3.2b: Semantics of the classification scale presented during interviews

This phase of the interview is crucial since it entails providing the stakeholder with sufficient understanding of the PRIME classification method for him to assimilate it and apply it later on.

4. The fictional accident scenario: 10 GBq (=10 billion bequerels) cesium-137 are released non-stop into the atmosphere for 24 hours on 1st July 2008. Weather conditions during this 24-hour period remain constant: light rain and wind resulting in a substantial deposit of radioactive pollutants in the immediate vicinity of the site. The exercise begins on 10th July. The cesium-137 deposits are supposedly known and the experts have therefore been able to implement the PRIME method for computing criteria concerning the various environments in addition to the economic consequence criteria. Figure 3.2c illustrates the environment classification ratings in a map format as a result of applying the software prototype.

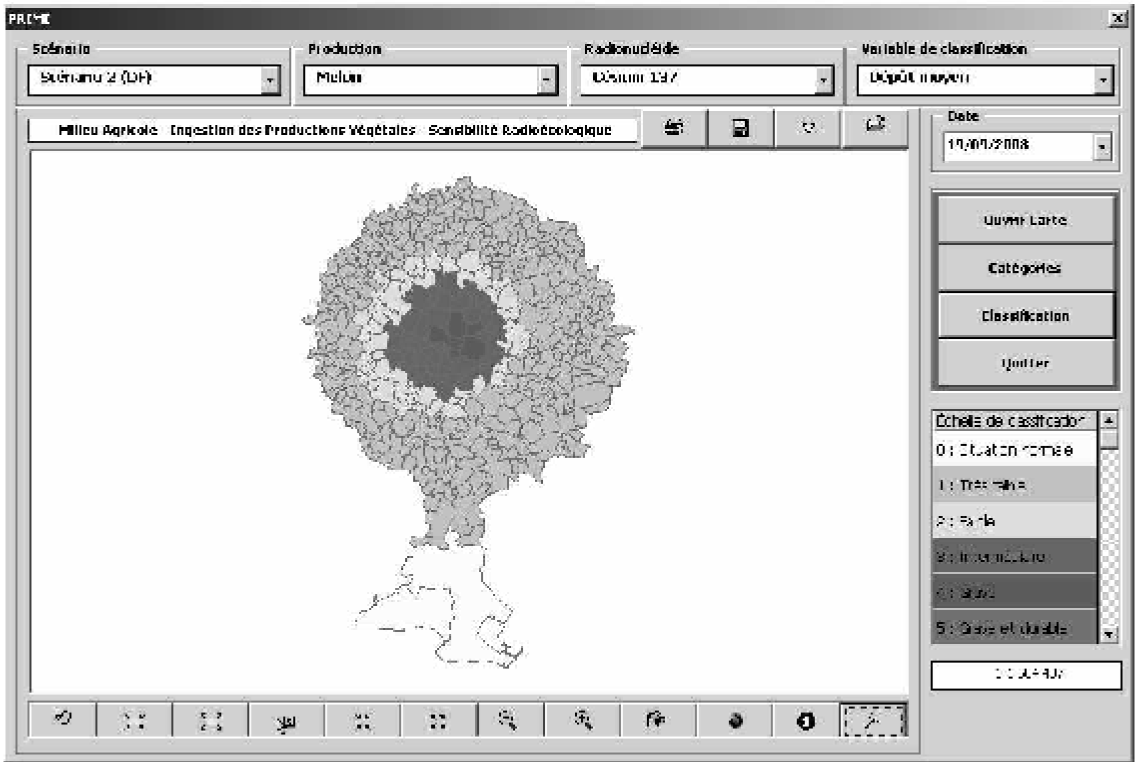

Figure 3.2c: Example of how environment classification criteria are presented (in French language)

This phase preparing for the simulation ends with the sentence "Now, you rate the global vulnerability of each district with a view to establishing action priorities..."

5. This is followed by the enumeration of 18 examples of districts presenting various combinations of classification ratings for each of the 6 environments (agricultural, built-up area, Rhône river, underground water supplies and coastal area). An example of how criteria are presented to stakeholders is given in figure 3.2d. For each geographical district, the stakeholder is then asked to define the value of the global rating of radioecological vulnerability or a range of values for this rating and then to distribute 8 counters along a cardboard ruler calibrated from 0 to 5 to illustrate his preference for one level of the classification scale rather than another.

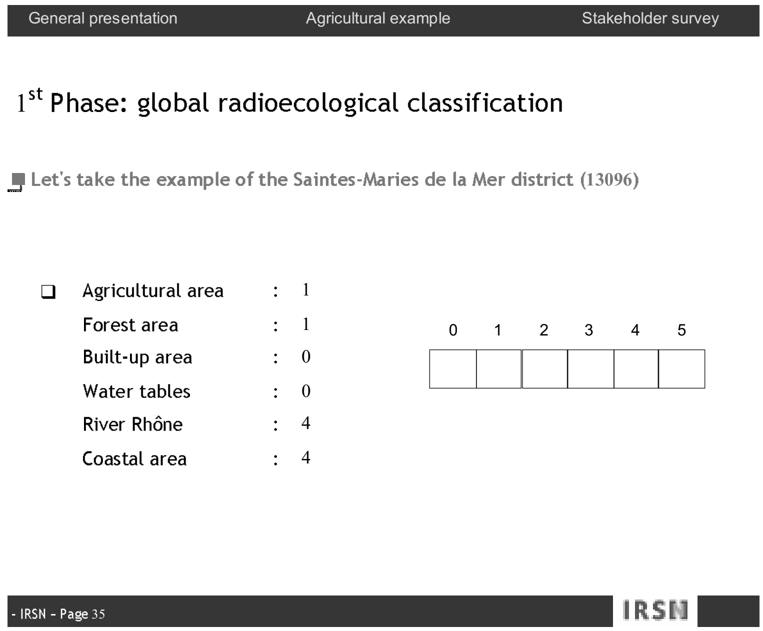

Figure 3.2d: Example of how information is presented during interviews

6. Once presentation of the 18 examples is over, the specific question of ranking the criteria linked to environment contamination by order of importance is addressed based on the Simos method (Simos 1990).

7. The method is then reapplied from point 5 onwards to include the economic criteria. The stakeholder has to propose a rating for each district based on the 6 criteria ratings relative to environment contamination plus the 4 criteria ratings relative to economic factors (real estate value, tourism, added value business and employment). He then uses the Simos method for the 10 criteria.

Two interviews have been carried out to date along these lines and 3 others are scheduled. To endorse the interview guidelines, the exercise was carried out by an engineer in the IRSN team on his own before tackling the interviews. There are currently 3 sets of data to illustrate the future potential for using the method once all the different points of view have been collected.

4. Results

Generally speaking, the interviews did not reveal any major difficulties in carrying out the simulation. The two stakeholders, one of whom had been present at all the PRIME WG meetings (labelled PP) and the other who had not (labelled CAL), both participated wholeheartedly in the simulation. The PP stakeholder nevertheless had some reservations concerning the validity of the global classification given the approach's many limitations with respect to economic criteria.

4.1. Radioecological vulnerability

Examples of results for the two stakeholders and for the IRSN engineer (labelled CM) are given in figure 4.1a, where a rating or range of ratings is assigned to sample districts and in figure 4.1b, for the Simos method results.

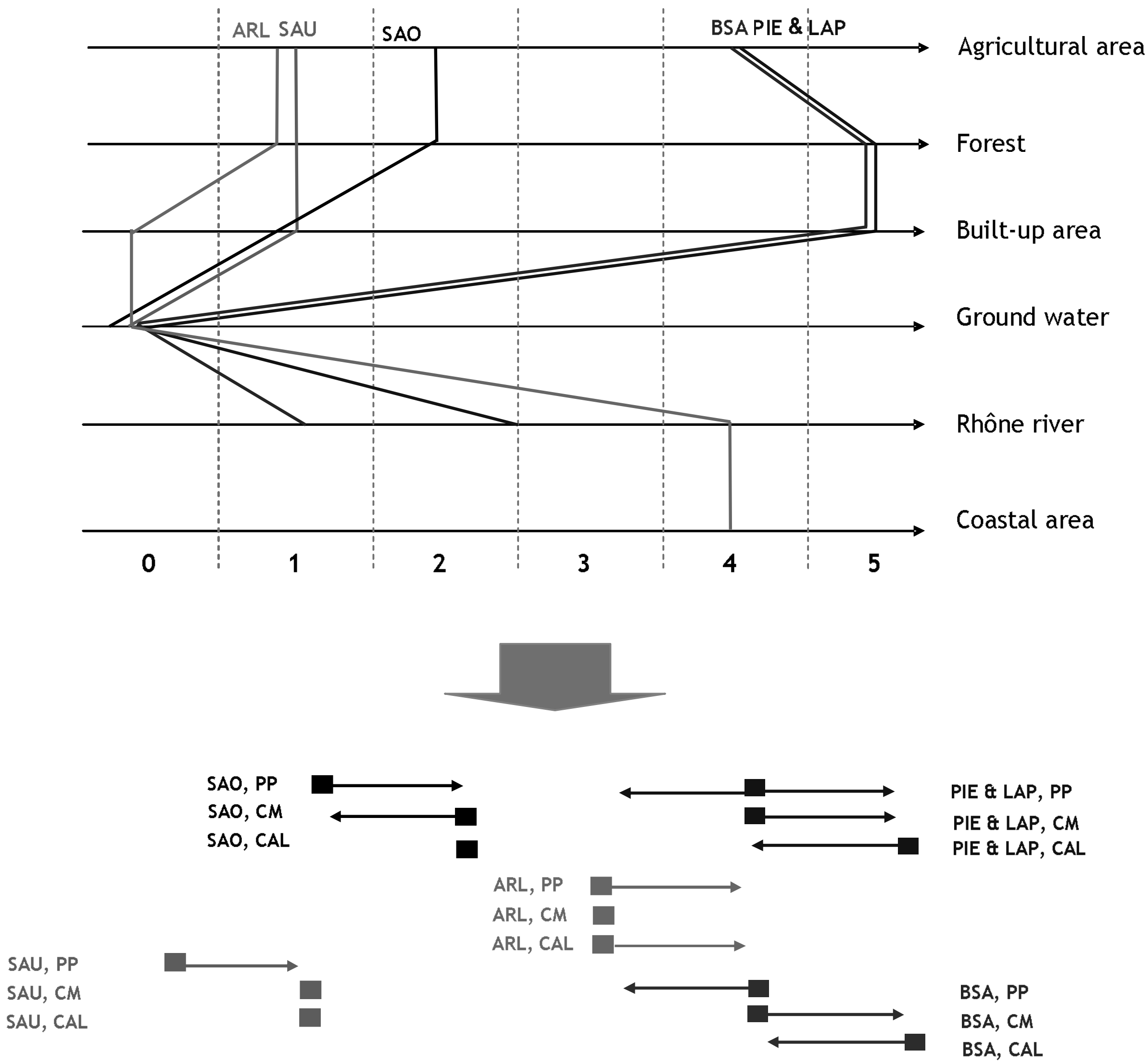

Figure 4.1a: Results for sample geographical districts

Figure 4.1a shows the profiles of environment criteria values for 6 districts labelled ARL, SAU, SAO, BSA, PIE and LAP. In the lower section of figure 4.1a, we find the ratings given by the stakeholders (■) and occasionally the range of possible ratings (←→).

The results obtained by the Simos method were used to establish the weighted values for each criterion and for each stakeholder, distributing a global weight of 100% among the various criteria in the order provided by the stakeholders. Since the number of radioecological criteria is variable depending on the district (some districts in the survey zone have no shoreline and therefore, no coastal area, and the River Rhône does not flow through others), the distribution of the global weight takes the unrepresented media into consideration by distributing their weight over the other media in the proportions determined by the Simos method. Thus, for the PIE district with no shoreline, the weight of 17 allocated by PP is redistributed among all the other media resulting in the following weighted values: 28 for the River Rhône, the water tables and the agricultural areas, 13 for the built-up and 4 for the forest areas.

These weighted values are then used as input parameters for the IRSN Sunset computer code which applies the ELECTRE TRI multi-criteria analysis method (Roy 1985; Mousseau 1993; Dias et al. 2002). The calculations are then used to define the possible range of ratings for each geographical district setting the majority threshold at 55%. The variability in ratings proposed by Sunset corresponds to the hypotheses retained to handle situations of indifference or incomparability. If these situations are processed from either a systematically pessimistic or systematically optimistic perspective, we obtain a possible range of ratings for each district in line with the order obtained by the Simos method.

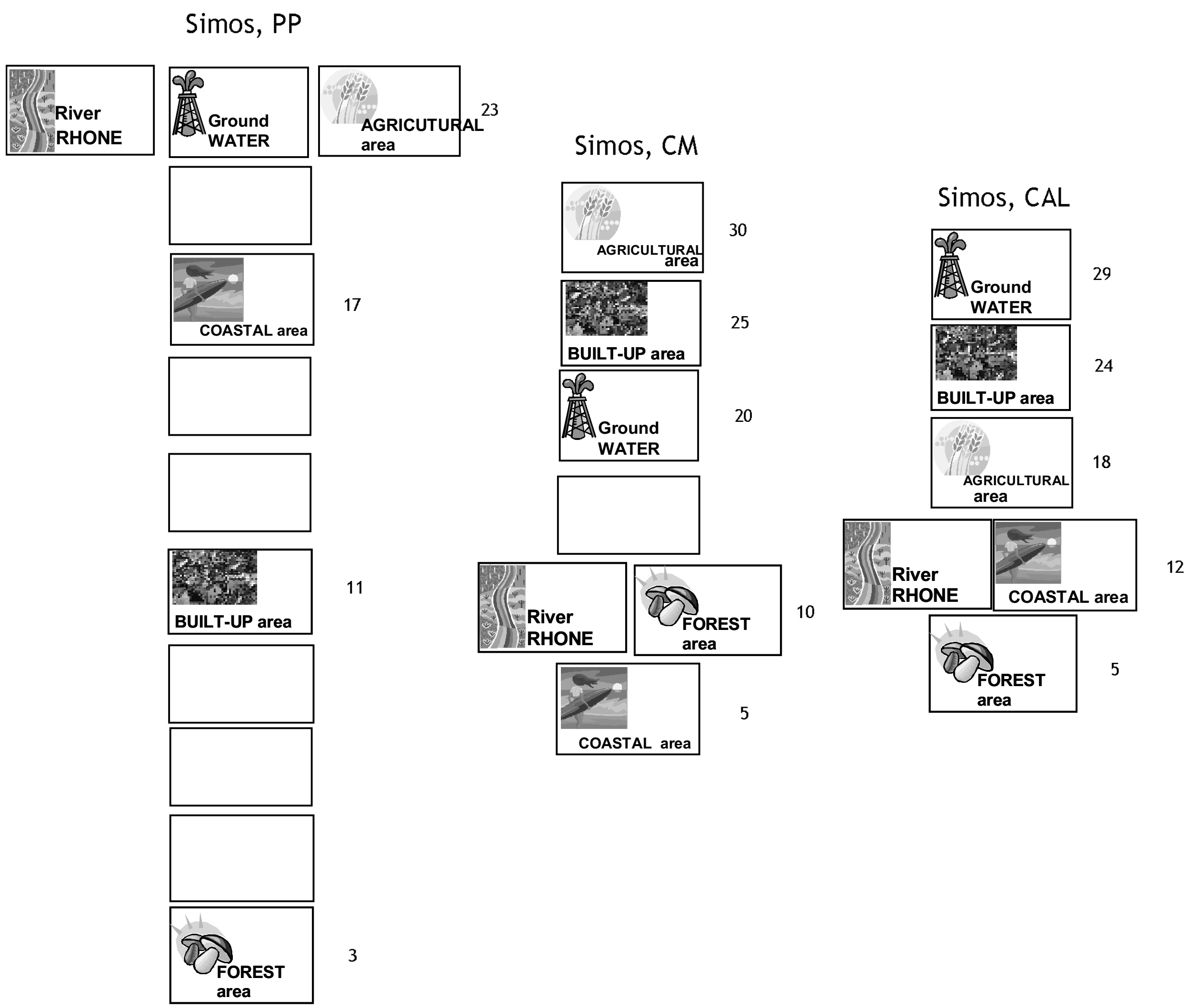

Figure 4.1b: Results of the Simos method for radioecological vulnerability (to the right of the cards, the weighted values when all media are represented)

On the whole, the three stakeholders applied the same reasoning to prioritising environments: “people first, then the environments” (quote from one of the interviews). The first resources needing protection are therefore water (underground water supplies and in some cases the Rhône), foodstuffs (agricultural areas and maybe the sea) and/or housing (built-up areas). One of the stakeholders recognised that he was “particularly fond of the coast, a fact which could lead him to considering coastal areas as the equivalent of agricultural areas if there were an accident in a coastal zone". The other stakeholders consider the coast, and also forest areas, as leisure areas.

Table 4.1A shows that examples of stakeholders’ ratings are sometimes at odds with results processed using the Simos method.

Table 4.1A: Comparison of the stakeholders' direct ratings for environment contaminations with the Simos method results, processed by the Sunset software.

	CM stakeholder		PP stakeholder		CAL stakeholder	
Geographical districts	Rating	Sunset	Rating	Sunset	CAL Rating	Sunset
PIE	4	4-5	4	4	**5**	**4**
LAP	4	4-5	4	4	**5**	**4**
BSA	4	4-5	4	4	**5**	**4**
BOL	5	4-5	4	4	**5**	**4**
VIC	3	2-3	2	2-3	**3**	**2**
SAU	1	1	0	0-1	1	1
AVI	**3**	1-2	2	1-2	2	1-2
BED	1	1	1	1	1	1
AUB	3	2-3	2	2-3	2	2-3
VAL	3	3	2	2-3	3	3
GRA	3	3-4	2	2-4	3	3-4
LUS	3	2-3	2	2-3	3	2-3
BEA	2	2-3	2	2-3	3	2-3
MON	2	2	1	1-2	2	2
VES	2	1-2	1	1-2	2	1-2
SAO	2	1-2	1	1-2	2	1-2
ARL	**3**	**1**	**3**	**1-2**	**4**	**2**
STE	**3**	**0-1**	**3**	**1**	**3**	**1-2**

The systematic disagreement for the AVI, ARL and STE districts is due to the minority criteria for the River Rhône and the sea which do not have enough influence on the ELECTRE method result to move the rating up the scale to another category, being blocked by the other criteria globally in majority. A solution for compensating this drawback would be to lower the majority threshold to 35%. This option would mean that the method could be adapted to the stakeholders' reasoning according to which when there are enough criteria with the same value (even if this does not represent the majority of criteria in the voting sense), then this vulnerability rating value could be assigned to the district as a whole.

For the CAL stakeholder, disagreement concerning the districts rated 5 (PIE, LAP, BSA and BOL) can be explained by the fact that CAL gives a 5 rating as soon as any major criterion is rated 5. According to this stakeholder, "There is a major difference between the levels 1-3 and the levels 4-5; for levels 1-3, we're talking about monitoring and we are going to establish averages; for levels 4-5, we enter the sphere of health impact and here we're going to be dealing with extremes, we're talking about actual figures and no longer about averages". From a formal point of view, we could take this reasoning into consideration by applying a veto process to the environment contamination criteria as soon as one of them is subject to major and lasting impact.

Finally, if we aggregate the Simos method results for the three stakeholders, we obtain the following sequence (the sum of weighted values for the three stakeholders is in brackets):

Groundwater (72) ~Agricultural area (71) > Built-up (60) > Rhône (45) > Sea (64) > Forest (18)

4.2 Global vulnerability

The results for global vulnerability (criteria linked to environment contamination plus economic criteria) were processed in the same way as for radioecological vulnerability. Figure 4.2a shows the Simos method results for all 10 criteria.

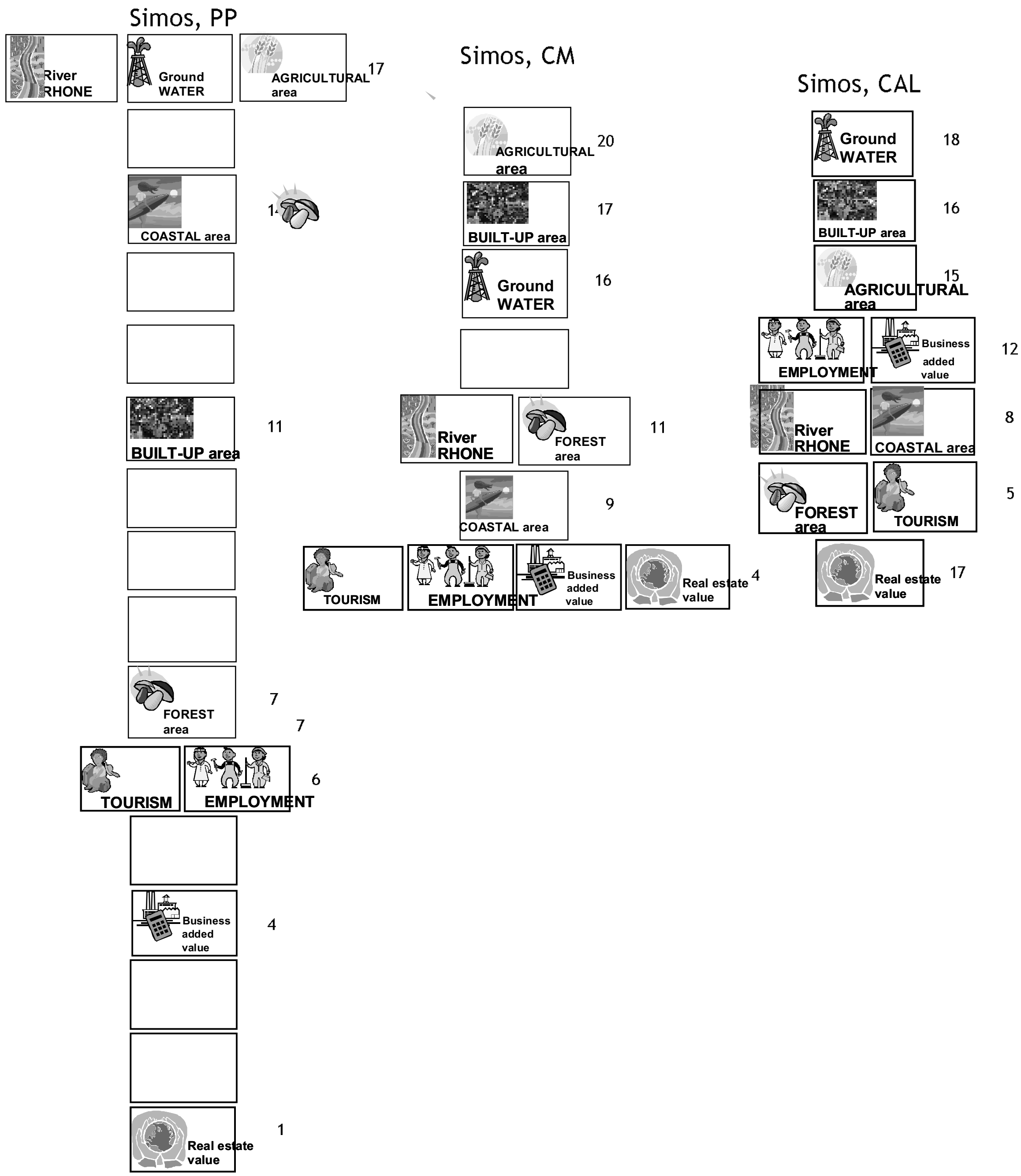

Figure 4.2a: Simos method results for global vulnerability

On the whole, the stakeholders feel that economic criteria are less important than criteria linked to environment contamination. This is particularly the case for the stakeholders PP and CM who give economic criteria a total weighted value of 17 and 16 respectively. For these two stakeholders, awareness of the numerous limitations encountered when creating the economic criteria probably has an influence on the way they use them. These two stakeholders believe that there are two groups of criteria: those linked to environments and those linked to economic factors. The third stakeholder makes finer distinctions in his reasoning and believes the criteria fall into three groups: the water tables and built-up areas (protection of man), agricultural areas, employment and added value (protection of human activities perceived as fundamental), the Rhône river, coastal areas, forests, tourism and real estate (protection of human activities perceived as secondary). This stakeholder nevertheless recognises that with respect to "groundwater, built-up and agricultural areas, we can be proactive and make decisions. With respect to the added value of businesses and employment, the State will be reduced to providing support in the light of consequences". The issue of differences in temporality was also raised by the stakeholders during the various interviews: "action kinetics differ depending on the environment", which leads to ranking agricultural and built-up areas as being more vulnerable whereas *a contrario* they will probably be less lastingly affected than forest areas.

Table 4.2A shows that examples of stakeholders' ratings are sometimes at odds with the Simos method of processing results. In particular, we see the effects of minority criteria and veto mentioned in the previous paragraph.

Table 4.2A: Comparison of the stakeholders' direct ratings for global vulnerability with the Simos method results processed by the Sunset software.

	CM stakeholder		PP stakeholder		CAL stakeholder	
Geographical districts	Rating	Sunset	Rating	Sunset	CAL Rating	Sunset
PIE	4	4-5	4	4	**5**	**4**
LAP	4	4-5	4	4	**5**	**4**
BSA	4	4-5	4	4	**5**	**4**
BOL	5	4-5	4	4	5	4-5
VIC	3	2-3	2	2-3	3	2-3
SAU	**0**	**1**	**0**	**1**	1	0-1
AVI	**3**	**1-2**	2	1-2	2	1-2
BED	**0**	**1**	**0**	**1**	1	1
AUB	3	2-3	2	2-3	2	2-3
VAL	3	3	2	2-3	3	2-3
GRA	3	3	2	2-3	3	2-3
LUS	3	2-3	2	2-3	**3**	**2**
BEA	2	2	2	2-3	**3**	**2**
MON	2	2	1	1-2	2	1-2
VES	2	1-2	1	1-2	**2**	**1**
SAO	2	1-2	1	1-2	**2**	**1**
ARL	**3**	**1**	**3**	**1-2**	**4**	**1**
STE	**3**	**1**	**3**	**1-2**	**3**	**1**

For CM stakeholder, the economy has little influence on the global ranking of districts. Information on economic criteria leads the PP stakeholder to give quite a surprising rating to SAU and BED which should perhaps be checked with this stakeholder. For CAL, the order of criteria proposed by the Simos method should lead to changing the ranking of the LUS, BEA, VES and SAO districts whereas the stakeholder maintains his rating.

Finally, if we aggregate the Simos method results for the three stakeholders, we obtain the following sequence (the sum of weighted values for the three stakeholders is in brackets):

Groundtables (51) ~ Agricultural area (52) > Built-up (44) > Rhône (36) > Sea (31) > Forest (23) > Employment (22) ~ Added value (20) > Tourism (15) > Real estate (6).

The two economic criteria in top position are the impact on employment and the added value produced by businesses. This indicates that stakeholders first consider the consequences on economic activity generated by the geographical districts. Tourism is however close behind because in this region, tourism is also one of the main sources of income and the existence of strong links between these three criteria is mentioned during the interviews. The stakeholders also link economic criteria to the environment contamination criteria (for instance, employment and added value are linked to the agricultural area, real estate and tourism are linked to the forest area), thus confirming the relationships computed by the PRIME WG between the ratings for environment contamination and the ratings for economic consequences.

4.3 The approach's advantages and limitations and prospects

The PRIME project is based on an operational method which is somewhat innovative in the world of nuclear applications. The innovation lies mainly in the process of developing the method on the basis of dialogue, a process which allowed plenty of room for debate. Throughout the PRIME project, the traditional methods of assessing risks linked to the release of radioactive substances into the environment have been confronted with the region's perceptions of the event as expressed by the decision-makers (prefecture, mayor, safety authority) and by civil society representatives (associations, information centres). This desire to include a wide range of participants nevertheless came up against the practicalities of establishing a working group which necessarily limits the number of participants. To offset this difficulty, interviews with stakeholders other than those comprising the PRIME WG were carried out in parallel to the WG meetings.

The PRIME project enabled the creation of a database mapping the pertinent indicators for prioritising a region's vulnerability in the event of a nuclear accident. Research focused mainly on building a tool (coupling GIS software with a multi-criteria aggregation algorithm) and searching for available data to feed into it and also discussion on the limitations of this data. It is obvious that expectations in terms of decision-making tools go well beyond the mere characterisation of regions' vulnerabilities. During interviews, some stakeholders were clearly frustrated in not being asked the question “And what decision would you make here?”. One stakeholder suggested applying the ranking method to a scenario, deciding on a course of action and then determining if this action was really pertinent and applicable in view of the foreseeable consequences on both environment contamination and the economy. The stakeholders nevertheless recognise that characterising vulnerabilities is a fundamental prerequisite before contemplating action but determining strategies to reduce vulnerability could be considered a necessary extension to the PRIME project.

7. Conclusion

The use of multi-criteria analysis methods in the PRIME project has two advantages.
On the one hand, building the multi-criteria analysis method (discussing the pertinence of criteria, deciding on criteria assessment methods, identifying the limits of shared knowledge) leads to structuring information exchanges between participants and establishing a trusting relationship among them. During development of the methodology, relationships were undeniably established between experts in the technical fields of radioecology and radiation protection and regional stakeholders who generally have little experience in these fields but who are well-placed for contributing information on how things work in their region. The evaluation tools and in particular, the computer codes used for assessing environmental consequences were therefore improved thanks to information contributed by the regional stakeholders, which led to modifying the generic data sets to adjust them to the local context of the PRIME survey zone. At the same time, regional stakeholders improve their understanding of how the regions are represented on the administrative level and how this information is used to prepare management decisions.
On the other hand, with multi-criteria analysis methods it becomes possible to express the perspectives of the various participants, identify common practices in prioritising a region's vulnerabilities and characterise the differences. The PRIME exercise thus aims to make progress towards achieving a “differentiated consensus” (Noucher 207). In point of fact, the wide variety of participants in the PRIME WG makes it impossible to come to a compromise as the ideological gap between the organisations consulted reveals substantial limits to their cooperation. However, revealing differences in values attributed to this or that criteria or factor facilitates mutual understanding of the different ways of prioritising a region’s vulnerabilities and results in a more global vision without concealing the particularities of the various participants. Ultimately, decisions concerning the management of contaminated regions will remain the prerogative of State departments but the information made available to them will portray these contrasting views with respect to local vulnerabilities.

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