Environmental notions representation and description: Towards a redefinition of the relationships between information systems development and individual cognition

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Abstract

Environment is a broad and complex issue. It is likely be inaccessible to most laypersons, whereas, environmental experts are likely to have a limited field of expertise. Hence, there is a need for comprehensive and accurate environmental information in many situations. This research aims at building a tool providing basic scientific terminologies about the environment associated with a graphic and interactive model structured around six levels: Activities - polluting processes – pollutants - types of pollution - potential effects and impacts on humans and ecosystems. We approach this development through the framework provided by the field of knowledge management (KM) and information system (IS). It allows analysing the relative importance of tacit dimension of individual knowledge compared to tangible information sources during the development of IS. It appears that in complex scientific domains like the Environment, physical sources of information and the deterministic approaches of exact sciences remain important. The next steps of our research will investigate the interpretation,

I.N. Athanasiadis et al., *Information Technologies in Environmental Engineering*,
Environmental Science and Engineering, DOI 10.1007/978-3-540-88351-7_40,

the user's knowledge acquiring process and the willingness to use this tool whose development required many theoretical modelling phases.

1. Introduction to the concept of environmental notions description and representation

1.1. Environmental information: incomprehension and accessibility

Nowadays, environmental information plays a key role in various situations. In the public sector, it guides environmental decision-making processes [4]. In companies, communicating on environmental performance help to legitimise actions and to maintain the confidence of stakeholders [17]. At the general public level, environmental considerations modify some behaviour (e.g. responsible consumption).

Therefore, environmental studies increase. Many methods and tools are developed in order to assess environmental impacts (Life Cycle Assessment *henceforth LCA*, Environmental and Health Risk Assessment *henceforth EHRA*…). Hence, environmental information is produced in an important quantity and in many various forms [14].

However, **despite this abundance of environmental information, the needs for environmental information remain paradoxically dissatisfied**. Environment is indeed a polysemous [8], transdisciplinary [16], broad and complex [15] field. It is scientifically defined as the ecological component of the human quality of life [20], i.e. consisting of all living (people, fauna and flora) and inert (natural and artificial) elements composing human's area of life and all the interactions between them. Therefore, it includes various and heterogeneous notions (greenhouse effect, noise, species extinction ...) whose plurality and complexity are particularly difficult to grasp. *Environmental science* is a transdisciplinary field of research [16] lying at the crossroads of several disciplines (ecology, biology, chemistry, physics, geography…) that are often segregated from each other and sometimes contradictory.

These characteristics of environment lead to **difficulties, even impossibilities, of having a perfect knowledge of all its facets**. Each area of expertise has indeed specific rules (assumptions, models…) that do not allow them to describe the whole environment subject. Without a good overview of environment and a good understanding of the issues involved, laypersons solicit directly experts for their information requests. These requests are often vague so that their treatments are difficult and usually involve knowledge beyond the scope of an expertise. It is the case of questions such as "*Is the production of electricity from natural gas good or bad for environment?*" whose objective answering require information from both global environmental assessments such as LCA (e.g. global pollutants inventory such as greenhouse gases…) and local approaches such as EHRA (e.g. local pollutants inventory such as hydrazine).

In other words, the understanding of environment is one of the determinants of access to environmental information [13]. Actually, it seems necessary, for any actor - especially for those who have little or no expertise on the environmental subject - to have both an overview of it and basic notions about the concepts that compose it.

1.2. The project

In order to address this lack of environmental notions understanding, an assessment was initiated by Electricité De France R&D (EDF R&D) within the French Cooperative Research Network on Waste (RECORD[1]) in 2005. It proposed the *cartography of environmental issues* (Fig.1) as a means for establishing a general overview of the environment [21].

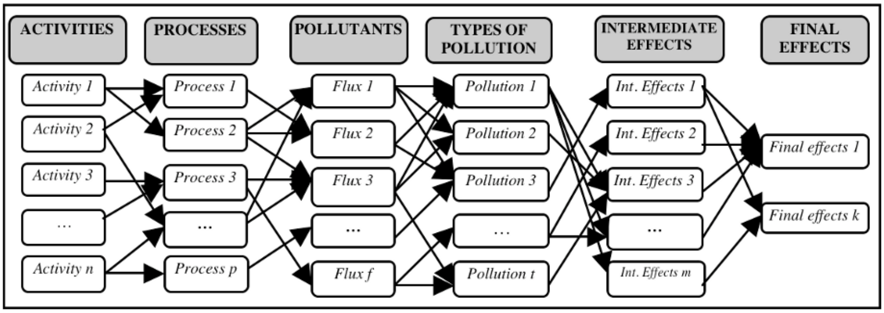

Fig. 1. Cartography of environmental issues [21]

The cartography of environmental issues (Fig. 1) is a model structured through an *impact pathway* overview containing six levels. It should be interpreted as follows : "*Each activity involves one process or more which release pollutants in the nature. These pollutants induces many different physical and chemical modifications (pollutions) which might lead to direct or indirect effets on the elements of the ecosystem*". The white cases represent environmental notions and the arrows represent the causal links between them.

[1] RECORD: Réseau Coopératif de Recherche sur les Déchets

Following this goal of environmental comprehension enhancement, our work aims at developing an interactive tool based on this cartography of environmental notions. The task consisted concretely on environmental notions inventory, their classification within this cartography and the association of a simple description to each of them. The software development (formal ontology development, deployment…) was conducted by an external computing service company hired by EDF R&D.

2. Methodological framework

2.1. Empirical questions

The model for environmental notions representation (Fig. 1) was tested on a pilot experiment covering two particular environmental problems (*wind-mill* energy and *carbon dioxide emission).* We encountered several difficulties linked with information gathering, representation and redaction which raised a number of important questions: *What type of information should be retained? What are the criteria for evaluating its scientific quality (validity, objectivity ...)? Where can it be found? Who should be involved in developing the information system? How to ensure that the system can be useful and accessible?*

Such issues are mainly related to the vagueness on the material (*Information and technology*) and human elements (*sources of information, tool developers and users*) of the information system (IS) for representing and describing environmental notions. In other words, the difficulties encountered were related to the relation that should be established between the human dimension and the material dimension of the IS, i.e. in what extent and in what order should they be considered during the IS development.

2.2. Theoretical concerns in the field of Knowledge Management (KM) and Information Systems (IS)

The consideration of the material and the human dimension is central to the debates in the management of IS and knowledge management (KM). Admittedly, as acknowledged by Weber (2007) [29], the integration of both dimensions in IS and KM approaches is one of their most important success factors. Nevertheless, it seems that the existing approaches consider human and Information Technologies (IT) in different proportions. This causes an epistemological debate between two main visions [24]: *(1)* the vision of those who consider IT as a support needed for the production, the capitalization and the transfer of structured and non structured information, which will provide knowledge ([22], [26]…) and *(2)* the vision of those who consider IT as the outcome of a KM process [27] i.e. constructed through a knowledge formalization.

According to Galliers and Newell (2000) [7], this debate refers to two major approaches. On the one hand, there are those who focus on the material dimension, mainly on its technological part. These *top down* approaches are promoted by researchers in IS such as Adam and Fitzgerald (1996) [1]. On the other hand, there are human centered approaches promoted by the organizational behaviorists such as Swan et al. (1999) [26]. This last family of approaches is characterized by another epistemological debate related to the boundaries and the definitions associated with the notions of tacit knowledge ([9], [12], [27]…). These conceptual differences lead to, at least, the two separate theoretical assumptions formalized by Hedesstrom and Whistley (2000) [12] (Table 1).

Type of tacit knowledge	Typical reason
Knowledge that **cannot** be formalized	Because it is embodied Because of the form of the knowledge
Knowledge that **has not yet** been formalized	Because of cost/time limitations

Table 1. Different types of tacit knowledge [12]

The first theoretical assumption, designed as *de facto school* by Hedesstrom and Whistley (2000) [12] follows Polanyi's (1966) [19] line of thinking. It claims that tacit knowledge, constituting the main part of individual knowledge, is the non-articulable part of individual knowledge insofar as they reside in their heads and are strongly embedded in their actions ([19], [27]…). The best way for sharing them between individuals is social interaction. This theory refers to *bottom-up* approaches i.e. approaches based on people, their perceptions and their interactions.

The second theoretical assumption, appointed by Hedesstrom and Whistley (2000) [12] as *difficulty school,* includes authors who assert that tacit knowledge is knowledge difficult to articulate, but it can be made explicit i.e. articulated and transformed into information or data through some appropriate devices (e.g. [18], [6], [2]). Various forms of codification may be used (e.g. oral or written text, various ITs) but the effective transfer of knowledge among individuals depends on the fact that they can interpret and internalize the tangible information through their interpretative scheme ([28], [10]). This moderate relativist vision (*middle vision*) refers to a wide variety of approaches such as those focused on processes [11], those focused on users [25]…

In short, the question of taking into account the human dimension and the material dimension (technology and information included) refers to 3 main families of approaches: *top down*, *bottom-up* and *middle* (Table 2).

Approach	***TOP DOWN***	***MIDDLE***	***BOTTOM UP***
Focused on…	MATERIAL DIMENSION (IT and information)	HUMAN DIMENSION	HUMAN DIMENSION
Main visions	IT is a necessary support for information management and knowledge creation	An IT and/or information modeling could be proposed *a priori* but should be validated and/or modified from people's point of view.	The solution only emerges from the observation of humans' interaction.
	Human dimension is not considered *a priori*.	Human tacit knowledge could be articulated by using appropriated means.	Human tacit knowledge couldn't be articulated. It should be gathered through social interaction.
Approach based on…	Theoretical formalization of IT and information	Mix of theoretical modeling and human interaction	Human interaction

Table 2. Different families of KM and IS approaches defined by the relationships between material dimension and human dimension of IS

Actually, there are not any references determining which of these approaches is best suited to a specific type of KM problems. In this paper, we try to answer this question for the problem of information, knowledge sharing and comprehension in the field of environment.

3. Method and tools

For identifying the approach for the development of the environmental notions representation and description system, we analyzed the benefits and limitations of the three families of approaches identified above regarding their practical feasibility and the expected quality of the results (validity and acceptability) (Table 3).

Approach	TOP DOWN	MIDDLE	BOTTOM UP
Validity of the results	Controversial (-)	Acceptable (+ / -)	Valid (+)
Feasibility	Easy to apply (+)	Flexible and controllable (+ / -)	Long duration (-)

Table 3. Advantages / limits analysis of the families of KM and IS approaches

- The *top-down* approaches, based on an *a priori* theoretical formalization of environmental information system would allow attaining rapidly the development. However, since it is only based on one point of view (the developer's conceptualization), it has the inconvenient of achieving a result that may be questionable, even unaccepted by the actors.
- The *bottom-up* approaches, focused on finding solutions through the combination of the different actors' points of views, would ensure the validity of the result. Nevertheless, they have limitations related to the duration of the study since their feasibility depends on the availability of actors.
- The *middle approaches*, combining the work of formalization, observation, collection of actors' ideas and/or needs, allow to achieve acceptable results. Compared with bottom-up approaches, they are much easier to implement since they are flexible insofar as they allow the developer acting and having much more control on his/her approach.

Because of these characteristics (acceptability and flexibility), we adopted a middle approach. It will allow us to both achieve the IS development and to observe the importance of the tacit dimension of individual knowledge on information gathering, modelling and description during the development process. We used the *Research Intervention* approach [5] that includes several phases of observation, interviews among the members of the company and theoretical modelling.

- The initial formulation of the problem addressed here and the first formalization of the solution (the RECORD model associated with the tool) have been made by RECORD (2005) [21] as mentioned above.
- Due to the novelty of the idea, the future users of the tool in the firm and its contexts of use cannot be defined *a priori*. Then, interviews have been conducted only with potential sources of information, namely: *(i)* EDF R&D environmental experts i.e. LCA specialists (4 actors) and EHRA ex-

perts (3 actors) and *(ii)* an academic expert in environmental sciences: Professor RAMADE[2] from the University of Orsay (France).
- The theoretical modelling phases refer to the activity of formalization conducted on the basis of physical sources of information such as reports, databases, generic works in environmental science and academic articles.
- Environmental information related to 9 electric power plants (nuclear, hydro, coal, gas, fuel, biomass, wind, marine and photovoltaic) have been used as case-studies.

4. Results

4.1. The model

The structure of the model, through an impact pathway overview with 6 fields, was maintained. Some fields were renamed. As much as possible, nomenclatures (categories and subcategories) (Fig.3) were associated to each field in order to facilitate the environmental notions positioning.

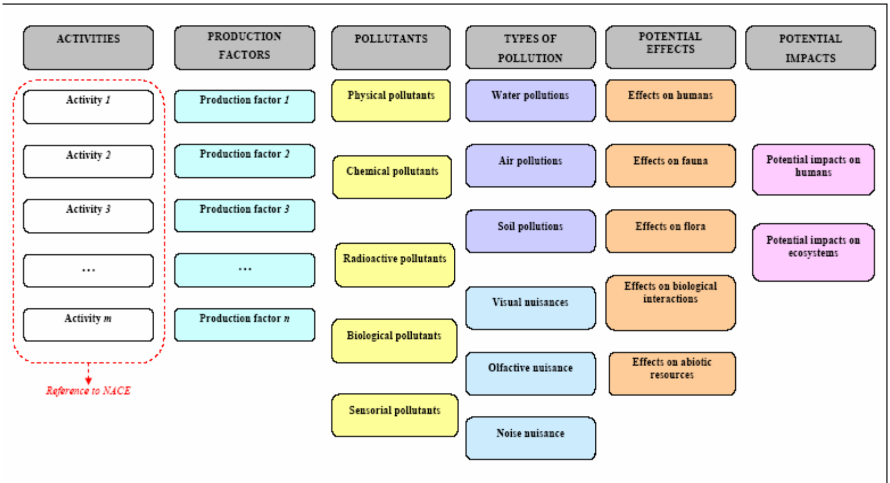

Fig. 2. Final model for structuring and representing environmental notions

[2] Professor RAMADE is the author of many recognized references on environmental sciences (*Dictionary of environmental science and ecology, Dictionary of pollutions, Introduction to ecotoxicology…*)

This model is supported by a graphic clickable interface. It is integrated on EDF R&D intranet website as a wiki platform. Each environmental notion (represented by cases) is linked to a page that provides its description. At this time, the tool contains 309 notions, namely:

- 1 activity: electricity production
- 9 production factors: the 9 electric power plants
- 95 pollutants including 75 chemical pollutants (global and regional pollutants such as green house gases, sulfur oxides, nitrogen oxides… and local pollutants such as chloroform, hydrazine, formaldehyde…), 14 radioactive pollutants (^{3}H, ^{14}C, ^{131}I, ^{110m}Ag, ^{63}Ni…), 2 sensorial pollutants (noise and infrasonic vibration), 3 physical pollutants (atmospheric surface occupation, dry and wet land use) and 4 biological pollutants (micro-organisms such as *Legionella, Amoeba, Non-cholera Vibrio* and *Cyanobacteria*)
- 172 types of pollutions including nuisances (noise, visual and olfactive nuisances), different pollutions on air, water and soil
- 24 potential effects on the elements of ecosystems including effects on human health, on fauna, on flora, on biological interactions (predation, parasitism, commensalism…) and on abiotic resources (natural resources such as boulders and artificial resources such as buildings and monuments)
- 8 potential impacts on human beings (quality of life, mortality, morbidity and natality) and on biodiversity (biodiversity loss, species extinction, impacts on ecosystem productivity and distribution)

The right part of the model (including potential effects and impacts) is invariable i.e., it could be used for other sectoral applications. The right and the middle part (activities, production factors, pollutants and types of pollution) need to be completed for other applications (e.g. agriculture, transport…). Nevertheless, most of the conventional pollutants (carbon dioxide and other green house gases, toxic metals, particles…) and their respective behaviour in the air, soil and water are already considered.

Each information sheet contains general notions about the environmental issue, its origins (natural and anthropogenic sources), its potential effects, some key-figures and/or anecdotes related to its extent and a list of references useful for learning more about it.

The tool allows the user discovering information in two ways. Firstly, he/she can explore the graphical structure by clicking on a case for highlighting the cases and the links related to the notion and for accessing to its description. Secondly, the user can use queries using full-text requests.

In its aim of providing simple description and classification of environmental concepts, this tool has some similarities with the on-line thesaurus of environmental themes such as GEMET[3]. The additive contribution of our tool is the graphic visualization and exploration which might enable the user to have an intuitive overview of the environment.

4.2. Implementation and findings

The approach was divided into 3 main steps, namely *(1) a preparatory phase, (2) an inventory of environmental notions and (3) a description of environmental notions*. Each step was conducted through a process of testing – errors, iteratively composed by theoretical modelling phases and a serial interviews with eight actors.

(1) The **preparatory phase** was an attempt to fill the model RECORD through interviews with the 4 members of the core team who pilots the project of environmental notions representation and description (EDF R&D's LCA team). These initial interviews concluded to a need for clarification of the proposed model. They clearly asserted that the titles of some fields of the initial model (namely on the "processes", "intermediate effects" and "final effects" fields) which may be misleading have to be reformulated. They also advised to associate with each field a terminology (definition) and a nomenclature (classification). However, these recommendations did not contain concrete propositions of titles formulation, terminologies and nomenclature. These have been conceptualized from theoretical modelling and submitted later to each actor interviewed for validation.

(2) For the **inventory of environmental** notions, we attempted again interviews with environmental assessment experts (the 4 LCA experts interviewed on phase 1 and on 3 EHRA experts). The actors were not only questioned on the basis of their own expertise. They were also asked to express their views (beliefs and perception, personal culture and memorization) on fields that are not directly related to their activities. However, in both cases, the identification and the representation of environmental notions was particularly difficult. The interviews resulted only in the identification of some environmental themes i.e. some general concepts composed of a chain of several notions. *For example, the theme "ecotoxicity" was mentioned by 3 actors as an impact of many types of pollution on the environment; whereas, as it is described in the literature, "ecotoxicity" is a theme including many different environmental notions such as "effects on aquatic fauna", "effects on birds", "eutrophication"...* For the identifica-

[3] GEMET : GEneral Multilingual Environment Thesaurus associated with the European Environment Information and Network (EIONET) website (http://www.eionet.europa.eu/)

tion of the notions themselves, each expert indicated references composed by physical supports of information (such as reports and databases). The effective inventory of environmental notions was then carried out through a theoretical modelling using both internal and external references. The result was also returned to each expert for verification.

(3) The **description of environmental notions** was prepared through an interview with Professor Ramade on the basis of his experiences in the development of generic references for a wide diffusion in the field of Environment. This interview aimed at defining some relevant elements of Pr Ramade's approach which may be used for our environmental notions description approach. It revealed that in writing his books, Pr Ramade mainly applies a determinist approach (*top-down approach*): his formalization is only based on a theoretical modelling of his own observations and on some information sources for which scientific validity is recognized. He does not consider subjective affirmations (opinions, beliefs, perception…)

Then, these findings led us to implement again a theoretical modelling for the description of environmental notions: (1) for each field of the model, a format for description was developed intuitively in order to standardize the level of information; (2) these formats were discussed and validated with environmental experts; (3) the information sheet has been established using these formats and then (4) each sheet has been submitted to the experts for comment, correction and validation.

Our approach revealed then several elements:

- The need for clarifying the RECORD model, through a formal explanation of terminology and a written nomenclature, reveals the importance of formalized information, otherwise known as explicit knowledge, in the field of environment.

-The difficulty encountered in the simplification and formulation of the environmental notions though interviews can be interpreted in two ways. Firstly, it reflects the difficulty of having an expert tacit knowledge on the whole environmental subject. Environmental expertises (such as LCA and EHRA) are usually partial and they are governed by specific rules (hypotheses, models of analysis, aggregation of parameters…). Therefore, **it is difficult, or even impossible, to have a perfect overview of all aspects of Environment**.

Secondly, given the diversity of environmental concepts, the extent and the complexity of the environmental subject, the enumeration of environmental concepts seemed impossible for the experts, even in their field of expertise. Indeed, the exercise consisted on a work of memorization which was particularly difficult. That situation is consistent with the *bounded rationality theory* [23] which states that each agent has a limited capacity of perception, memory and reasoning, especially in a subject with a high level of complexity. Therefore, **physical supports of information (containing explicit or codified knowledge) are of particular importance for all actors (including experts).** Tacit knowledge (know-how, skills and experiences) are only required to form a guide for action (e.g. for the identification of relevant information sources) [3].

- In addition, the importance acquired by the theoretical modelling in our approach reflects the importance related to both codified knowledge (i.e. information and data) and the deterministic approaches used by *exact sciences* in the field of environment. The approaches are mainly focused on the material dimension (formalized information) rather than on the human one (perception, beliefs, opinion...)

5. Discussions and perspectives

We show in this paper that in a complex scientific domain such as the environment, codified knowledge supported by physical sources of information is central in a terminological information system development. Then, we face to a particular case of IS development where experts' cognition has some limitations given the extent and the complexity of the domain.

As developer, we played a key-role in the determination of the IS design elements (model, concepts, information gathering and formalization). Therefore, because of this importance of our involvement in the development of this tool, some bias related to our own cognition and our personal choices are certainly included there. Admittedly, these choices received internal and external validations, but several questions remain namely concerning the interpretation of this tool by those who did not participate in its development. The high commensurability of the users' interpretation schemes with ours (reflected in the tool); i.e. the fact that users could be able to understand the information provided by the tool, would justify the effectiveness of such approach [28]. The test of the tool among a representative sample of actors in various contexts of use (e.g. preparation of environmental arguments, environmental advocacy campaigns, check-list for environmental assessment…) will be the focus of our future researches.

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