Life Cycle Assessment, a new environmental assessment tool to support local authorities' public policies: What kind of appropriation by sewerage services?

L'Analyse du Cycle de Vie, nouvel outil d'évaluation environnementale à l'appui des politiques publiques locales : Quelle appropriation par les services d'assainissement ?

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ABSTRACT

The sustainable development policies of local authorities lack support tools. An intervention-research with local authorities demonstrated the relevance of Life Cycle Assessment (LCA) as an environmental assessment method for decision-making in sewerage services. However, LCA results remain difficult to interpret by non-specialists and conventional decision criteria remain decisive.

Key-words

Environmental assessment, Life cycle assessment, Decision support, Sewerage services, Local authorities

RÉSUMÉ

Les politiques de développement durable des collectivités manquent d'outils supports. Une recherche-intervention auprès de collectivités locales montre l'intérêt de l'analyse du cycle de vie (ACV) comme méthode d'évaluation environnementale pour appuyer la prise de décision publique. Cependant l'interprétation des résultats d'ACV reste difficile pour les non-spécialistes et les critères de décision classiques restent déterminants.

Mots clés

Évaluation environnementale, Analyse du cycle de vie, Aide à la décision, Service d'assainissement, Collectivités locales

Acknowledgements: *The research presented here is the result of a call for environmental assessment projects launched by Irstea (member of the Carnot Institute). It benefited from the support of ONEMA (the French national agency for water and aquatic environments), the Rhin Meuse and Rhône Méditerranée Corse water agencies, and the Bas-Rhin and Hérault departmental councils.*

The authors wish to thank Philippe Roux, Laureline Catel, Evelyne Couliou and Eva Risch, researchers at Irstea who developed the ACV4E tool, for their involvement over the entire experiment, and the pilot local authorities which participated. We also thank the PACA regional environment and eco-development agency, which supported our work. We also want to thank the two anonymous reviewers who help us to improve this article and Grace Delobel for her translation work.

1. INTRODUCTION

While sustainable development considerations are now an uncontested component of public decision-making, it remains unclear as to which assessment tools would provide the most effective support.

Alongside qualitative approaches to the assessment of sustainable development (such as CSR[1]), which have been criticized for their incompleteness and lack of scientific rigor (Lauriol 2004 ; Leroy 2010), there are other approaches that seek to be rational and comprehensive. For the environmental pillar, life cycle assessment (LCA) was developed to be the most comprehensive multi-criteria assessment method possible given the state of current knowledge on environmental impacts[2]. The LCA method, described in ISO 14040 standards and recommended by the European Union (see European Platform of Life Cycle Assessment[3]), aims to quantify all of the environmental impacts of human activities by systematically identifying the emissions and consumptions linked to the production of a good or service.

For environmental assessments, LCA seeks to clarify an issue that often escapes notice: that of pollution transfers. Although LCA is already used widely in certain industrial sectors (energy, transportation, chemicals) as a reference method, its use in the French public sector remains limited except for waste management (ADEME & AMORCE 2005 ; Aissani *et al.* 2012).

We describe here a pioneering experiment involving the transfer of this new environmental assessment approach to the public water and wastewater sector. The use of non-financial indicators is already commonplace in this sector, where sustainable development issues feature strongly (Canneva & Guérin-Schneider 2011). A simplified LCA calculator developed by Irstea researchers was presented to local authorities as a new assessment tool meant to enable a better consideration of environmental impacts in public sector decision-making. The adoption of this tool, named ACV4E[4], was then observed and analysed. The main task was to consider the effects of this new tool on the actors' practices for investment choices. In other words, the experiment aimed to understand whether the introduction of a simplified LCA calculator as a new "environmental thermometer" could enrich the way sewerage actors perceived environmental impacts. The question steering our research was thus this: can LCA help guide an evolution in investment choices so that environmental considerations are better integrated into sustainable development efforts?

After a brief description of LCA as a management tool, we present our research questions and intervention-research approach. We then describe the results of an experiment conducted with six local authorities. Lastly, we discuss the practical and theoretical implications of the integration of this new environmental assessment tool into investment decisions, and more broadly sustainable development practices, of the sewerage sector.

1 Corporate social responsibility

2 The term "impact" is the accepted term in LCA to name the concept assessed by «midpoints». It therefore has a broader meaning than the term "impact" used in kinetics: it designates effects (complex interaction) and not only the impact of one body on another. Likewise, the term "damage"is the term to name the concept assessed by "endpoints". These concepts are presented in section 2.1.

3 The European Union dedicated a scientific and technical research report to LCA (JRC-IES 2010), available on the website publication.jrc.europa.eu: [http://publications.jrc.ec.europa.eu/repository/handle/JRC48157]

4 ACV is the French spelling for LCA (*Analyse du Cycle de Vie*); 4E: evaluation, environment, wastewater treatment, water (in French, *Evaluation Environnementale Epuration Eau*). The tool currently is available only in French. [https://acv4e.irstea.fr/fr/logiciel-acv4e/]

2. MANAGEMENT RESEARCH QUESTION
underpinning the LCA and the intervention-research approach

2.1. LCA, an innovative management tool to support consideration of the environmental dimension in public decision-making

2.1.1. Origins and challenges of the LCA method

While LCA is rooted in work dating back to the 1960s, it was formalized at the end of the 1980s against a backdrop of oil shocks (Basset-Mens 2005). In 1992, the first LCA framework integrating an inventory of the physical flows generated by an action and an assessment of the environmental impact of these flows was presented at a symposium organized by SETAC (Society of Environmental Toxicology and Chemistry). The method then continued to be developed primarily in the industrial world. In 1997, the first ISO 14040 standard defining the principles of LCA was published. It was complemented by other standards that were then revised, the last (ISO 14049) in 2012.

From a scientific perspective, LCA is a fertile field for the production of knowledge regarding environmental impact assessment. Among the many environmental assessment methods available (energy balance, carbon footprint, risk analysis, water footprint…), LCA is presented as one of the rare – if not only – assessment method able to quantify a plurality of environmental impacts over the entire life cycle of a system, from raw material extraction to system operations and end of life (dismantling, waste management) (Risch *et al.* 2012). The aim is to make explicit pollution transfers from one impact category to another or from one stage in a life cycle to another (transfer in time and space).

From a management science perspective, LCA can be considered to be a decision-support tool. Hatchuel and Weil (1992) propose a framework of analysis for management tools that distinguishes three features:

- the *technical substrate,* meaning the concept on which the tool is based,
- the *management philosophy*, meaning the principles underlying its development and expected uses,
- the r*epresentation of the organization* in the tool, meaning a simplified depiction of the relationships between different actors in the organization.

The technical substrate of LCA can be understood through the steps constituting the method. According to the ISO standard, LCA has four steps:

1. Definition of the goal and scope of the study.
2. Inventory (assessment of all pollutant emissions to the environment and of all resources consumed at each life cycle stage of the system studied).
3. Environmental impact assessment using two main groups of indicators (see Figure 2): midpoints, which are 18 indicators quantifying the impact on the environment, and endpoints, which are 3 indicators quantifying the damage to ecosystems, human health and resources.
4. Interpretation of the impacts assessed, which leads to conclusions and recommendations.

The environmental assessment principles underlying the LCA method are as follows: first, the functional unit is defined. The functional unit characterizes the service rendered for which the inventory and impacts will be calculated. For a sewerage service, the functional unit could be the collection and treatment of effluents of one inhabitant over one day.

Environmental impacts are then calculated at three levels: global impacts (greenhouse effect, depletion of the ozone layer…), regional impacts (eutrophication…), and local impacts (human toxicity, ecotoxicity…). As the methodology was refined, the list of the impacts considered was modified and enriched. This list constitutes what LCA experts call “midpoints”.

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A final step, one much less consensual from a scientific perspective, is to estimate the consequences of these impacts in terms of three damage categories: human health (measured in days of life lost), ecosystems (number of species lost) and depletion of natural resources (expressed in dollars). These are referred to as "endpoint" indicators. The level of incertitude is much higher at this step.

An LCA can be difficult to interpret due to the fact that, while the impact and damage indicators (respectively the midpoints and endpoints) are expressed quantitatively in physical units, they do not represent total quantities which are actually emitted on each site impacted by a product's life cycle. They are rather the quantities produced over the entire life cycle by one functional unit (for example, 1 kg of a product, 1 km transported, 1 object, etc.). The pollution flows calculated can in reality be one-off in time and space or, to the contrary, distributed in different locations involved in the physical processes by taking into account impacts at different timescales. Moreover, the functional unit selected does not account for the total amount of pollution produced on an industrial site over one year, but rather the quantity corresponding to the functional unit, for example the manufacture of 1 kg of the product studied (without worrying over whether the factory produces a few tons or thousands of tons over the year).

In this way, the LCA method is distinguished from impact analyses, which are site-specific and limited in time to the operating phase of the facility under study[5]. The overall principles of LCA are summarized in Figure 1.

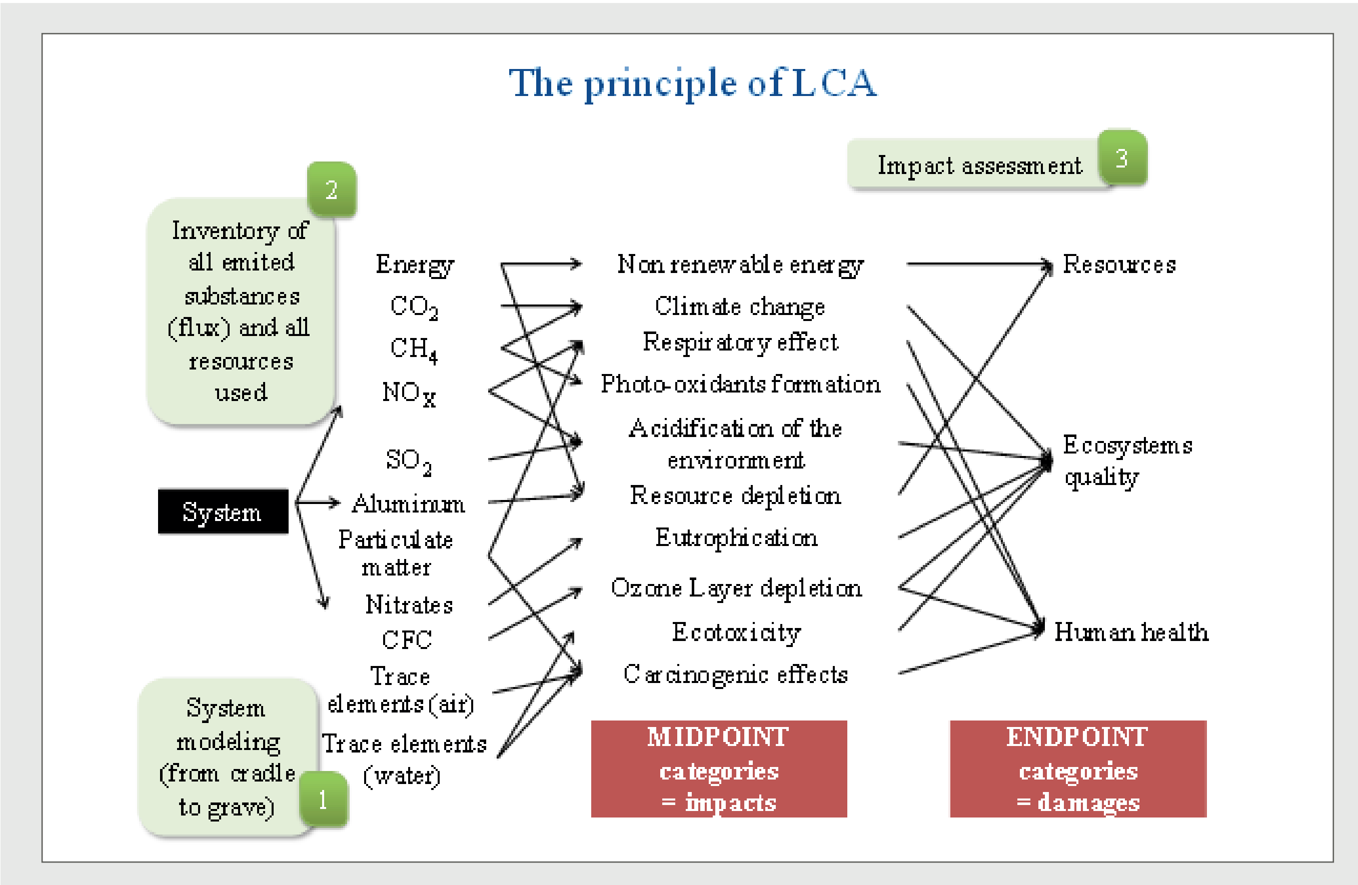

Figure 1 – Overall structure of the LCA framework
Source : Philippe Roux and Laureline Catel, Irstea, 2014

5 For a detailed overview of the LCA method, please refer to the dedicated ISO standard and to the pioneering work by Jolliet (Jolliet *et al.* 2004). The recent article by (Hellweg & Milà i Canals 2014) also proposes a complementary summary of emerging LCA approaches.

The first step (1) is to model the system. This enables all of the stages in the life cycle to be detailed and to reconstitute the process.

The second step (2) builds on the first to establish the inventory (assessment of all pollutant emissions to the environment and of all resources consumed at each life cycle stage of the system studied) and produce the total sum of emissions and consumptions over the life cycle.

To determine the environmental consequences (3), LCA draws from the model of the physical, chemical and biological processes which link the substances in the inventory to the midpoints, then more globally to environmental damage (endpoints). This is what LCA experts call impact pathways. An impact pathway allows marginal transfer functions to be built, which gives the amount of output produced per supplementary unit of input. These functions provide characterization factors resulting from the combination of fate, effect and exposure factors. Reference models (for example, the ReCiPe[6] model) propose impact pathways validated by the LCA community. LCA expert software programs use the data available on different processes (for drawing up the inventories) and propose some pathway reference models for the calculation of impacts and damage.

LCA thus provides an assessment through quantitative models drawing from impact models (pathways) and matrix calculations to consolidate the impacts on the life cycle. SimaPro, which applies the ReCiPe impact pathway method, is one of the most widely used programs. LCA enables technical options producing the same functional unit to be compared. The comparisons are conventionally presented in the form of histograms. All of the indicators are presented in a single graph. The scenario with the highest impact is assigned a value of 100% and is used as the reference point. The other scenarios are expressed as percentages relative to the reference scenario. The scenario with the highest impact can vary from one criterion to another. The following graphs, derived directly from the SimaPro program, illustrate a typical LCA result presenting a comparison of two alternative wastewater sludge treatment systems.

The initial formatting was retained with the original captions in English. The objective is to highlight the (still inadequate) effort made in the simplified ACV4E calculator to make outputs easier to use.

2.1.2. LCA as an innovative sustainable development management tool

From the perspective of management philosophy, LCA refers to a holistic vision of sustainable development. The consideration of pollution transfers in environmental impact assessments is meant to avoid erroneous solutions to environmental issues and to require all consequences of investment and operation choices to be considered.

Belhani (2008) notes that the first reference to LCA as a sustainable development tool dates back to the 2000s with the Malmö Ministerial Declaration, which was developed at the 2002 World Summit on Sustainable Development in Johannesburg. Under the aegis of SETAC and the United Nations Environment Program (UNEP), the Summit fixed an objective to promote and disseminate "life cycle" thinking to encourage the consideration of pollution transfers in environmental assessments.

LCA is furthermore a tool aiming to capitalize on a large body of scientific knowledge, notably by sharing impact calculation methods and developing inventory data bases. This approach gives the method strong scientific legitimacy.

LCA also is part of a prevailing management tradition which holds that "what is not measured can't be managed" (Kaplan & Norton 1998). In this, LCA is based on a positivist view of decision-making: it seeks to give comprehensive information about the environmental impacts of a decision to be able to determine its relevance.

Lastly, LCA is intended to contribute to two key operational uses:

- eco-design, which consists of taking into account the environment from a system's design stage to reduce its impacts;
- decision-support by comparing two technical solutions to select the one with the least impact on the environment.

6 [http://www.lcia-recipe.net/]

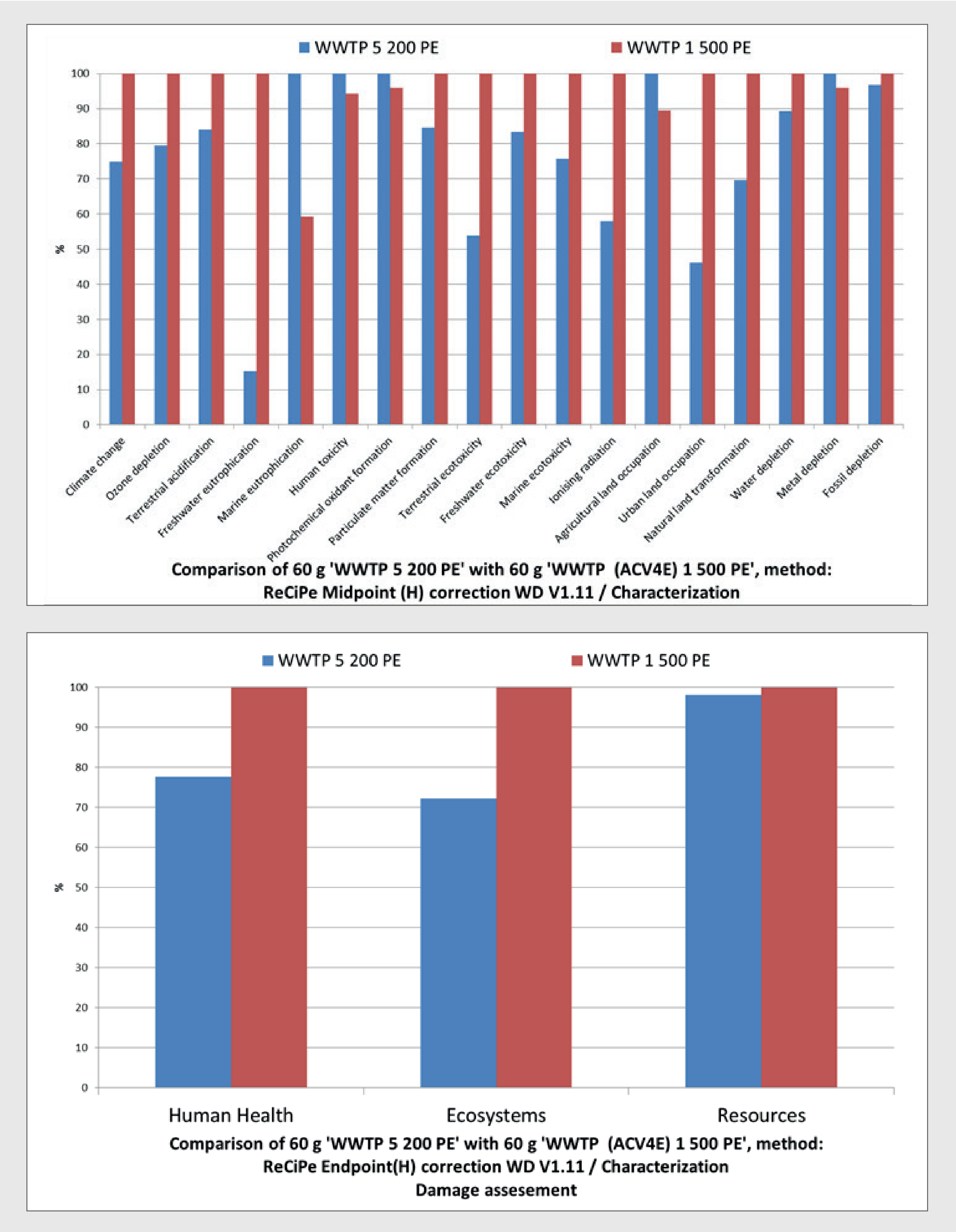

Figure 2 – Standard presentation of LCA environmental impact indicators
(midpoints below and endpoints on the following page) as provided by LCA expert software programs
Source : SimaPro software (comparison of two types of wastewater sludge treatment systems)

From a practical perspective, LCA also can serve as a tool to justify a decision to third parties.

The final dimension of a management tool according to Hatchuel and Weil (1992), that of the image of the organization conveyed by the tool, is much more difficult to grasp. LCA is a method developed independent of a given organization. It does not explicitly contain requirements in terms of users. It does not assume a certain type of relationship between actors. However, it assumes that the organization has strong technical skills to use the LCA software program, interpret the results, and conduct an analysis.

2.2. The introduction of LCA in the management of sewerage services

The complexity of public action, and particularly of decision-making processes, is an established fact. It is related to the plurality of goals to be achieved and to the ambiguity introduced by the political dimension (Bozeman 2007 ; Gibert 2008). The consideration of the environment in the domain of public action increases this complexity. As Froger and Oberti (2002) note, environmental effects are often long-lasting, irreversible phenomena exist, an absence of scientific certitude on the consequences of decisions casts a shadow, and the overlapping of spatial scales requires interactions to be taken into account.

These reasons can justify calling on multi-criteria decision support tools, as Montgolfier and Bertier (1978) already were emphasizing as early as the 1970s. LCA can be classified as a multi-criteria assessment tool even if it is the subject of academic research in a disciplinary field oriented more towards process engineering than decision science. Yet the use of LCA as a strategic decision-making tool remains quite rare among local authorities, particularly in the public water services sector. The method's relatively novel character and the expert dimension that makes it difficult to use are two reasons for this.

To overcome this obstacle and remedy the shortage of environmental assessment tools in the water sector, LCA researchers from the ELSA[7] research platform and Irstea researchers working on the efficiency of wastewater treatment systems developed the ACV4E program. This software aims to make LCA easier for non-specialists to use in order to promote its use in local authorities. ACV4E was developed to support investment decisions in the wastewater sector (Risch *et al.* 2012). The developers of ACV4E (ACV researchers) hypothesized that the introduction of multi-criteria environmental indicators would help objectify the debate by rationalizing discussions about environmental choices.

ACV4E takes the form of a simplified calculator enabling a technician in a local authority to model choices between different networks and wastewater treatment systems. The principle is simple: the software's developers conducted LCAs for diverse elements of a treatment system. Different types of mains, equipments, or wastewater treatment systems are provided in the tool as building blocks that users can configure to create a scenario. The software thus draws from a data base of unitary impact calculations for different components of a sewerage system. Users simply need to specify the technical characteristics of the wastewater treatment systems that they wish to compare. They assemble a system using the building blocks available and specify the parameterization of these elements (sizing, performance level of the wastewater treatment plant, consumables...). They do not need to calculate the LCAs themselves as these are already incorporated in the software. After configuring the different investment scenarios under consideration, the software calculates the midpoints and endpoints and enables them to be compared. The figure below summarizes the calculation model implemented in the ACV4E software.

ACV4E was developed under an initial research project staffed exclusively by LCA researchers (process engineering specialists). A second project involving management researchers was linked to the initial project to introduce the ACV4E tool to volunteer local authorities. The adoption of the tool was observed under the framework of an intervention-research approach.

7 ELSA (Environmental Life Cycle and Sustainability Assessment) is a research group dedicated to Life Cycle Assessment and industrial ecology applied to agro-bio processes. It gathers researchers from several agencies, including Irstea.

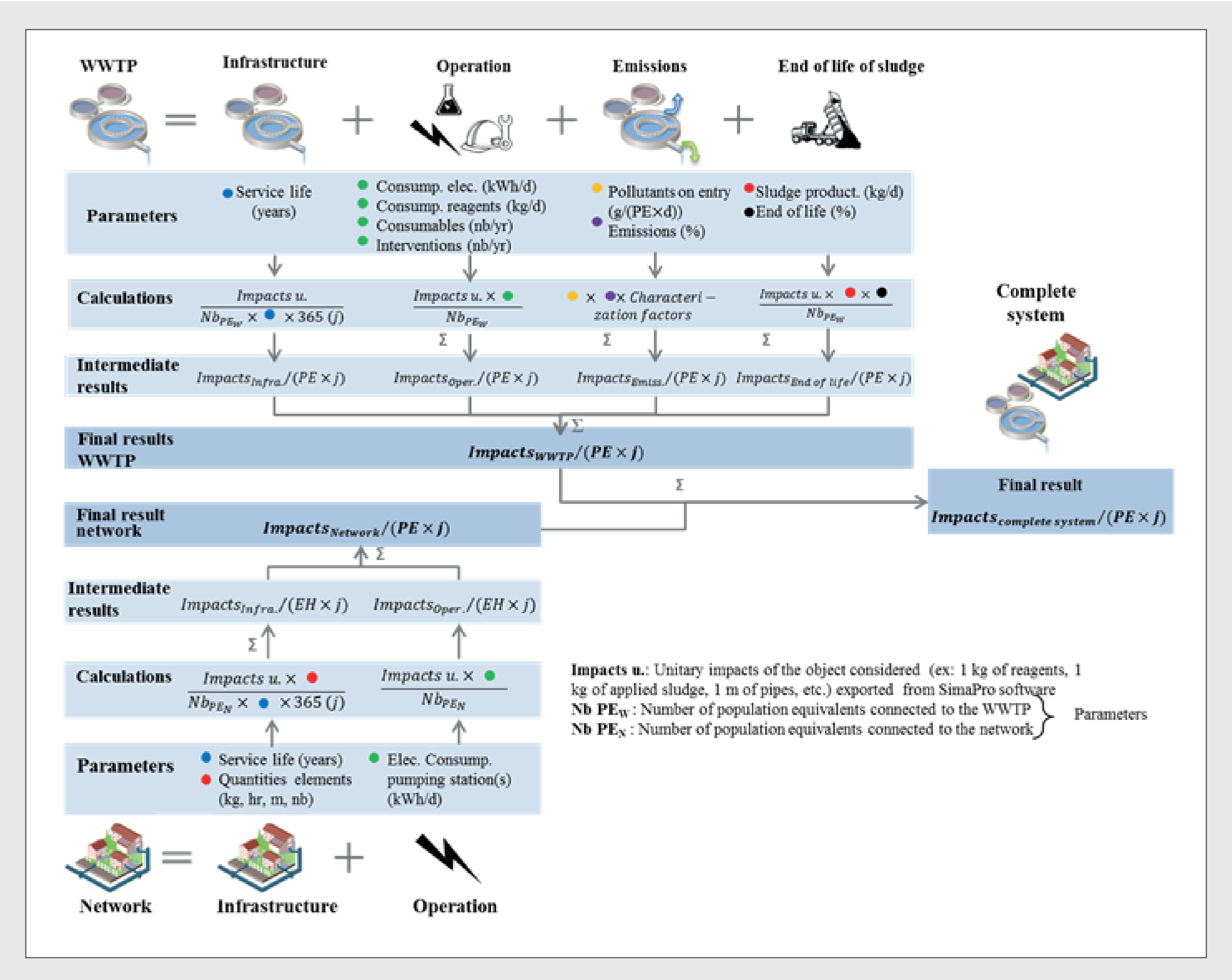

Figure 3 – Schematic presentation of the parameterization and calculations made in the ACV4E environmental assessment tool

Source : Document produced by Laureline Catel, Irstea, 2015

2.3. Presentation of theoretical-empirical questions and the intervention-research approach

2.3.1. The intervention-research questions

The intervention-research project was built around four theoretical-empirical research questions.

The first falls within the technical dimension and concerns LCA technology; the task is to identify improvement to the software that developers could integrate into their tool (Q1). However, as we will see, this dimension can also be enriched from a management perspective, focussing on the needs of users facing decisions.

The following three questions address management issues more directly:

- analyse the gap between actual and planned uses (Q2),
- understand how the environment is taken into account in the public management of sewerage services (Q3),
- analyse the degree to which actors adopt new references (LCA) and the effect of the LCA tool on how decisions are made and justified within local authorities (Q4).

To address these questions, it would seem *a priori* interesting to observe:

- how the tool is adopted (or not) by the different levels of actors involved in public decision-making: technicians, directors or heads of services, elected officials, institutional partners working with local authorities (decentralized state services, local councils, water bodies), and even citizens and service users;
- what types of uses would emerge from the experiment.

2.3.2. Description of the intervention protocol established to observe the process by which the tool is adopted

Intervention-research, inspired by action-research (Lewin 1951), was developed in France (David 2008; Moisdon 1984; Riveline 1991) but also has spread abroad (Midgley 2003). It posits that theory and practice are methodologically linked in a partially shared process of knowledge generation. Savall defines intervention-research as an "interactive method (between the researcher and the field) with a transformative intent (Savall & Zardet 2011). The creation of knowledge is thus intimately entwined with change. Intervention-research has worked extensively on management tools in the field (Moisdon 1997).

In our case, the intervention was focussed on the ACV4E software program. The details of the protocol developed are presented in the table below.

Diverse facility sizes and management modes (direct management of the sewerage service or contracted out to a private company) were sought in the selection of local authorities to participate in the experiment. In most of the cases, sustainable development was an issue in varying degrees of intensity.

The test took place over a three-year period between 2013 and 2015. All of the local authorities did not become part of the observation mechanism at the same time.

STEPS OF THE PROTOCOL	METHODS AND TOOLS USED
Definition of the research question, objectives and means	Intervention-research contract written collectively Steering group set up for the experiment comprising field actors and researchers
Development of the intervention-research approach	Meetings to raise awareness of the LCA tool within the management and administrative hierarchy Training of agents destined to use the tool by ACV4E's developers Construction of the investment choice scenarios to be tested Free use by the local authorities with technical support from the development team with the possibility to adapt the software to needs Analysis of the characteristics of the ACV4E tool and interviews with the developers
Formalisation of the collection of field material	Interviews of decision-making and management actors in the sewerage services Participatory observation Logbooks kept by tool users Intervention-research journal maintained
Exploitation and analysis of material gathered	Reflexive back and forth discussions between field actors and researchers through: - a working group - collective feedback sessions

Table 1 – Description of the intervention protocol followed

3. RESULTS OF THE ACV4E TOOL TEST

With one exception, the different test sites all implemented the software. The experiment proved to be a valuable learning experience. Although the application and use of the software took place in varied contexts, observations converge concerning the issues at stake in the interpretation and use of LCA results.

3.1. Implementation of the software by the local authorities

In practical terms, after the training session in how to use the tool, the time required to conduct the simulations and enter service data was reasonable and compatible with agents' workloads (from 1 to 3 days).

The local authorities followed different approaches to define the scenarios corresponding to the investment

LOCAL AUTHORITY*	Type of local authority (management mode**)	Degree to which sustainable development is considered in the organization's operations
Montpellier Méditerranée Métropole (M3M) 430 000 inhabitants	City (delegated)	Commission of elected officials on the topic: Agenda 21, climate plan.
Partnership involving the Rhin-Meuse Water Agency, the Alsace Moselle Water and Sanitation Syndicate (SDEA***) and the Bas-Rhin Departmental Council 800 000 inhabitants	Inter-municipal syndicate (delegated and direct management)	Partnership agreement on sustainable development training between the 3 local actors SDEA certified as a "sustainable development and environment" organization Effort to reduce carbon impact of structures
Vienne Agglo 67 800 inhabitants	Agglomeration community (delegated and direct management)	Environment department (climate plan) separate from the department overseeing water networks
Châteaurenard 37 000 inhabitants	Township (direct management)	Agenda 21 program with an elected leader and a sustainable development orientation
Sarrians 5 800 inhabitants	Township (direct management)	No department dedicated to sustainable development
Puget-ville 3 800 inhabitants	Township (direct management)	Proactive policy on the part of elected officials with the adoption of a sustainable development charter and a task officer

* The predominance of local authorities from the Rhône Méditerranée Corse basin is due to the fact that the project received funding from this Water Agency to constitute a pilot group.

** Direct management: service operated by a public entity under the direction of the local authority.
Delegated: service operations delegated to a private company.

*** *Syndicat des Eaux et de l'Assainissement d'Alsace Moselle.*

Table 1 – Principal characteristics of the ACV4E tool's test sites

choices to be assessed. Some chose to assess the environmental impacts of equipment decisions that were in process, others used the LCA on decisions that already had been made to verify a posteriori the environmental relevance of their choice.

In the large local authorities, the software was operated by technicians from the sewerage service and the results were then presented to department heads and other interlocutors when appropriate (Departmental Council, water agency). In the case of Bas-Rhin, where ACV4E will continue to be used beyond the end of the intervention-research project, a task officer was specifically recruited to operate the software. The results were presented in four feedback sessions and were the topic of collective discussions at different steps of the experiment within a designated working group.

In the smaller local authorities, the software was used either directly by the head of the service (an engineer) or by a technician under his or her command.

Only one local authority (one of the smallest) did not advance to the use stage of the software. It stopped at the choice of the decision to assess (definition of the scenarios that could have been studied by ACV4E).

Due to the current state of the tool's development, the LCA results were not presented to any elected officials, users or consumer associations by the technicians from the pilot local authorities. This was a deliberate choice on the part of the service heads, who esteemed that after a few months of testing, they had not adequately mastered the interpretation of LCA results to present and discuss them with elected officials.

The implementation of the LCA tool in the local authorities clarified the project's research questions:

- those with an instrumental scope (research questions Q1 and Q2),
- those which pertain to the effects produced by the tool's use on how environmental assessment is perceived and on ostensibly sustainable development practices in the wastewater sector (questions Q3 and Q4).

3.2. Main difficulties in adopting and interpreting results: the questions raised by the use of an expert tool (Q1)

The local authorities' use of ACV4E during the pilot experiment highlighted two types of difficulties:

- difficulties related to the modelling of actual operational features of wastewater treatment systems (in particular the catalogue of available technologies) upstream of the LCA,
- difficulties related to the interpretation of results following the LCA.

The first finding was clear: it was impossible to immediately use the initial version of the software. A certain number of wastewater treatment systems and facility sizes were missing. Likewise, actors could not find their usual operational categories in the objects defined by the developers. The first type of improvement made was to enrich the catalogue of equipment provided in the software to construct scenarios, and to broaden the operational categories used in the field (for example, to describe the network).

Another finding concerns the adoption process of the tool by actors and the obstacles encountered. The first obstacle involved how results were visualized. The real difficulty lay in the fact that the software simply reproduced the standard format used in LCA for results visualization without seeking to adapt it to the context of local authorities.

Figures 4 and 5 provide examples of the results produced by the software program. They consist of screen shots of the ACV4E[8] software program showing the impacts (midpoints) and damages (endpoints). The colour variations indicate the contributions of different components of the sewerage system (network, plant infrastructure, plant operations…). The values in these two figures are given as an illustration and vary from one local authority to another.

In Figure 4, a centralized solution (a hamlet is connected to an existing wastewater treatment plant (WWTP) by installing mains and pumping stations to centralize effluents) is compared with a decentralized solution (a

8 Such as those in the version used during the experiment. After the test, the visualization of results was modified in later versions

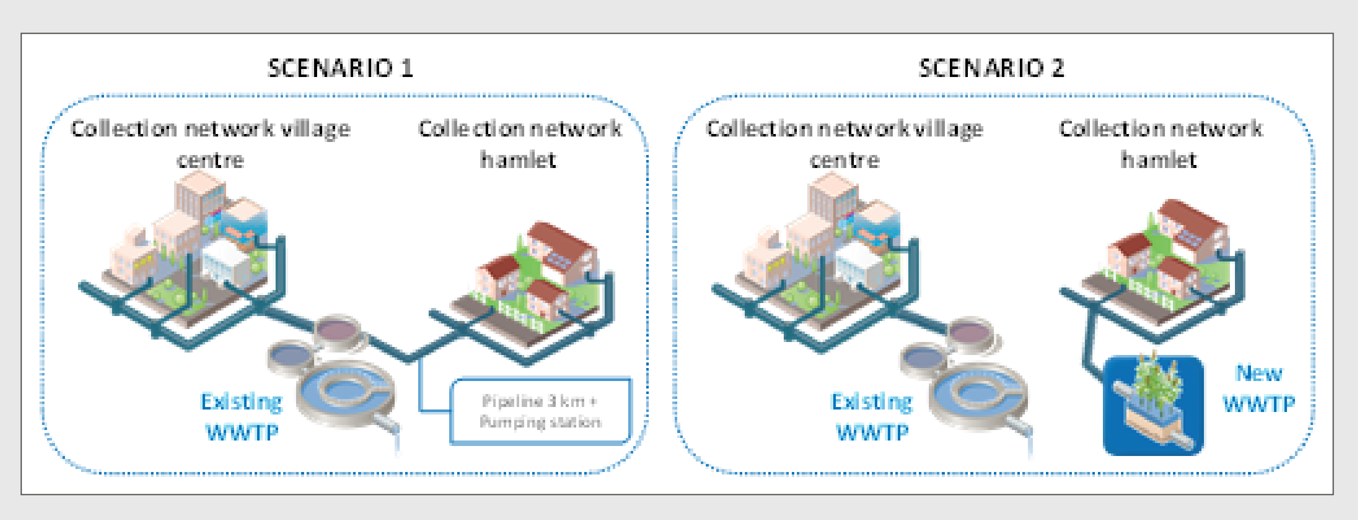

Figure 4 – Diagram of a centralized (scenario 1) and a decentralized (scenario 2) solution to create a wastewater treatment system for a hamlet

small treatment plant is built with an extensive on-site process, limiting the transport of effluents).

The software produces histograms presenting the comparison relative to the impacts (midpoints) and damages (endpoints) in a format very similar to that of programs used by LCA specialists (see Figure 4). While the simplified calculator resolves some of the difficulties of LCA by sparing the user from needing to make the inventories and impact calculations, it remains entirely up to the user to interpret the results.

Several problems arose when these graphs were used by the local authorities involved in the experiment.

The first was ergonomic, as can be seen by comparing Figure 2, generated by the expert software SimaPro, with Figures 5 and 6, generated by the simplified calculator ACV4E. While ACVE4 presents the graphs in French and tries to provide additional clarifying elements through the set of colours representing the contributions of different steps in the process, the graph remains quite similar to the standard graph produced by expert software. The initial version of ACV4E software does not allow for the possibility of personalizing the graphs (for example, by increasing the size of the captions). The results presentation and export features are extremely limited, which renders it difficult to integrate items into a report or a video presentation. This reflects a development bias: the team that developed the first version of ACV4E, before working with a pilot group of users to co-construct the tool, consisted exclusively of LCA experts. In their view, the added value of the software was that non-specialists were spared from conducting the LCA themselves. In contrast, the step of visualizing results was not thought through per se.

The second difficulty was cognitive: too many impacts (midpoints) are presented. As soon as the variations do not point in favour of the same scenario, it is no longer possible to mentally process all of the criteria. The endpoints (obtained through the aggregation of the effects of impacts) do not provide an adequate response. On one hand, a divergence between the three spheres of damage can persist and, on the other, LCA specialists themselves reject the method of aggregating midpoints into endpoints, describing it as controversial from a scientific perspective (see2.1).

The third difficulty involved the users' level of expertise: the meaning of impact categories is not easy for non-specialists to understand (what is "photochemical oxidant formation" or "marine ecotoxicity"?). When the impact categories do not refer to clear notions, it is difficult to link them to environmental issues.

The fourth difficulty pertained to an interpretation bias in the histogram presentation: by presenting all of the midpoints without ranking them on a scale of 0 to 100% (in relation to the scenario with the highest impact), the software gives the false impression that all of the criteria are equally important. The variations observed between two scenarios can be great, but apply to pollution flows which are negligible in absolute terms. If one scenario

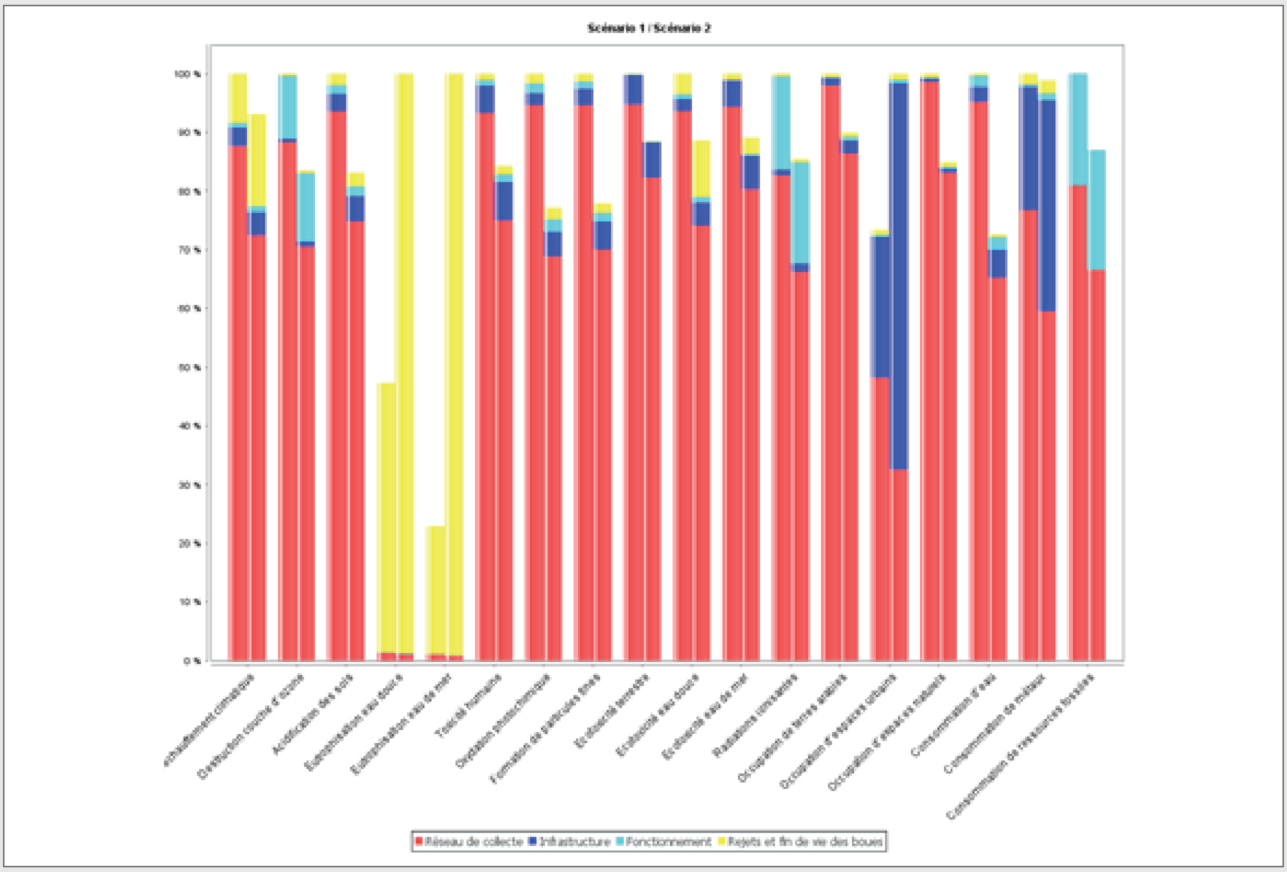

Figure 5 – Example of the visual presentation of midpoints for two scenarios as produced by ACV4E (screen shot)

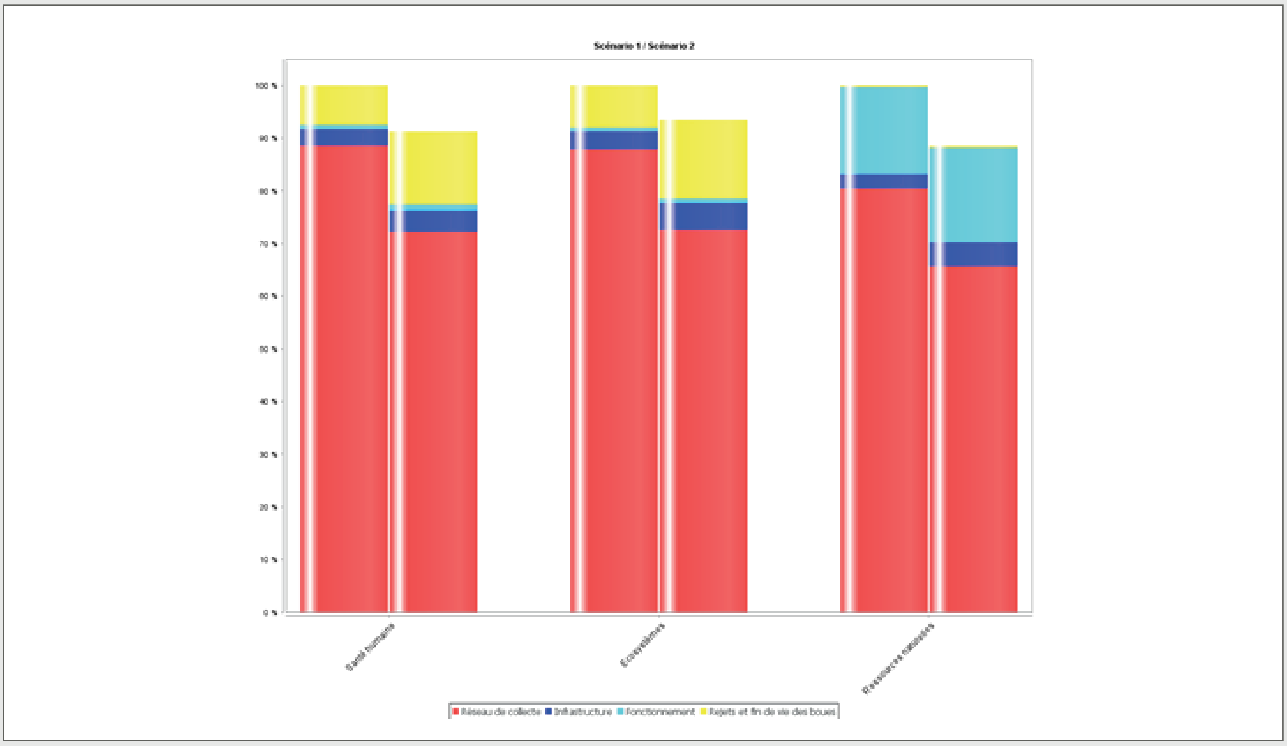

Figure 6 – Example of the visual presentation of midpoints for two scenarios as produced by ACV4E (screen shot)

produces three times more fine particles than another, but the quantity emitted is low, it would be better not to accord much importance to this criterion in choosing between the two scenarios.

Users are thus faced with too many criteria whose importance they cannot estimate. This multitude of criteria renders the analysis more complex and does not facilitate the development of evaluative judgment needed for decision-making.

In the framework of this experiment, the fundamental assumption on which all multicriteria analyses are based (decision makers are able to express preferences and they can be described by a system of preference relations) proved to be unfounded.

The use of LCA results assumes an interpretive capability on the part of the user that must be developed and does not exist *a priori*. In several local authorities, this was the reason mentioned by technicians (service head level) to justify why the tool could not, at this point, be presented to either elected officials or service users.

3.3. A use potentially richer than planned (Q2)

Despite the difficulties in interpreting results, the test of the tool gave a much richer idea of the possible uses of environment assessment in the sanitation sector than that foreseen by ACV4E's developers.

According to the developers, one of the major reasons for disseminating the ACV4E tool was the absence of adequate environmental knowledge on the part of political actors facing technical choices. The use foreseen for the tool was to clarify investment choices by providing scientifically grounded information. They thus foresaw supporting investment choices as the sole use for ACV4E. Yet the actors in the pilot local communities envisioned three other types of potential uses.

The relevance of the different uses of LCA varies depending on the size of the local authority and the type of management (delegated to a private company or directly managed).

Large local authorities make investment decisions more frequently than smaller ones. For small local authorities, a plant is only constructed every 5 to 10 years, and it would not be logical to maintain in-house software and capabilities which are used so infrequently.

However, in the small local authorities directly operating services and the largest local authority in the sample (SDEA-Moselle), the idea of using the results of ACV4E for operations germinated. The task was to use the new information produced by the software to analyse the environmental impacts of wastewater treatment mechanisms and to improve their operations. This new use assumes, however, that action levers can be identified (which operations choices contribute to environmental impacts), which the initial version of the tool only partially allowed.

Lastly, SDEA managers saw in this new tool a potential means to support benchmarking between the wastewater treatment plants operating across their intervention area. SDEA finds this interesting due to the size of its sewerage system facilities, which cover the entire department[9]. This proposed use raised a question that is difficult to resolve, namely the definition of the wastewater treatment plant to be used as the reference model.

In the end, the size of the local authority and the degree of expertise of users in the local authority appeared to be factors shaping the use of the simplified LCA calculator.

3.4. Fuzzy perception of environmental issues (Q3)

Elected officials in all of the pilot volunteer local authorities were in favour of better taking the environment in account in their local water policies.

However, concretely speaking, environmental consideration remained fuzzy and difficult to objectivise. With the exception of one local authority undertaking a carbon footprint certification process, there were no approaches or methods enabling a quantification of the environmental scope of actions undertaken, and no local authority had so far conducted an LCA.

9 France is divided into 100 departments that are administrative divisions of the national territory.

Types of LCA use envisioned by local authorities		Problematics* to which this use responds
Investment choice	Comparison of different facilities possible prior to an investment policy decision	Clarify the decision by the choice of a sub-set of possible actions which is as limited as possible in order to choose one action (*optimums* and *satisfecums*) ⇨ Choice or selection procedure
Eco-design	Comparison of several technological variants (the choice of the type of facility already having been made) prior to the design of equipment	Clarify the decision by a description of actions and their consequences using appropriate terms. ⇨ Description or cognitive procedure
Eco-exploitation	Comparison over time of the environmental impacts of existing equipment (inter-annual monitoring)	Clarify the decision by placing all or all or part of all the most attractive actions into equivalence classes that are completely or partially ordered according to preferences. ⇨ Ranking or ordering procedure
Process benchmarking	Compare the environmental impacts of several existing facilities to a reference	Idem ⇨ Ranking or ordering procedure

* As defined in the multicriteria methodology for decision aiding (Roy 1996).The word *problematic* is the translation of the French term "problématique" that has been retained in the English version of Roy's book.

Table 3 – The main groups of uses emerging from the ACV4E experiment

The observations and interviews made it possible to identify the criteria, in the absence of quantified impact assessments, on which sanitation investment decisions typically were based. These are presented in the following table.

In our case studies, sanitation investment decisions thus appear to be chiefly dominated by regulatory obligations (respecting treated water discharge standards), which are themselves dependent on technical criteria (reliability of the wastewater treatment technology). Before even considering cost criteria, local authorities want a treatment system guaranteed to meet regulatory obligations. In fact, the State water policing services can compel a local authority to rebuild a wastewater treatment plant that is not in compliance with regulatory standards.

Cost comes third. Environmental considerations (save for discharge standards) are practically marginal and focus mainly on local features (distance from housing, odour nuisances). Global environmental impacts scarcely come into play (energy consumption, sometimes carbon footprint).

Most environmental assessments moreover remain qualitative. A local impact assessment is the only environment-related mechanism required by regulations. Such a study only takes place once the investment decision has been made for plants of a certain size (subject to approval), and only looks at local impacts generated by the establishment of the chosen facility.

Criteria (level of importance in the decision)	Elements considered
Regulatory obligations (+++)	- wastewater treatment performance (level of discharge into the environment) - respect of rules in terms of distance from housing
Technical dimension (+++)	- capacity to maintain wastewater treatment performance (reliability) - capacity during thunderstorms (reliability) - feedback available (reliability) - degree of technicality (simple to operate) - consistent with existing facilities (easy to operate) - innovative facility (sometimes seen as an advantage)
Economic dimension (+++)	- investment cost - operation cost
Environmental and social dimensions (outside regulatory obligations) (++)	- energy consumption, carbon footprint - recycling sludge - physical footprint - integration into the landscape - minimized nuisances (odour, noise...)
Administrative dimension (+)	- consultation and call for tender procedures easy to handle

Table 4 – Criteria usually considered by local authorities in investment decisions for a wastewater treatment facility (resulting from our field observation)

The environmental dimension is thus reduced exclusively to the quality of the water discharged by the wastewater treatment plant into the receiving environment (generally a river). Yet a wastewater treatment system has a number of other environmental impacts. The potential contribution of the LCA method thus appears significant: it renders the consideration of the environment objective and enables a much broader picture of the pollution generated.

3.5. What is the potential effect of LCA on decision-making and local sustainable development practices? (Q4)

The local authority which went furthest in integrating LCA results into decision-making was Montpellier Méditerranée Métropole. The LCA was conducted by the technician responsible for setting up the plant project. This LCA was made in parallel with a technical-economic study conducted by the consulting firm charged with proposing technical solutions. The results were presented to different service heads (including the director of the environment) of Montpellier Méditerranée Métropole.

Several points emerged from the experiment:

- Dialogue concerning the environment was enriched. The presentation of impacts and damages created an opportunity to spend more time considering the environmental dimension. Implicitly, it gave the dimension more weight. The dominance of the other criteria (capacity to respond to discharge requirements, technical constraints, costs) was not called into question. However, in this case, the dominant criteria were unable to distinguish clearly between the facilities under consideration. The presentation of the LCA led to additional attention being given to a solution which might have been discarded because it seemed less technically reliable.

- In the case of Bas-Rhin, the test examined an investment choice that had already been made. In this local authority, the intervention-research approach was structured around reflection about sustainable development that already had been initiated by water actors at the departmental level through SDEA's actions to reduce the carbon footprint and the Rhin-Meuse Water Agency's leadership role. These three organizations participated actively in the process. The hiring of a task officer for the environmental assessment, and in particular the test of the ACV4E tool, enabled more in-depth work compared to the other local authorities. Here, the feedback sessions on the results of the scenarios and the reception of these results by actors demonstrated that the link between environmental assessment and investment choices is not always immediate. There is a trajectory to be organized and monitored, notably around the question of which criteria are sufficient and useful to distinguish between investment choices from an environmental perspective.

- In the other local authorities, the use of the LCA was more limited. No investment decisions were taken.

The LCA thus seems to be able to modify decision-making by local authorities under certain conditions, but this cannot happen without first passing through a stage in which technicians and managers appropriate the results.

For certain local authorities, LCA seems to be an argument likely to be used before external actors to justify more extensive technical solutions, notably the State water policing services. Exploratory interviews were conducted in several services in charge of water policing to assess their interest in this method. It seems that while they can be receptive to arguments produced by LCA, regulatory constraints remain significant concerns for officers of these State services.

4. DISCUSSION

The research conducted provided a first look at the extent to which LCA can be an assessment method that contributes to introducing sustainable development to decision-making by local authorities. This research needs to be deepened and completed by further studies, but it enables an enriching discussion to be initiated regarding the theoretical and empirical aspects of the instrumentation of innovative management. Five main elements emerge.

4.1. LCA and the black box effect

The principles underlying the LCA method, and the LCA expert software used to capitalise LCA results in ACV4E (see section 2.1) leads to a nesting of models and the use of data bases encapsulated in the software. ACV4E users have access to neither these models nor these data, which creates a black box effect. This black box effect of LCA in public decision-making has already been discussed by Schlierf et al (2013). Several perverse effects are possible:

- difficulty in understanding the nature of impacts and the method used to calculate them, which can lead to the results being rejected,
- risk of manipulation due to the fact that the builder of the model can choose the settings, or a selection of a subset of impacts that modifies the results in favour of a scenario already chosen based on other criteria,
- risk of an excessive reduction of information when endpoints are used as the sole criteria.

The use of a simplified calculator partially limits these risks without totally avoiding them. Part of the black box is certainly opened and the process is easier to understand: users model the process themselves by building the scenarios. Under the test conditions, users also followed a preliminary LCA training program (also available in the software's online help service). A technician trained to use ACV4E theoretically could play the role of passe, as LCA entrepreneur, and facilitate the engagement of elected officials as noted by Baumann (2000) and Collins and Flynn (2007) in an industrial context. But the test showed that local authorities' managers involved in the test did not deem it relevant to associate elected officials as they had not yet mastered the interpretation of LCA results.

The fact that users can only access the settings of the process (choice of scenarios) and the limited number of settings of the prior LCA (for example, the choice of the energy mix[10]) also reduces the risk of manipulation without entirely ruling it out. Lastly, the risk of reducing information is also limited by the fact that the software requires the visualization of midpoints at least once, but this does not guarantee that users will not fixate on endpoints alone.

This limit is important to recognize in a context where an environmental assessment will not only serve to support decision-making, but also will be used to justify, or even bring under debate, this decision before others. The LCA tool's lack of transparency within the frame of democratic debate thus is a real issue.

4.2. LCA and the decision context

Despite the water actors' proclaimed interest in sustainable development, our research confirmed a lack of environmental assessment tools within the local authorities in general and in the water and sanitation sector in particular.

LCA's first contribution as a management tool lies in the management philosophy that it conveys: it encourages a multi-dimensional and trans-territorial view of environmental impacts. The ACV4E simplified calculator favoured such a conception of environment assessment to spread among local actors. Thus, despite the difficulties in interpreting the results, the workshops organized during the experiment were occasions for reflexive discussions on the extent and true scope of environmental considerations in practice.

The introduction of LCA into the investment decision-making process in the public wastewater sector also clarified the nature of the relationship between elected officials and technicians. The governance of public water services is strongly influenced by technical profiles. Our experiment confirms the relative weakness of political expression and the important role of technical experts held by engineer managers (Tsanga Tabi & Verdon 2014). Regardless of the size of the local authority, decisions about treatment systems were thought through by the technical departments. While elected officials are the ones to choose to establish a new plant to meet their urban planning objectives, it is the technicians who determine which technical solutions are implemented.

Unlike what has been observed in the waste sector (Barbier *et al.* 2014), the figure of the user remains quasi absent from our study sites, undoubtedly because sanitation matters are less subject to controversy than projects to set up waste treatment or storage facilities.

The experiment demonstrated the strength of regulatory referential in restricting public action. The obligation to comply with pollution control standards could impede the dissemination of LCA. It imposes a focus on discharge into the aquatic environment and contradicts the consideration of pollution transfers.

Conversely, in the waste management sector, where the environment code requires environmental assessments, regulations promote the development of LCA, which is used as the reference tool.

This illustrates how innovations in methods and tools can lead to tensions within conventional policies of public action (Gibert 2000).

4.3. Innovation process: the benefits of a co-constructed approach

This empirical research examining the transfer of the ACV4E tool demonstrated the benefits of approaches in which academic researchers and operational actors build management tools together. This is particularly relevant in the environmental sector where new forms of governance are continuously being invented (Theys 2003).

Certain factors impeding the adoption of ACV4E (overly limited catalogue of facilities, visualization of results unsuitable for non-specialist users) result from the failure of the initial developers of the software to take final users into account. In the tool's transfer stage, the modifications of ACV4E that have been made[11] seek a

10 If one chooses the French energy mix, dominated by nuclear energy, instead of a European energy mix, with more coal-fired power plants, the impacts are increased in terms of ionising radiation and limited in terms of greenhouse gas production.

11 It was possible to address the visualization of results with the pilot local authorities in a later stage of the same intervention-research project.

compromise between the perspectives of the developers and users, which is characteristic of constructivist approaches in management sciences. These are part of the "subject-object interaction principle" for knowledge production (Le Moigne 1990).

These results can be interpreted in the light of the typology of management innovation diffusion in organizations defined by David (1996). Before being transferred to the pilot local authorities, the ACV4E software belonged to a management model which David calls "technocratic":

- a tool oriented around knowledge which gradually becomes more complex to achieve a greater level of detail,
- a tool developed in a laboratory with little contextual background and which acquires a high level of formalization.

The first version of the software developed by the team of researchers did not properly consider the actual organization of a local authority; the ACV4E's capacity to meet managers' needs consequently was thus limited.

Consequently, obstacles to appropriation existed from the start in the three consecutive dimensions of a management tool:

- a technical substrate (visualization of results through a histogram of midpoints) ill adapted to non-specialists,
- a management philosophy of LCA (idea of taking pollution transfers into account) out of sync with the sector's prevailing philosophy both with regard to regulations (focus on water pollution) and local policy practices (focus on impacts on the local territory),
- an overly narrow view of the organization (for example, differences between technicians and elected officials not considered).

One of the added values of the test was to involve management researchers and users. This induced the addition of a supplementary module to the software for a more pedagogic and ergonomic presentation of results (a feature which is not explored in depth in this article, which focuses on decision-making, but which should be explored in a specific article under reviewing process in the *Journal of Cleaner Production*).

By assuming a logic of co-construction which was clearly affirmed during the intervention-research, the dissemination of the innovation comes closer to the model which David calls "managerial": innovation begins with a knowledge-based framework, but it gradually integrates the relational dimension, leading to modifications of these relationships. The tool in turn becomes more contextualized, including in its knowledge dimension (as defined by David 1996).

4.4. Back to the vision of the LCA simplified calculator's developers

From a practical perspective, the test of ACV4E in sewerage services demonstrated that operating the tool was less of a problem than interpreting the results. With the exception of one of the smallest local authority, entries could be made and the tool produced results, but the interpretation and appropriation of these results by non-LCA specialists were difficult.

The hypothesis made by the tool's developers also could not be fully verified: access to knowledge about pollution transfers is not enough to produce effects on non-specialists of environmental assessment. This limits the LCA potential for transformation in decision making.

Worse, the presentation of results in the conventional format of a histogram of midpoints is likely to lead to the LCA being rejected because these histogram graphs retain a black box effect. It can discredit the method. This limitation already has been observed in other public management contexts (Barbier *et al.* 2014; Bras-Klapwijk 1998).

The notion of objectivity must also be questioned. LCA supporters emphasize that the method makes a scientifically-based contribution to take into account different environmental dimensions. Yet is LCA an objective tool? Nothing could be less certain. On one hand, LCA involves a sufficiently large number of criteria, often divergent, for a decision-maker to bias the interpretation, unconsciously or intentionally, by selecting criteria which coincide with his or her *a priori* choice.

The LCA method itself also is a vehicle for implicit values. Some implicit values already have been discussed extensively within the community of LCA experts. For example, an LCA must choose between three hypotheses regarding the time scale to consider (short, medium and long-term impacts) which reflect three value systems (hierarchical, individualistic and egalitarian). Others have been discussed less extensively. They involve notably how criteria are weighed. As we have seen, LCA presents all of the impacts as equally important, which can lead to putting on equal footing impacts corresponding to different challenges. Lastly, LCA has an implicit subjectivity due to the fact that, while claiming to be as comprehensive as possible, it only considers impacts that can be characterized and quantified. The absence of a complete impact pathway thus impedes the consideration of certain midpoints in endpoints (water depletion and marine eutrophication).

4.5. Factors favouring the dissemination of LCA

This study made it possible to identify the conditions that could favour the development of LCA in sewerage services.

The visualization of results still needs to be adapted to render LCA a tool accessible to non-experts, notably elected officials.

The direct use of ACV4E by local authorities is only possible if the latter are large enough not only to have the capabilities required, but also to need to make investments sufficiently often to justify investing in such a tool.

To ensure the dissemination of the LCA method, the test confirms the importance of having an "institutional entrepreneur" LCA advocate within the organization who will immerse him or herself in the method and present it to other interlocutors in the local authority (Baumann 2000 ; Collins & Flynn 2007).

Lastly, the regulatory context can hinder or help the dissemination of LCA depending on whether or not it is coherent with the management philosophy of the tool.

CONCLUSION

In the end, our research demonstrates the extent to which the development of a management tool benefits from incorporating both academic knowledge and practical know-how. This experiment underscores the importance of taking into account not only factors related to the organization of local authorities, but also sector-specific characteristics. This is necessary to improve the dissemination of new management tools within the public sector.

The limits of our intervention-research must nonetheless be noted. While certain shifts in initial investment decisions could be observed in certain places, the impact of LCA on the decision-making process should be studied over a longer observation period. The perspectives of elected officials also are missing because the technicians involved in the experiment did not deem it relevant to present the LCA to them.

The use of intermediary actors such as independent engineering firms may be another means of disseminating LCA that could be explored[12]. It could overcome the obstacles posed by certain local authorities' small size and lack of technical knowledge.

The comparison with the waste sector has only been outlined. This work encourages more in-depth, trans-sectoral analyses to be conducted, comparing the adoption of LCA in the different areas of intervention managed by a local authority.

Finally, this work indicates that there is still a long road ahead before environmental assessment methods and tools become widespread supports for sustainable development policies in the public sector.

12 The initial results of the continuation of this intervention-research project, show that transfering ACV4E via engineering firms serving as intermediaries with the local authorities seems more likely to introduce elected officials into the process. These results nonetheless remain to be confirmed.

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