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Title: Seeking industrial synergies in the French Chemical Valley territory: A Methodological approach for decision support.

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Scope: Sustainable development and environmental management in information, technology innovation & adoption

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Biography

C. Harpet, 45 years old, is a researcher at EHESP in Rennes on Environmental Management and Environmental Health Assessment. He holds a Master's Degree in Environmental Management from INSA, Lyon. His work focuses on Environmental Urban Management, Industrial and Territorial Ecology and decision processes. He led the research initiative titled "Vallée de la Chimie, Intelligence Territoriale" (Territorial Intelligence in the Chemical Valley), in 2006-2008.

C. Blavot, 55 years old, Senior Engineer and Director of Ecologie Industrielle Conseil (EIC), works with economics stakeholders and territorial decision makers. Along with Suren Erkman, he contributed to the Metabolism System Analysis of the Industrial Area of Grand-Synthe (2001), and the Metabolism System Analysis of the Chemical Valley (Vallée de la chimie) (France, 2006-2008).

E. Gully, 25 years old, is a Materials Engineer with a Master's Degree in Environmental and Energetic Management from INSA Lyon (France); she is a Junior Researcher for the EITANS research project in Industrial and Territorial Ecology. She contributed to the Tools Comparative Analysis of the wastewater treatment systems in the French Chemical Valley. She currently works as an environmental engineer for A3i Innovation.

J. Bonnet, 25 years old, is an Environmental and Energy Engineer from INSA Lyon and a Junior Consultant Engineer at INSAVALOR. She conducted multi-criteria analyzes on waste and wastewater treatment systems for several companies and territorial stakeholders in France.

J. Mehu, 55 years old, is an Environmental and Energy Engineer from INSA Lyon, Associate Professor in Waste Management Systems at INSA Lyon; he is also the Director of the Provademse Environmental Experimentation Platform in Lyon, France.

1 ABSTRACT:

The Chemical Valley in France, a territory composed of various industrial platforms, is facing sustainability challenges. These business parks are located in the vicinity of strategic resources (water networks, pipeline networks). Their organization allows the pooling of services, equipment and resources. Industrial ecology reveals existing and potential industrial synergies. Environmental management services within the companies include facility and employee safety, waste management and effluent treatment. The aim of the research conducted on an industrial consortium is to strengthen synergies between willing industrial entrepreneurs by testing various decision support tools. The proposed methodology in industrial ecology consists in identifying the various flows, defining collective action strategies, and then comparing synergy scenarios using a multi-criteria analysis (acid-base exchange, wastewater sludge recovery).

Keywords (10 words): industrial ecology, industrial synergies, industrial waste; material and energy flows, methanation; wastewater treatment plant sludge; multi-criteria analysis; industrial metabolism; environmental management.

2 INTRODUCTION

2.1 INDUSTRIAL AND TERRITORIAL ECOLOGY

Industrial and Territorial Ecology (ITE) is a multidisciplinary and interdisciplinary field of research as well as an operational approach for economical and territorial stakeholders in the prospect of sustainable development. This scientific approach involves a paradigm and representation shift: the industrial system can be considered as a specific type of ecosystem[1]. This approach can apply to a specific sector, company, industrial facility, industrial area, territory, region, material, etc. It refers to methods of scientific ecology (Allenby, Cooper, 1994)[2], science engineering (Ayres, 1989)[3], thermodynamics (Georgescu-Roegen, 1971)[4], management science (Strebel, 2004)[5], etc. Moreover, from an operational approach, the ultimate purpose of industrial ecology is to guide the organization and management of human activities (industrial, agricultural, etc.) and territories (territorial intelligence) towards the development of a local, sustainable development model (Korhonen, 2004)[6]. It is based on four key principles: developing closed-loop material and energy flows (which includes the recovery of waste as a resource), dematerializing operations, controlling diffuse discharges and emissions, reducing excessive use of certain substances (fossil carbon, nitrogen,...)[7].

This approach is based on the following four skill levels:

- industrial systems and process engineering (physical and informational exchange networks, process chains, waste treatment channels, etc.);
- management of organizations and human resources (skills, trades, qualifications, etc.);
- governance and management of exchanges between companies and territories (prevention of industrial risks, administrative procedures to obtain authorizations, development plan, etc.);
- product and service eco-design (industrial design, marketing, function-oriented business models, etc.);

Beyond engineering and management competencies, engaging in an industrial ecology system consists in establishing relationships between businesses and territories based on resource and waste exchange in a vision of circular economic and ecological processes (Graedel, 1994) rather than linear (end-of-pipe approach). A materials and energy flow analysis (MEFA) (Brunner, 2004)[8] involves identifying all inputs and outputs in order to optimize processes and identify effective synergies (recovering byproducts, reducing or even neutralizing pollutant emissions). Various decision support tools can be used to identify and document possible synergies, which can then be assessed with respect to environmental, economic, technical, social and health criteria.[9]

2.2 RESEARCH CONTEXT

Historically, the Chemical Valley industrial area in the Rhône-Alpes region (France) has been marked by the anchoring of synthesis activities in pharmaceuticals, parachemistry, fine chemistry and intermediate chemical products. This business activity area is the third employment cluster in greater Lyon, accounting for nearly 46,000 jobs in 2008, particularly in the sectors of industry, logistics and waste treatment. The 1,500 hectare Lyon Chemical Valley business park holds more than 1,000 facilities and institutions including 6 research centres with nearly 20,000 jobs[10]. The purposes of this strategic activity in the region are export, research and development (it hosts

the French Petroleum Institute, the Central Analysis Service of the CNRS, and research laboratories of large companies such as Rhodia Research, Arkema Recherche, etc.). Chemical and petrochemical activities (4,000 jobs or one-third of all jobs in the urban area in this sector) are represented by Total Refining, Arkema, Rhodia operations Condat Total Additives and Special Fuels. This area is a stronghold of the French chemistry sector with 1,900 researchers and 6 scientific R&D centres. The field of fine chemicals and specialty products (plastic processing, pharmaceuticals, textile, metallurgy) represents 288 institutions (2005 DRIRE census[11]), including 200 companies with 20 employees or more (a total of 27,000 employees). The major chemical industries of the Rhône-Alpes region have formed a consortium called Pôle de Compétitivité (Competitive Cluster) specializing in chemistry and the environment (AXELERA[12]) and where research and development activities are focused on eco-innovation (bio-resources, energy efficiency, carbon-free energies, recycling processes, eco-design processes).
This territory has a particular configuration since it runs along the axis of the Rhone River valley and spreads from the city of Lyon to the Mediterranean sea, where it ends at the threshold of the Marseille Autonomous Port. Issues such as the reduction of technology related risks, the sustainability of economic activities, the reduction of environmental impacts and the optimization of resources (raw materials of fossil origin) led a group of public and private partners[13] to create a consortium for applied research in industrial and territorial ecology.

2.3 PURPOSE

The purpose of the applied research on Territorial Intelligence in the Chemical Valley (Intelligence Territoriale sur la Vallée de la Chimie en Rhône-Alpes , or ITVC) is to structure a collective approach for industries around a territorial ecology project. The ultimate aim is to develop a more mature organizational model close to an industrial ecosystem according to Braden Allenby's analysis (Allenby and Cooper, 1994)[14][15]. The idea behind the approach is to achieve a type II ecosystem according to Allenby's typology, formed by an intensified exchange process between industrial entities, and creating complex interaction networks. In other words, the first research phase consisted in defining the initial stage of existing synergies between companies in order to develop new synergies allowing for the reduction of pollutant emissions, and of the removal of non-renewable resources. One primary scientific objective was to identify and map the energy and material flows and exchanges between companies from a same business sector (chemistry), a same geographical area and partly bound by customer-supplier relationships (outsourcing). The so-called "operational" purpose is the implementation of innovative actions in the field of the environment. In this, environmental management serving Industrial and Territorial Ecology (ITE) is the core competence to organize a cooperative and innovative system between companies based on established, shared, evaluated and validated knowledge.

The initial strategic planning of the approach with the 11 industrial partners[1] was conducted over two successive years (2006-2008, ITVC project) and was then focused on 5 of them in the second phase (2011-2012, ADEME's EITANS project). Three specific intervention methods were applied:

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[1]Industrial Partners: ADISSEO, ARKEMA, GIE CASPER, GIE OSIRIS, GEPEIF, LAFARGE, NOVASEP, PRAYON, RHODIA, SARP Industry, SECHE-TREDI.

- **Building a framework for technical and scientific knowledge for an ITE approach**. The selected approach first consists in defining the scope of action in terms of geographical area, companyies' business sector and data to be collected. The objective is to define detailed specifications for the research, which include tasks such as identifying relevant businesses located within the perimeter, establishing partnership agreements with companies, collecting and processing flow data (material, energy, waste), and mapping all exchanges of energy and material flows between companies.
- **Managing Inter-company Projects**. The ITE approach becomes a cooperative action (intensifying and organizing collective and strategic intelligence) if industrial entrepreneurs are involved as early as possible in the process, with a systemic vision and a forecast period of 10 to 20 years.
- **Analysis of implementation conditions for collective action in industrial and territorial ecology**. The purpose of decision support tools is to objectively and collectively define, based on selected criteria, channels for process optimization, recovery of byproducts of industrial origin (waste, effluents) through the exchange of material and energy flows across the territory in order to reduce environmental impacts and economic costs of these flows.

3 METHODOLOGY

In view of the Chemical Valley's geographical size, which spreads over 60 km, defining a scope of action was crucial in order to initiate an approach aimed at developing inter-company management processes. The adopted principle was to identify "core" key companies of significant size, with a strong historical presence on the territory, located between the greater Lyon southern urban area and the chemical platform area located in Péage de Roussillon, 60 km south of Lyon. Using a mapping tool developed by the services of the Ministry of Industry (DRIRE)[16], which produces a list of all companies required to annually report amounts of emitted pollutants (solid, liquid, gaseous), a systematic census of the companies located within the perimeter was completed. Of the 80 companies initially identified within the perimeter between Lyon and the Roussillon platform, 25 were solicited as structuring industries, or so-called "key" industries within the territory. The notion of "key industry" reflects three main criteria: critical size (over 250 employees), positioning in the production scheme (centralizes significant material and energy resources) and economic activity structure (significant number of subcontractors, clients and co-contractors)[17].

Government services (DRIRE), in charge of inspection and control of installations classified for environmental protection, sent a personalized letter to each of the business leaders identified among priority companies (based on their size, the importance of their activities and reported pollutant emissions). In light of the French administration practices, this solicitation letter is particularly exceptional. The panel of firms declaring their willing partnership in this initiative included 11 industrial companies. Each company agreed to sign an agreement containing confidentiality clauses with regards to data transmitted to the research project's pilot plant. However, we note the refusal of certain companies solicited, which are, nonetheless, very structuring within the sector, each having expressed an interest for this innovative approach although refusing to commit to it.

The geographical area defined for this research on industrial and territorial ecology includes the three major chemical activity centres of the greater Lyon, the sites of Les Roches de Condrieu and Roussillon.

The official and confidential data collection (input and output energy and material flows on each site) conducted over three successive years (2004, 2005, and 2006) served to establish a solid and structured basis to identify potential synergies, substitutions and exchanges between partner industries. The 11 partner companies signed the confidentiality agreement on the exploitation of data: we all know how sensitive this subject is in the chemistry world. As three companies operate several industrial sites in the study area, the collection of flow data covered a total of 16 industrial sites.

Figure 1: Distribution map of the 16 industrial sites in the study area.

The systematic inventory of company material and energy flows was conducted on each site with the agreement and support of the management teams (Site Director, Head of Environmental Management), during facility visits. The review guide contains thirty items concerning each relevant category of flows for a comprehensive review. Data collected over 3 successive years was then compared and supplemented with public data reported annually to public authorities (DRIRE).

The entire database of material and energy flows collected at each of the 16 sites formed the metabolism of the three different industrial platforms. However, the complexity of intertwined flows already being exchanged required a reading more specifically adapted to the search for new synergies between companies. A graphic representation using OMMI[18] software facilitated this reading and understanding of the energy and material flow exchange channels. Construction using Sankey boxes also adds pedagogical value enabling industrial entrepreneurs to understand how the metabolism of such companies works. It also allowed for collectively identifying opportunities for the recovery of very large flows (in million tons or cubic meters) across the 16

industrial sites.

Various opportunity scenarios were created and assessed in order to invite industrial partners to engage in collective actions committed to sustainable development (including socio-economic, technical and environmental aspects).

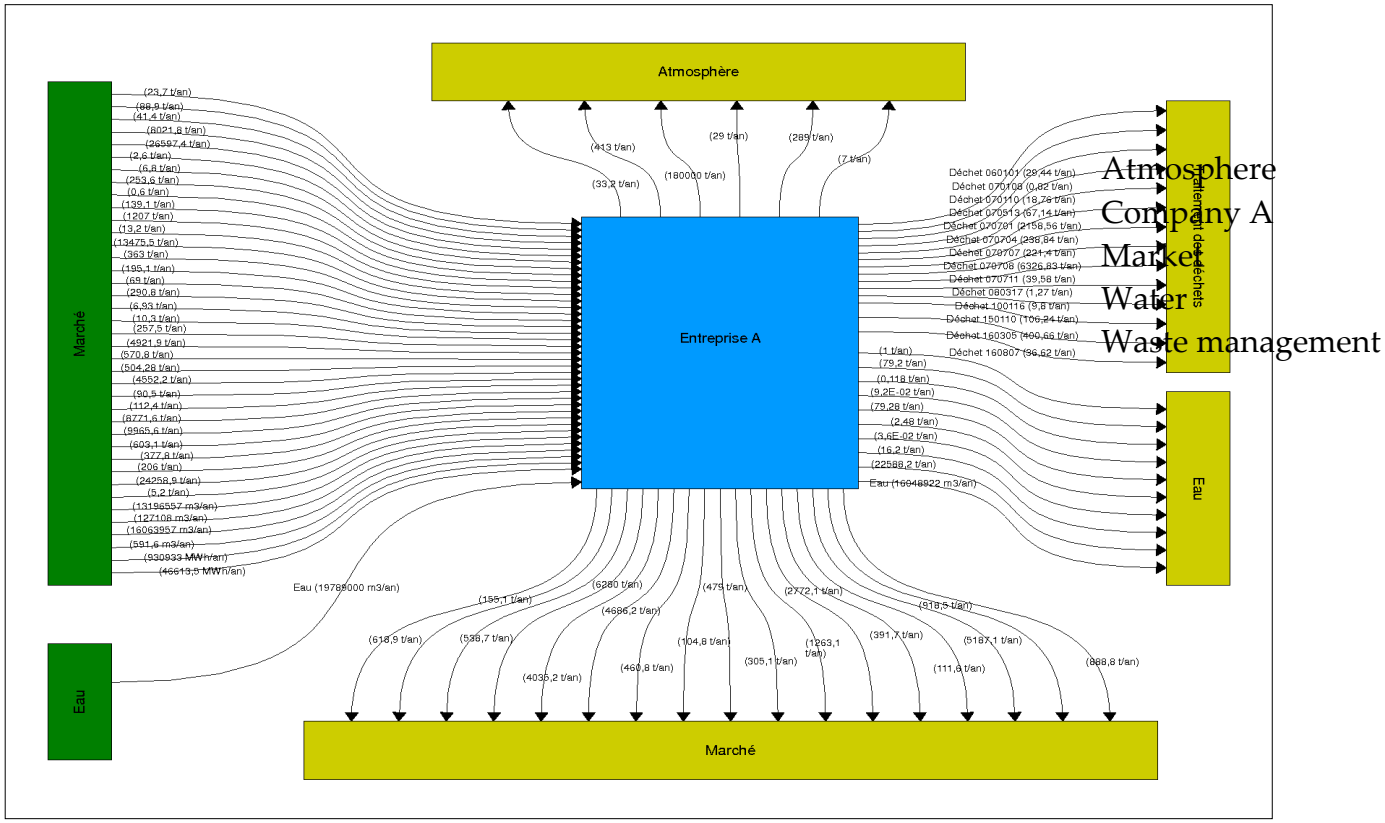
The mapping of physical flows (metabolism[19] of activities) was the basis for identifying innovative actions collectively carried out in a "win-win" approach. The proposed synergy channels pertained to waste and effluent recovery, material flow substitution (pollution reduction, economic gains), emissions and energy dissipation control, and equipment and resources pooling. Four synergistic action scenarios were modelled in more detail and presented to the industrial partners. We will describe the development procedures for the construction of these industrial ecology scenarios, and we will discuss decision support tools with respect to their impact on risk-taking for industrial entrepreneurs in their commitment to synergistic action.

4 RESEARCH RESULTS

4.1 THE METABOLISM OF COMPANIES' FLOWS AND SYNERGIES

The Les Roche and Roussillon chemical platforms have the advantage of being structured and organized industrial clusters which allow for the pooling and optimization of most flows. The history of these companies, originally forming a single entity known as the Rhône-Poulenc company and subsidiaries, and the formation of Economic Interest Groups resulted in a search for joint service and synergy opportunities allowing significant gains. A mapping of exchanges initially established by the DRIRE in 2006 served as premise to an industrial ecology scheme.

Figure 2: Schematic mapping of energy and material flows for a company (input and output flows), under OMMI software, C. Adoue, Systèmes Durables, 2006.



Company metabolism mapping, flow-per-flow and site-per-site, provides an overview of the density of activities and exchanges. However, it is not sufficient to show potential synergies and innovations to be created. A comparison of all 16 industrial sites was necessary in order to identify common flows reaching critical sizes in quantity and forsaking flows of small quantities or too specific to a company.

In order to strengthen the systematicity of an approach based on cooperation and operational optimization, scientific methodology primarily proceeds according to three stages:

- Inventory and classification of all identified flows;
- Creation of collective action scenarios;
- Assessment of scenarios in terms of sustainability.

1- Inventory and Classification of Flows

A physical balance sheet of the input and output flows of the 16 industrial sites was completed and recorded into a comprehensive database. These 1200 lines of material-energy flows were identified as too specific to allow for a (?) an analysis of recovery potential. In order to prioritize and classify the main flow categories and agree on a common language with the various industrial partners, we eventually defined 25 compound categories.

1-Acids	15-Cyanides
2-Bases	16-Polycyclic aromatic hydrocarbons
3-Alcohols	17-Aromatic cyclic hydrocarbons
4-Aldehydes	18-Other aromatic cyclic hydrocarbons
5-Metals	19-Other oxygenates compounds (cetones, esters, furan compounds)
6-Halogenated substances	20-Volatile organic compounds
7-Halogenated solvents	21-Greenhouses gases
8-Nitrogen compounds	22-Alumino-silicates minerals
9-Fluoro compounds	23-Mineral compounds
10-Phosphorus compounds	24-Water
11-Sulfur compounds	25-Others compounds
12-Alkali salts	
13-Phenols	
14-Benzene, toluene, ethyl benzene, xylene	

Table 1: Classification of the 25 chemical compounds categories, extract from the Research Report, Intelligence Territoriale sur la Vallée de la chimie (Territorial Intelligence in the Chemical Valley), Harpet C. Mehu J, INSA Lyon, 2008.

The database includes the 1 200 flow channels, ranking them in 14 successive columns from the "input-output" category to the origin and destination of the flows. However, a flow can be part of several families of chemical compounds and will be classified accordingly in columns C1, C2, and C3 (the three primary compound categories)

Figure 3: Classification table for material and energy flows, extract from the Research Report, Intelligence Territoriale sur la Vallée de la chimie (Territorial Intelligence in the Chemical Valley), Harpet C. Mehu J, INSA Lyon, 2008.

2- Creation of Collective Action Scenarios

In the second phase, selecting priority and common flows based on quantities (emitted tonnage and volumes), the number of occurrences (frequency of compounds found in the industries), and the extent of costs (purchase of raw materials, transportation, or emission permits) oriented partners towards a series of collective and cooperative actions.[20] In response to economic and environmental issues, 9 strategic action scenarios were selected through consultations with industrial entrepreneurs: ***1) carbon footprint, 2) transportation and logistics, 3) energy assessment, 4) treatment of effluents and aqueous waste, 5) acid-base neutralization, 6) management optimization for wastewater treatment plants (WWTP), 7) biomass recovery, 8)***

containers and packaging, 9) collective purchasing policy.

3- Assessment of Scenarios in Terms of Sustainability

In the third phase, implementation of short-term action scenarios became crucial to the cohesion between the 11 partners and adherence to the ITE initiative. To reinforce the value of potential actions, three scenarios were assessed using a multi-criteria analysis based on environmental, technical, economic, social and health aspects. The three selected scenarios offered sufficient available data to ensure consistency of actions with the issues at stake (optimization of resource consumption, and reduction of socio-economic and environmental impacts). The selected actions are those characterized by the ease of implementation (transportation optimization), the presence of existing skills and trades on the territory (management of flows through synergies between inputs and outputs of raw materials and waste, specifically acid and base flows) and the potential for creation of jobs and activities around bottom ash and incineration residue valorization through synergy with players not yet involved.

This decision support method (called AMTRAD), further detailed in this article (Section 5.1) explores action scenarios based on criteria of usefulness, reliability, consistency, completeness, discrimination and non-redundancy. Each action is then detailed in a diagram reflecting the existing situation (overview), subject to an assessment on criteria pertaining to a sustainable development approach ("environment", "technical", "social", "economic" criteria categories), each criterion then being supplemented with parameters relating to the issues (e.g. "greenhouse gas emissions" in the "environment" classification.)

Action 1 focuses on **substituting road freight with inland waterway and rail transportation**.

80 000 tons of hazardous waste are produced each year and transported by road to Industrial Landfill Sites (Centres d'Enfouissement Technique or "CET", today designated as Hazardous Waste Storage Facilities (Installations de Stockage de Déchets Dangereux or "ISDD")). However the Rhône River in the south and Saône River in the north provide waterway accesses for a combined transportation mode, involving no extra cost and putting three companies to work instead of one. This method would result in significant reduction of atmospheric impacts and energy consumption.

Action 2 consists in managing the **flows of acidic and basic products** used for current neutralization operations without resorting to convenience products.

Given the significant amounts of certain acids required by companies in the area, buying from local businesses offers the opportunity, depending on costs, to acquire the appropriate quality and quantity of products. This scenario reduces transportation of goods. As chemical manufacturers use many similar products, a group purchasing policy could optimize transportation as well as price negotiation capacities.

Action 3 consists in developing a prospective scenario for non-existent activities pertaining to the recovery of Bottom Ash from the Incineration of Industrial Waste (Mâchefers d'Incinération de Déchets Industriels or "MIDI") and incineration residues. The Chemical Valley generates over

50 000 tons of waste incineration residues in the shape of bottom ash each year. These MIDI produced by the incineration of hazardous waste (today designated as Bottom Ash from the Incineration of Hazardous Waste (Mâchefers d'Incinération de Déchets Dangereux or "MIDD")), are sent to class 1 storage facilities. However, this treatment is costly (10 million € per year) and causes environmental issues. The absence of Industrial Landfill Sites (Centres d'Enfouissement Technique or "CET", or ISDD) in the Rhône-Alpes region points to the proposal of recovery of "materials" in roadway techniques. A 1993 study conducted by a research team (POLDEN INSAVALOR) for a recycling trade association showed that Bottom Ash from the Incineration of non-hazardous Industrial Waste is better in quality than Bottom Ash from the Incineration of Municipal Solid Waste (Mâchefers d'incinération des ordures ménagères or "MIOM", now designated as Bottom Ash from the Incineration of Non-Hazardous Waste (Mâchefers d'incinération de Déchets Non Dangereux or "MIDND").

A feasibility study represents a capital cost of 1% of the annual waste treatment cost. Such a study guarantees optimal conditions of recovery for the MIDD (non hazardous and technical compliance). The recovery of "materials" reduces the tonnage of hazardous waste generated in the Chemical Valley by 64%.

4.2 SPECIFIC ANALYSIS OF A WASTE RECOVERY CHANNEL: WASTEWATER TREATMENT PLANT SLUDGE

The EITANS project (2010-2013)[21] has extended the ITVC research by focusing on the assessment of a decision support tool in ITE. The choice of equipment such as Waste Water Treatment Plants (WWTP), critical facilities in today's industrial ecosystem, was based on the fact that each site has at least one industrial sludge treatment facility (Péage de Roussillon, St. Clair les Roches, St. Fons, Pierre-Bénite, and Chasse-sur-Rhône). Such facilities are part of an effluent treatment system involving high amounts of pollutants and primarily intended for industrial landfills or incineration, without material or energy recovery. This waste treatment channel is an "end-of-pipe" process. Wastewater treatment plants have become critical as they are involved in several scenarios of eco-industrial synergies.

This type of structure was selected in order to test tools supporting the development of eco-industrial synergies, using a realistic – although fictitious – example, based on the data provided by one of the treatment plants. The aim of the study is to develop a methodology. The idea is to build several treatment and recovery scenarios for industrial wastewater treatment plant sludge and assess them. The tools tested as part of this study were those developed in the COMETHE project[22], supplemented by an analytic study of synergies using the PRESTEO© software, followed by a more detailed and quantified environmental assessment using the SimaPro software and finally by a multi-criteria analysis of possible scenarios for the recovery of effluents (AMTRAD method, PROVADEMSE team).

The industrial wastewater treatment plant south of Saint-Font, south of the greater Lyon, is operated by the GEPEIF Economic Interest Group. With the agreement of the management, all necessary information for the establishment of baseline scenarios was collected through site visits and analysis of technical operating conditions. In agreement with the site manager, comparative analyses will only be performed on treatments and recovery processes of sludge from wastewater treatment. At present, this sludge is incinerated with sludge from the Greater Lyon Urban Community's wastewater treatment plant nearby.

Sludge from industrial treatment plants can be sent to several treatment and recovery channels[23]:

- agricultural recovery through landfarming;
- composting;
- methanation;
- incineration;
- storage in class 2 facilities.

For the EITANS research project, we decided to focus on landfill (as the baseline scenario serving as a comparison basis for others), incineration and methanation scenarios.

Indeed, recovery through landfarming (on agricultural land) or composting present two problems justifying removal from the potential options. On one hand these technologies subject the producer to strenuous quality and stability standards in the sludge composition, which are not always compatible with industrial constraints. On the other hand, even if the characteristics of

the sludge are compatible with health and environmental protection standards, these recovery channels are not viable because of the scarcity of sites that allow them.

4.3 FOCUS ON THE AMTRAD MULTI-CRITERIA ANALYSIS OF INDUSTRIAL SYNERGY SCENARIOS

The multi-criteria analysis performed with the AMTRAD tool was the key step in the decision support process. Indeed, results obtained from a comparative analysis of three effluents recovery channels helped inform policymakers and funders. A decision simulation from realistic (although fictitious, since not implemented) scenarios of effluents recovery channels presents key criteria in terms of environment, health, economy and social affairs. We opted for a focus on the multi-criteria analysis, followed by a discussion.

Although the effluent treatment scenarios were developed for the study, they are based on realistic situations. These scenarios take into account the local context of the area, including the players located around the WWTP, involved in the following processes:

- sludge disposal in landfills, including specialized facilities, with or without biogas recovery;
- sludge incineration in fluidized bed furnaces;
- sludge methanation with digestate dehydration.

The quality of a multi-criteria analysis depends on the selected criteria. They must reflect the object to be evaluated in the most relevant way possible. Each criterion should therefore summarize an action according to a set of predefined attributes (usefulness; reliability; consistency; completeness; discriminance (or selectivity); non-redundancy). The analysis can then be structured through coherent sets or categories of criteria. For the purpose of the study, twelve criteria were selected and grouped into four categories:

- the "technical" category;
- the "economic" category;
- the "environmental" category;
- the "intangible capital" category.

	criteria	parameters	score calculation	range of variation
a) Technical aspects category	technical complexity	Technical evaluation with COMETHE	The assessment tool for the COMETHE technical aspects helps assign a score to the synergy (0 to 5). The reference scenario (without synergy) got a score 0.	[0;5]
	robustness	POLDEN reference	Qualitative scores are assigned based on experience feedback. A negative score corresponds to a more robust process than the processes in the reference case. A positive score corresponds to a less	[-5;5]

			efficient process.	
	technical performance of depollution	POLDEN reference	Qualitative scores are assigned based on experience feedback. A negative score corresponds to a more efficient process than the processes in the reference case. A positive score corresponds to a less robust process.	[-5;5]
b) Economic aspects category	amortized cost	Amortized cost (€/t MS) for the infrastructures and equipment (order of magnitude)	The difference between amortized cost for the reference scenario and the submitted scenario is estimated on a scale of scores from 0 to 5. A negative value for the "amortized cost" criteria corresponds to a lower cost than the reference cost. An amortized cost higher than the reference cost (such as double the value) corresponds to a +5 score, and a cost lower than half of the reference cost corresponds to a -5 score.	[-5;5]
	operating cost	Operating cost (€/t MS) for consumables, labour, maintenance, waste and effluent disposal (order of magnitude)	Same case with amortized cost	[-5;5]
	Revenues	Revenues (€/t MS) for the sale of by-products	The ratio between "revenues" (cost <0) and the cost of treatment (amortized cost for investment + operating cost) shall be multiplied by 5. The score revenue higher than the «treatment cost» is -5.	[-5;0]
c) Environmental aspects category	greenhouse gases	Quantity of emitted or avoided greenhouse gases (kg CO_2 eq./t MS)	A score of 0 is assigned to the quantity of greenhouses gases emitted in the reference scenario. An emission of zero or a negative quantity corresponds to a score of -5.	[-5;5]

	depletion of natural resources	Quantity of extracted or non extracted natural resources (kg Sb eq./t MS)	Ditto.	[-5;5]
	human toxicity	Quantity of emitted or avoided toxic products for humans (kg 1,4 DB eq./t MS)*	Ditto.	[-5;5]
	ultimate wastes	Quantity of generated or avoided ultimate wastes (kg /t MS)	Ditto.	[-5;5]
d) Intangible capital category	reputational risk	Qualitative score (from scientific literature)	As with the reference scenario, the reputational risk is higher if: specific oppositions: + 2 Nuisances for neighbours (smell, noise): +1 to 2 Scores between 0 and 4 are assigned on a scale from 0 to +5	[0;5]
	benefits for the image	Qualitative score (from scientific literature)	As with the reference scenario, the reputational risk is lower if: Exemplary organization : -1 to -3 Benefits for the local area: -1 Scores between -4 and 0 are assigned on a scale from 0 to -5.	[-5; 0]
		*The unit "kg 1,4-DB eq" concerns the Human Toxicity Potentials (HTP). A substance's HTP is calculated with the single unit to the 1,4-DB chemical reference substance (1,4-Dichlorobenzene) human toxic reference value.		

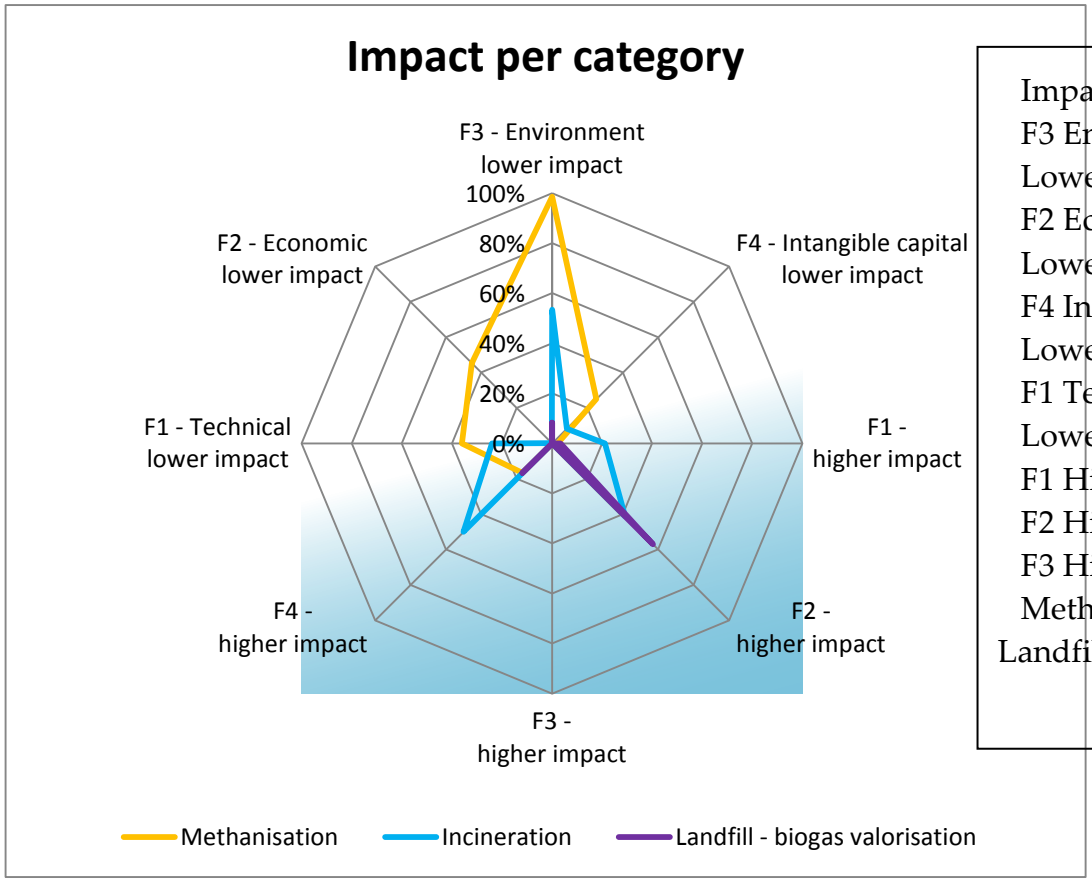
Table 2: Criteria parameters and scoring for the (a) technical, (b) economic, (c) environmental and (d) intangible capital categories.

Each criterion can be assessed against one or several parameters, which are measured or observed properties. The parameters are then assessed according to a scoring system that allows

for the comparison of the criteria.

For the environmental criteria category, parameters are derived from the lifecycle analysis of the sludge treatment and recovery process. These parameters are calculated using the SimaPro software and the EcoInvent database.

For the purpose of comparing scenarios, disposal in landfill without biogas recovery scenario is defined as the reference scenario, and its score is always zero. A higher score indicates a greater impact for the given criterion, while a lower score indicates a lower impact. The criteria are then weighted in order to reflect the priorities of the decision maker. The mathematical processing of data produces results in the shape of a graph that allows for overall comparison of all scenarios. Criteria were partially aggregated into categories in order to facilitate reading.



Impact per category
F3 Environment
Lower impact
F2 Economic
Lower
F4 Intangible capital
Lower impact
F1 Technological
Lower impact
F1 Higher impact
F2 Higher impact
F3 Higher Impact
Methanation – Incineration – Landfill-biogas valorization

Figure 3: Diagram of the various criteria categories' impact rates for the three effluent recovery scenarios (landfill with biogas, incineration, methanation) (EHESP-Insa-Provademse, Expertise for the EITANS research for ADEME 2012).

Although none of the three scenarios compared to the reference scenario is ideal, we can see that they all have lower environmental impacts. However, they all represent a certain level of risk for the company's image and higher treatment costs.

According to our hypotheses and selected criteria, methanation seems to be the most advantageous sludge treatment method since it has obtained the highest negative score in

absolute value along with the lowest positive score. This result is due to the fact that all by-products derived from this scenario are expected to be recovered. It should be noted that this hypothesis may be idealistic, and it shall not mean that methanation is always the best treatment method for WWTP sludge.

In real situations, the methanogenic potential of the sludge needs to be verified, given the fact that the industrial origin may impact the choice of treatment. Moreover, the hypothesis of a digestate compatible with the NF U 44-051 standard[24] pertaining to organic amendments, as well as the hypothesis of ashes in the incineration scenario, which is compatible with the EN 450-1 standard[25] for use as a cement substitute by analogy with coal fly ash, should be verified.

It should be reminded again that these results are the product of realistic but fictitious data, collected with the purpose of testing decision support tools for industrial and territorial ecology; therefore, they should not be used for other purposes.

5 DISCUSSIONS

Following our five-year research, we retain four discussion points. These four points are as follows: first, the collection of data useful to ITE; second, the geographical scope and business sector; third, the decision-making process; and fourth, the benefit of decision support tools.

1- ***The first discussion topic*** pertains to the collection of data on material and energy flows between companies. This is a decisive step in the building of a database for industrial metabolism (Ayres, 1997)[26,27]. This step involves making an inventory of all flows; it is tedious. Moreover, initiating progress does not require full completeness. One criticism expressed by industrial entrepreneurs pertained to the systematic collection of non-strategic, irrelevant or uninteresting data prior to initiating cooperative actions. Indeed, flows should be prioritized (according to specific criteria) at the earliest stage possible for such project: strategic guidelines must be defined in order to quickly initiate cooperative and incentive actions with visible efficiency to confirm the need for inter-company environmental management. This being said, one should question the heuristic nature of an exhaustive collection of data that could highlight "dead angles" in strategies applied by companies. Any strategy is based on an element of knowledge. If it is determined at the early stage of collection, it will logically favor a search for information confirming the element of knowledge.

   A second potential issue is the request for data already provided to public authorities (in compliance with regulations) for the purpose of scientific research. However, in some cases, such data appeared different from those recorded by public authorities. Lastly, access to such sensitive (confidential) data regarding industrial and commercial core activities leaves little or none room for manoeuvre (strategic challenge of the company). Therefore, it is important to examine actor interactions that not always match a reality of competitive advantage.

2- ***The second discussion point*** is methodological and pertains to the definition of scopes, whether geographical for intervention or industrial sectors. The Chemical Valley territory covers an area not limited to administrative divisions. It could be an area covering all large

chemical industrial sites, from the Marseille harbor to the north of France. The perimeter could also cover the pipeline network linking raw material production and processing sites. For practical reasons, our research essentially covered the perimeter of the three industrial platform areas located along the Rhône river in the Rhône-Alpes region. Additionally, the selection of activities pertaining to chemistry was completed based on a sufficiently strategic sector, diversified by divisions (fine chemistry, parachemistry, chemical intermediate chains, etc.) without the need to recruit other companies from different industrial sectors. In reality, by excessively fragmenting the activity scope and limiting it to one single sector, we run the risk of engaging into an approach that is too andogenous (chemistry-chemistry) for an ITE approach.

3- ***The third discussion point*** pertains to the decision-making process, hence on the ITE governance of such project. The stakeholders from partner companies were positioned at two different levels of the decision-making process. First, a "corporate" level (within an industrial group) where decisions originate from a strategic orientation for all activities of an industrial group, oftentimes at national and international levels. At this level, decision-making takes time, since it travels across various stages, often against a global backdrop, which could devalue the benefits of a single territory approach. The second level of the decision-making process is short and local: it is the level of industrial site managers who become direct stakeholders, involved in research experimentation, although with limited decision-making authority. Approximately half of our eleven partners is part of the latter decision-making process.

4- ***The last discussion point*** pertains to decision support tools. This research covered 5 successive years and tested several tools designed to facilitate the ITE approach. For the EITANS program on decision-making processes, we tested three tools: the PRESTEO© software, the COMETHE approach, and the multi-criteria analysis tool AMTRAD. These tools are used at different stages of an ITE project:

- The PRESTEO© software is a software package designed to detect all synergy opportunities existing according to flow reports from two or more companies. This is a methodological and technical tool used for collecting as well as processing information.
- COMETHE offers a range of simple tools for a quick first assessment of a synergy identified as realistic, to determine whether it is, at first glance, feasible from a regulatory, economic and technical point of view, and beneficial from an environmental and sanitary point of view, then to identify risks.
- The AMTRAD (for Analyse Multicritères de Traitement des déchets et Aide à la Décision, multi-criteria analysis of waste management and decision-making tool) is an input tool used to compare various scenarios based on definite criteria. This method applies to viable scenarios to visualize strengths and weaknesses for each of them from economical, technical, environmental and social points of view. In reality, perfect scenarios rarely exist, and a multi-criteria analysis makes it possible to form an opinion based on the various criteria.

6 CONCLUSION ON THE COMPARATIVE ANALYSIS OF TOOLS FOR AN ITE APPROACH

Searching for synergies between companies within an industrial ecology approach requires an analysis of material and energy flows and resources of each entity located within an activity zone or territory. The systematic strenghtening of synergies requires increasingly efficient tools to identify recovery opportunities for waste and effluents. In this study on the Chemical Valley[28][29], the focus was on creating realistic, although fictitious, scenarios for the processing and recovery of sludge from industrial wastewater treatment plants (WWTP).

The various COMETHE assessment tools helped us in the early stages, to create complete, consistent scenarios by guiding us towards essential data to be collected. Therefore, we can say that such tools (used at their most basic level), very user-friendly, provide a useful "*checklist*" of elements to be taken into account when implementing a synergy. In addition, they facilitate the assessment of benefits and potential issues to be expected throughout the project. When scenarios are completed, such assessments can allow decision-makers who are inexperienced in industrial and territorial ecology to rapidly evaluate the benefits of a synergy by reviewing all potential deterrents to its implementation and sustainability.

Nonetheless, this is still a qualitative assessment making it possible to form an opinion on the benefit of a synergy, without covering any quantitative assessment of technical/economic feasibility (which actually is not part of the COMETHE purposes). A full assessment requires additional methods, specific to the area under examination, such as a lifecycle analysis (LCA) for environmental assessment.

The SimaPro software was used to complement the COMETHE assessment tools for synergy feasibility. The software made it possible to complete an environmental assessment of the scenarios under consideration and to compare their environmental impact based on four criteria. The objective and scope of this tool are very different from those of COMETHE: they are complementary with regards to decision support in industrial and territorial ecology. Where a COMETHE environmental assessement only identifies flows likely to have an environmental impact different from the pre-synergy status, the LCA is a mean to quantify such impacts.

An environmental assessment is part of a multi-criteria analysis (according to the AMTRAD method) that also includes technical, economicla, and intangible capital. The advantage of this approach is to provide elements of judgement to companre scenarios from various points of view. The last step of the assessment includes processing such independent classification levels and results from the mathematical aggregation or non-aggregation of such results.

Generally, feasibility assessment tools for a synergy as offered by COMETHE are useful at the onset of the analysis (prior to the feasibility study), and adapted to an audience who has not expertise in industrial and territorial ecology. Each module helps the decision-maker to quickly assess the economical and environmental benefits of synergies. Each option is presented along with potential issues justifying a more in-depth analysis. Hence, module tools meet the objectives determined by the COMETHE project team. In the event the benefits are considered sufficient, the implementation of option(s) requires a multi-criteria analysis (such as AMTRAD) and, as a result, a more specialized decision support tool that quantifies positive and negative impacts of

the synergy at relevant levels. A comparison based on each criteria using specific indicators (environmental, economical, and social) for each scenario created in industrial and territorial ecology produces a matrix for decision-making.

Table of figures:

Figure 1: Distribution map of the 16 industrial sites in the study area.

Figure 2: Schematic mapping of energy and material flows (input and output flows), under OMMI software, C. Adoue, Systèmes Durables (Sustainable Systems), 2006.

Figure 3: Diagram of impact rates across criteria families for the 3 effluent recycling scenarios (solidwaste treatment with biogas valorisation, incineration, methanation) (EITANS study, EHESP-INSA-Provademse, 2012).

Content of tables:

Table 1: Classification of the 25 chemical compound categories, extract from the Research Report, Intelligence Territoriale sur la vallée de la chimie (Territorial Intelligence in the Chemical Valley), Harpet C. Mehu J, INSA Lyon, 2008.

Table 2: Criteria parameters and scoring for the (a) technical, (b) economical, (c) environmental and (d) intangible capital categories.

Research Team

This study was conducted in two phases, with the following programs:

- « Intelligence territoriale sur la vallée de la chimie (ITVC)», 2006-2008, directed by the Institut National des Sciences Appliquées de Lyon (C. Harpet, J. Mehu ; *Laboratoire du Génie Civil et Ingénierie Environnementale-LGCIE, and* laboratoire STOICA, *Savoirs, Techniques, Organisation, Innovation, Conception Appliqués*), EI Conseil (Christophe Blavot, Jonathan Sueur, Leïa Abitbol), the Systèmes Durables company (Cyril Adoue), the Université de Technologie de Troyes UTT (Dominique Bourg, laboratoire CREIDD**,** Centre de Recherche en Ecologie Industrielle et sur le Développement Durable), l'ICAST (Institut pour la Communication et l'Analyse des Sciences et des Technologies, Genève, Suren Erkman).

- « Ecologie Industrielle et territoriale : analyse des facteurs socio-économiques et anthropologiques pour sa mise en œuvre » (Industrial and territorial ecology: an analysis of social-economical and anthropological factors for implementation), 2010-2013, financed by ADEME, directed by the Université de Technologie de Troyes (UTT, Sabrina Brullot, with EHESP of Rennes (Ecole des Hautes Etudes en Santé Publique), Cyrille Harpet, Systèmes Durables (Cyril Adoue) and EIConseil (Christophe Blavot).

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