

# Strategy and Method for the Elaboration, Development and Optimization of an Innovative Recycling Process

Elisa Bonaldi

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THESE PRESENTEE EN VUE DE L'OBTENTION DU GRADE DE

# DOCTEUR

DE

# L'UNIVERSITE DE LORRAINE

Spécialité : GENIE DES SYSTEMES INDUSTRIELS

PAR

**Elisa Bonaldi**

*Strategy and Method for the Elaboration, Development and Optimization of an Innovative Recycling Process*

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## *ABSTRACT*

Regulations on product recycling rates, but also growing consciousness on the importance of eco-design, enforce industrials to seek for solutions to recycle their products at their end of life. Growing environmental concerns in the industry allow new business opportunities and require organizational changes to support transition toward more sustainable industrial activities.

Building a recycling industrial activity for materials coming from end of life products is a great challenge that requires an analysis of the opportunities and threats and the added value of industrial partners, in the scope of a collaborative project (or a collaborative network). This kind of projects aims at designing a new recycling supply chain and to design a new product that will be manufactured by this supply chain. R&D collaborative projects enable to gather complementary competencies in order to propose solutions to increase the recycling rate on the territory. Nowadays, experiences such as collaborative projects are witnessed, giving various new business possibilities in the recycling industry. However, a literature review we have performed points out that there is no existing method permitting to analyze the opportunity of a recycling value chain and to guide industrials in the definition of a "recycling collaborative project". Moreover, for such projects, the selection of the partners is of great issue for the industrials. Indeed, the values brought by the partners make the interest of the project and favor the success of the collaboration. However, there is no existing method to choose R&D collaborative project partners efficiently in the scope of the recycling industry.

A literature review presents the industrial and scientific state of the art and highlights the existing best practices in order to take them into account for the proposal of an original contribution. From the state of the art we can highlight a lack of methods that would associate R&D collaborative project organizations with the development of recycling supply chains; this positioning contributes to the originality of the work realized.

Our contribution is to propose three methods to help industrials to define a collaborative project for the design and building of a new recycling supply chain:

- The first method we propose facilitates the understanding of a recycling emerging industry mechanisms, act simultaneously on the environmental impact by recycling end of life products and on the business competitiveness by differentiation in new industrial activities.
- The second method we developed must helps recycling R&D project managers to define a "recycling collaborative project", the target market, the recycled product that will be manufactured and the potential structure of the future supply chain.
- The third method is related to the question of partner selection with the proposal of a ranking method and the definitions of adapted criteria for such selections. In this respect we used Multi-Criteria Decision Making (MCDM) techniques to help industrials in this selection process.

A case study is developed on the French textile recycling industry and a R&D collaborative project that introduces recyclable raw material from end of life vehicles and garments, for the development of a new product. An application of our research is conducted on a specific recycling collaborative project in order to discuss the initial results, and perspectives are highlighted for further research investigations.

## *KEY WORDS*

Eco-design, Recycling, Recovery, End of Life materials, Supply chain design, Recycling supply chain, Value chain, R&D Collaborative project, Virtual enterprise, Innovation process, Partner selection; Multi-Criteria Decision Making

## *RESUME*

Les réglementations sur le recyclage des produits, mais aussi le développement de l'écoconception, obligent les industriels à rechercher des solutions de recyclage pour leurs produits en fin de vie. Les préoccupations environnementales croissantes dans l'industrie créent de nouvelles opportunités d'affaires et nécessitent des changements d'organisation pour accompagner la transition vers des activités industrielles plus durables.

Une activité industrielle de recyclage de matières issues de la fin de vie d'un produit, se déroule idéalement avec la participation de différents partenaires industriels dans le cadre d'un projet collaboratif. Cela permet de développer une nouvelle supply chain de recyclage et de concevoir un nouveau produit, fabriqué grâce à cette supply chain. Les projets collaboratifs de R&D permettent de rassembler des compétences complémentaires dans le but de proposer des solutions pour accroitre le taux de recyclage d'une matière dans le domaine considéré. Aujourd'hui, les expériences de projets collaboratifs existent créant de nouvelles opportunités de marché dans l'industrie du recyclage. Cependant, nous observons qu'il n'existe pas de méthode opérationnelle permettant de guider les industriels dans la définition d'un projet collaboratif de recyclage. De plus, la sélection des partenaires pour de tels projets est une réelle difficulté pour les industriels. En effet, les valeurs apportées par les partenaires créent l'intérêt du projet et favorise le succès de la collaboration. Cependant, nous constatons qu'il n'existe pas de méthode dans le cadre du recyclage industriel pour faire un choix efficace de partenaires de R&D sur un projet collaboratif.

Une revue de la littérature est présentée, pour connaitre l'état de l'art industriel et scientifique, avec un éclairage sur les meilleures pratiques existantes de façon à les prendre en compte et les intégrer, afin de proposer une contribution originale. A partir de cette revue de l'état de l'art, nous mettons en évidence un manque de méthode associant les organisations de projets collaboratifs R&D et le développement de supply chain de recyclage ; cela contribue à donner une posture originale à notre recherche.

Notre contribution est de proposer une combinaison de méthodes pour accompagner les industriels dans la définition d'un projet collaboratif pour la mise en place d'une activité de recyclage.

- La première méthode facilite la compréhension des mécanismes d'une industrie émergeante du recyclage, agissant simultanément sur l'impact environnemental, en recyclant les produits en fin de vie, et sur la compétitivité d'une entreprise, par sa différenciation vers de nouvelles activités industrielles.
- La deuxième méthode développée est une aide pour le chef de projet R&D lors de la définition d'un « projet collaboratif de recyclage », avec la spécification du marché, du produit recyclé et de la structure projetée de la filière de recyclage.
- Nous développons également la question de la sélection des partenaires d'un projet collaboratif de R&D dans le domaine du recyclage, en proposant une méthode d'évaluation ainsi que la définition de critères adaptés à ce nouveau contexte. Sur ce point, nous utilisons les techniques d'aide à la décision multicritères que nous combinons, afin d'aider les industriels dans ce processus de sélection.

Une étude de cas est développée concernant l'industrie française du recyclage textile, ainsi qu'un projet de R&D collaboratif impliquant l'utilisation de matières premières recyclables provenant des véhicules hors d'usage et de vêtements fin de vie, pour l'éco-conception d'un produit nouveau. L'application de

la combinaison des méthodes proposées, conduites dans le cadre d'un projet de recyclage spécifique, permet de discuter les premiers résultats et d'ouvrir ce sujet sur des perspectives de recherche à venir.

## *MOTS CLES*

Eco-conception, Recyclage, Valorisation, Conception de chaîne de valeur, Projet collaboratif de R&D, Matière fin de vie, processus d'innovation, Sélection de partenaires, Supply chain de recyclage, Outils d'aide à la décision multicritères

*« Rien ne se perd, rien ne se crée, tout se transforme »*

*Antoine Lavoisier*

*« Rien ne naît ni ne périt, mais des choses déjà existantes se combinent, puis se séparent de nouveau »*

*Anaxagore*

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## *LIST OF ABBREVIATIONS*

***Conventional Abbreviations***

ADEME: Agence De l'Environnement et de la Maitrise de l'Energie

AHP: Analytic Hierarchy Process

CIFRE: Convention Industrielle de Formation à la REcherche in English: "Research Training under Industrial Convention"

DEMATEL: Decision-Making Trial and Evaluation Laboratory

DfR: Design for Recycling

DfX: Design for X

EoL: End of Life

INSEE: Institut National de la Statistique et des Etudes Economiques (French Statistic and Economic Studies Institute)

LCA: Life Cycle Analysis

MCDM: Multi-Criteria Decision-Making

R&D: Research and Development

SCM: Supply Chain Management

TOPSIS: Technique for Order Performance by Similarity to Ideal Solution

***Abbreviations used in this PhD work***

FMSP: Federal-Mogul System Protection

FTRI: French Textile Recycling Industry

IARC: International Automotive Recycling Congress

RRM: Recyclable Raw Materials

RSC: Recycling Supply Chain

RSCDP: Recycling Supply Chain Design Process

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## *RESUME ETENDU EN FRANÇAIS (EXTENDED ABSTRACT IN FRENCH)*

Cette recherche concerne une stratégie d'entreprise prenant en compte l'éco-innovation comme un outil de différenciation au service de l'amélioration de la compétitivité.

Les produits nouveaux voient le jour grâce à l'évolution de notre environnement. Les exigences nouvelles auxquelles doivent répondre ces produits permettent de remettre en cause les processus de conception de ses nouveaux objets, dépendant eux-mêmes des processus de gestion de l'innovation de l'entreprise. L'Eco-innovation est considérée comme une manière d'implanter une conscience environnementale en introduisant de la nouveauté dans le système. Le développement de l'industrie du recyclage représente un changement et une opportunité pour des marchés alternatifs avec l'apparition de nouveaux « business models ». Toutefois, si le recyclage permet de réduire l'exploitation effrénée des matières premières, les entreprises, qui recherchent des solutions, font face à de grandes difficultés.

L'industrie du recyclage est jeune, et peut être considérée comme une industrie émergente. En effet, les organisations doivent être repensées ou renforcées (amélioration de la traçabilité, meilleure définition des statuts des produits fin de vie…), les chaînes de valeur du recyclage doivent être conçues. C'est particulièrement le cas pour l'industrie du recyclage textile en France, que nous avons étudié tout au long de ce travail de recherche.

Le recyclage, même s'il concerne chaque activité industrielle pour penser la fin de vie des produits, est considéré comme une contrainte plutôt qu'une opportunité par la majorité des industriels. La plupart du temps, lorsqu'il existe une opportunité économique, les industriels prennent des risques calculés pour leurs activités qui se terminent en succès ou en échecs.

Cependant, prendre part à l'industrie du recyclage est considéré comme un risque industriel majeur. Le manque d'organisation, le fait que la plupart du temps elle n'est même pas considérée comme une industrie à part entière, la mauvaise réputation du recyclage, considéré comme générant des coûts de transformation élevés et une qualité faible, n'attirent pas les investissements potentiels. Cela explique également pourquoi les industriels préfèrent payer une écotaxe, plutôt que de développer des solutions en interne pour améliorer l'impact environnemental du cycle de vie de leurs produits et leur recyclabilité.

Le gouvernement Français incite au développement de cette activité du recyclage en utilisant particulièrement le levier de la réglementation. En effet, le renforcement de la réglementation Européenne et de la loi Française, concernant la gestion des déchets, peut être considéré comme moteur pour le recyclage. La responsabilité élargie du producteur, pour la gestion des différents déchets tels que les emballages, pneumatiques, appareils électroniques et textiles, l'incite à prendre en compte la fin de vie des produits introduits sur le marché. Toutefois, ce système requiert une participation financière du consommateur lors de l'achat d'un nouveau produit : l'écotaxe.

On observe que les industriels adoptent des comportements différents face à l'évolution de la règlementation. D'une façon générale, les fabricants sont davantage conscients de l'impact de leurs activités sur l'environnement. Le type de comportement qu'adopte un industriel dépend de son niveau de maturité (Rejeb, 2008). Les entreprises les moins matures, réagissent seulement en tentant d'éviter l'écotaxe, ou en affichant une diminution des émissions de $CO_2$. Des entreprises plus matures

considèrent le recyclage comme une opportunité, par exemple, dans le but d'une meilleure maîtrise de la consommation de leurs matières premières. S'ils peuvent recycler leurs propres produits, ils créent une offre de matières premières recyclées, qui peuvent potentiellement être réintroduites dans leurs produits. Ce contrôle des flux de matières premières peut apporter un avantage compétitif en fonction du coût de mise en œuvre pour l'élaboration de cette matière première recyclée, par rapport au coût de la matière vierge.

D'une certaine façon, les activités de recyclage suivent un modèle économique circulaire selon le concept du « berceau au berceau » (McDonough and Braungar, 2002). Dans ce concept, les déchets des uns deviennent les ressources des autres. Le travail de recherche que nous avons conduit sur l'industrie du recyclage textile en France, interroge la possibilité d'utiliser des matières premières recyclables (à partir de déchets de l'industrie du textile fin de vie), issues d'un segment industriel, de les transformer, et de concevoir un nouveau produit satisfaisant un nouveau marché.

L'industrie du recyclage textile en France délimite le champ de notre étude d'analyse structurelle de l'industrie. Nous proposons une méthode originale d'analyse d'une chaîne de valeur potentielle en utilisant des approches génériques (Porter, 1985), et en tenant compte de nos observations et du retour d'expérience de précédentes études industrielles. Au travers du cas d'étude, nous présentons l'angle de vue spécifique de l'entreprise hôte de cette thèse, Federal-Mogul System Protection (FMSP), un fournisseur de produits automobiles. La méthode proposée a pour but de comprendre les opportunités, et les mécanismes de cet environnement nouveau. En faisant l'analyse de cet éco-système complexe, nous montrons les opportunités de nouvelles activités industrielles pour une entreprise comme FMSP.

Notre hypothèse est que le pilotage de l'innovation permet de créer des opportunités, notamment dans l'industrie du recyclage, par l'utilisation de processus d'innovation adaptés. L'objectif de cette formalisation est de proposer une approche plus proactive pour développer une activité industrielle. En utilisant les tendances de l'évolution des considérations environnementales, les nouveaux produits recyclés, les nouveaux projets collaboratifs de recyclage et les nouveaux marchés conscients du modèle de pensée circulaire, l'objectif est de créer de nouvelles offres. L'étude de l'innovation contribue au processus d'intégration de nouveautés dans un système comme décrit par (Rejeb, 2008). Dans cette recherche, cela correspond au développement d'une activité de recyclage qui suit un processus spécifique d'innovation. Pour conduire ce projet de développement d'une nouvelle activité, les acteurs ont besoin de compétences particulières en gestion de l'innovation et en conception d'une nouvelle chaîne de valeur pour le recyclage. Ces nouvelles compétences doivent être supportées par des méthodes spécifiques.

Les bonnes pratiques de l'éco-conception et de la conception pour le recyclage doivent être formalisées pour une utilisation par les ingénieurs. Toutefois, le respect ou non des normes de l'éco-conception, la prise de conscience des impacts environnementaux et la connaissance du cycle de vie du produit, aident déjà les développeurs à introduire des pratiques éco-efficientes (McDonough and Braungar, 2002) ; le but étant de prendre en compte les effets dès la phase de conception. Mais cette nouvelle prise de conscience n'est pas communiquée au travers de la chaîne logistique (*supply chain*) et chaque maillon travaille de manière indépendante, ne favorisant pas la prise en compte de la recyclabilité des produits initialement conçus. En effet, le produit peut être pensé pour avoir un meilleur impact environnemental dans sa phase d'utilisation, mais la conception pour le recyclage est peu utilisée dans la communauté des développeurs, ce qui pénalise généralement l'activité du recyclage.

Le fait de considérer le cycle de vie des produits dès la phase de conception, permet de favoriser le développement de produits éco-efficients. Encore une fois, le recyclage n'est pas toujours pris en compte. Ainsi, par exemple, l'application de l'analyse du cycle de vie du produit sur chacune de ses étapes (« utilisation »; « fabrication » ; « fin de vie »), permet de considérer la répartition de l'impact environnemental, ce qui permet aux experts de s'intéresser à l'étape qui doit être traitée en priorité, et qui est en général celle qui cause le plus de pollution. Cependant, sur un produit tel qu'une voiture, la phase d'utilisation est celle qui a le plus d'impact, particulièrement avec les émissions de $CO_2$ et des polluants atmosphériques (voir *Figure 14*). Mais l'impact de sa mise au rebut est aussi majeur, considéré indépendamment, ce qui n'est pas révélé par l'utilisation de l'analyse de cycle de vie.

Nous considérons, dans cette étude, la chaîne logistique inverse (*reverse supply chain*) comme la chaîne logistique de recyclage, comportant toutes les activités, depuis la fin de vie des produits, en passant par la transformation des matières premières recyclables, jusqu'au nouveau produit issu du recyclage. L'élaboration de cette chaîne logistique innovante nécessite la collaboration de plusieurs entreprises et organismes partenaires possédant des compétences complémentaires pour définir et réaliser les activités de cette chaîne logistique. Nous distinguons la phase de conception de la chaîne logistique et sa phase d'exploitation. La majorité des travaux de recherche que nous avons trouvés dans la littérature est relative à l'exploitation de la chaîne logistique, c'est-à-dire à la planification ou à l'optimisation des tournées.

En phase de conception, la chaîne logistique est considérée comme une chaîne de valeur dont la définition requiert l'étude des opportunités et barrières à l'apparition d'une nouvelle activité de recyclage pérenne (c'est-à-dire, indépendante d'éventuelles aides publiques) la définition de chacune des activités à valeur ajoutée, le choix des partenaires, leur intégration et répartition dans la chaîne de valeur du recyclage. La démarche de FMSP est de rechercher de nouveaux marchés en participant à la définition d'une nouvelle chaîne de valeur de recyclage et en mettant en place la chaîne logistique correspondante.

Par ce positionnement spécifique, qui vise à accroitre des actions compétitives, notre hypothèse est qu'un projet de R&D collaboratif est un moyen, permettant d'accéder à de nouveaux marchés, particulièrement lorsque les projets sont complexes comme dans le domaine du recyclage. Le fait qu'une collaboration de R&D permette de partager des risques et de développer des opportunités de marché n'est plus à démontrer, faisant l'objet d'une thématique de recherche largement investie depuis les années 1980. Toutefois, c'est une dépense pour l'entreprise qui choisit de conduire de tels projets. Le challenge, de l'idée à sa réalisation, doit être entrepris avec précaution, et les industriels manquent de guides pratiques pour définir la stratégie et la structure d'une chaîne de valeur du recyclage.

Pour le déroulement des projets, le constat général est que pour 10 projets, 1 est un succès, 2 permettent juste un retour sur investissement et 7 sont des échecs qu'il a fallu financer. On observe également que 20% des projets proviennent d'un travail scientifique et que 80% sont lancés à partir d'une analyse du marché, bien que les idées issues d'un travail scientifique se révèlent 3 fois plus rentables. A partir de ce constat, nous avons l'intention de contribuer à l'augmentation du potentiel de réussite d'un projet collaboratif de recyclage.

Comment élaborer un tel projet au sein de l'industrie du recyclage pour favoriser la stratégie de différentiation de l'entreprise? Quel support pour le travail de l'ingénieur en charge du montage d'un tel projet ? Nous positionnons cette étude sur ces données d'entrée, avec, comme objectif du projet,

développer une nouvelle chaîne logistique de recyclage, prenant en compte les nouveaux aspects réglementaires. Considérant ces différentes données d'entrée et des observations issues du terrain industriel, ainsi que l'état de l'art scientifique sur cette thématique, nous avons construit un ensemble de méthodes spécifiques, pouvant être appliqué par des industriels ayant l'objectif de développer de nouvelles chaînes logistiques de recyclage. Ce processus est élaboré avec les principes du "Stage to Gate", déjà diffusé et utilisé par les ingénieurs. C'est donc un moyen opérationnel, qui répond à la possibilité d'intégrer et d'appliquer des pratiques d'éco-conception. Dans le cadre de notre étude, ce processus intègre les meilleures pratiques identifiées. En phase amont de conception, pour la définition d'un projet collaboratif, nous décrivons l'organisation de chaque activité, de l'élaboration initiale du business model à la définition du produit et à la sélection des partenaires projets.

Cette méthode permet, à partir de considérations conceptuelles de l'éco-conception, de proposer un processus d'innovation opérationnel, ce que nous considérons comme un manque dans notre domaine de recherche. Nous sommes convaincus que les préoccupations environnementales doivent être prises en compte dès la phase de conception du produit, lors de la définition des exigences des parties prenantes de tout le cycle de vie du produit. La méthode permet d'orienter la question du recyclage, et de l'intégrer pleinement. Aujourd'hui, particulièrement dans l'industrie automobile, nous observons que l'impact environnemental d'un produit est largement pris en compte par l'ingénierie pour la phase d'utilisation, par exemple, avec l'objectif de décroître le poids total du véhicule afin de réduire les émissions de $CO_2$. Cela représente un gain financier pour l'utilisateur et un avantage marketing pour le constructeur automobile. De ce point de vue, par exemple, le constructeur BMW travaille sur le remplacement de l'organe de structure du véhicule en métal, pour utiliser des composites en carbone. Cependant, le recyclage de ce nouveau matériau, bien que plus léger, est techniquement instable, et son coût de transformation, quatre fois plus élevé que le prix du carbone brut. Ainsi, le modèle économique et les considérations environnementales doivent être considérés sur toutes les phases du cycle de vie du produit.

Dans ce contexte, notre objectif est de justifier l'utilisation des méthodes proposées. Elles doivent satisfaire les demandes des industriels d'une façon simple et applicable, pour construire une chaîne logistique de recyclage écologique et économiquement pérenne. Pour y parvenir, chaque étape du processus de conception est mise en évidence, et on prend en compte des orientations vers les outils nécessaires ; ce n'est pas ici notre but de développer, ou d'identifier chaque outil pour chacune des activités. Nous décrivons chaque activité et leurs liens, à prendre en compte par le responsable du projet, à partir de retours d'expériences industrielles et de l'état de l'art scientifique.

Une donnée d'entrée spécifique est qu'un marché pour l'application du produit issu du recyclage doit être identifié en phase amont du processus de conception. En effet, un des retours d'expérience majeurs est que, sans avoir identifié ce marché au préalable, l'étude intrinsèque de la transformation des matières premières recyclables, peut s'avérer un échec de l'innovation, ces nouvelles matières ne trouvant pas de débouchés. Le marché peut donc tirer la transformation de matières premières recyclables et supporter ses coûts de transformation pouvant alors être comparés à ceux de la matière première vierge.

Ce projet doit être réalisé de façon collaborative afin d'intégrer les acteurs de la chaîne logistique envisagée et de partager les risques financiers liés au développement. Dans ce sens, nous proposons d'aborder un aspect particulier de la définition du projet, qui est le modèle de sélection de partenaires. En effet, dans le champ de la gestion de la chaîne logistique (*supply chain management*) et de la sélection de partenaires de R&D (*R&D partner selection*), des méthodes utilisant les techniques d'aide à la

décision multicritères ont été développées en recherche. Toutefois, la spécificité de notre application, liant à la fois les projets de R&D collaboratifs et la sélection de partenaires dans le cadre de la gestion de la chaîne logistique de recyclage, est un positionnement original, qui n'a pas été observé dans l'état de l'art scientifique. Pour l'élaboration de ce modèle, nous identifions d'abord les critères à prendre en compte et nous en élaborons une définition précise avec des experts. Puis, parce que chaque projet aura ses propres exigences, nous proposons une méthode d'évaluation des critères en utilisant une combinaison de techniques (AHP – DEMATEL – TOPSIS). Le résultat obtenu par l'application de ce modèle aide l'industriel à faire le choix de ses partenaires potentiels, pour augmenter les chances de succès de l'ensemble du projet. En effet, il est mentionné dans la littérature, que le choix initial des partenaires est un point crucial pour la réalisation du projet.

Ce travail de recherche s'inscrit principalement dans la discipline du génie industriel. Il a permis la collaboration de deux laboratoires Français, ITECH (« Institut Textile et Chimique », à Lyon) et ERPI (« Equipe de Recherche des Processus Innovatifs », à Nancy), dans le cadre de l'école doctoral RP2E de l'Université de Lorraine. Cette thèse a été financée par l'industriel Federal-Mogul, dans le cadre d'une CIFRE (« Convention Industrielle de Formation à la Recherche ») avec le soutien de l'ANRT (« Association National de la Recherche et des Technologies »).

En référence aux différents sujets présentés dans cette introduction, cette thèse est structurée de la façon suivante. Le premier chapitre investit les premiers questionnements industriels, positionne notre problématique et présente les différents champs d'investigation théoriques ; les techniques d'analyse structurelle d'une chaîne de valeur au sein d'une industrie ; les processus d'innovation et d'éco-innovation ; l'éco-conception ; le supply chain management prenant en compte la dimension environnementale ; et enfin les projets de R&D industriels collaboratifs.

Le chapitre II présente une méthode d'analyse originale d'une chaîne de valeur au sein de l'industrie du recyclage, et son application à notre champ de recherche industriel, l'industrie textile en France.

Le chapitre III propose un modèle de processus d'innovation pour la définition d'une activité de recyclage sous la forme d'une collaboration de R&D avec une vision chaîne de valeur. L'objectif de cette contribution est d'apporter au chef de projet un support de conception de cette chaîne de valeur de recyclage lorsqu'une stratégie de collaboration est décidée par son entreprise pour définir et mettre en place la chaîne logistique correspondante.

Le Chapitre IV présente une contribution plus théorique que les précédentes et propose une combinaison de techniques d'aide à la décision multicritères, pour l'aide à la sélection de partenaires dans le cadre de projets de définition d'une chaîne de valeur du recyclage. Dans ce but, une arborescence de critères est élaborée et des techniques telles que AHP, DEMATEL et TOPSIS sont combinées, pour proposer une méthode de sélection originale. Celle-ci permet de supporter une activité clé du processus proposé dans le chapitre III.

## *GENERAL INTRODUCTION*

This research is related to a **business strategy** considering **eco-innovation** as a way to reinforce its competitiveness and to promote differentiation. New offers are driven by changes, and its concretization depends on the innovation management process of the company. Eco-innovation is considered as a way to implement environmental consciousness when introducing newness into a system.

The development of the **recycling industry** represents a change and an opportunity for innovative business to pursue alternative markets and develop new offers. However, even if recycling is obvious to inhibit the craziness of raw material exploitation, its relative complexity[1] is a barrier for many businesses which are seeking for solutions. The recycling industry is still at its infancies and can be considered as an emerging industry. Indeed, the whole organization has to be elaborated or strengthened and the supply chains must be designed. It is particularly the case for the **French Textile Recycling Industry** (FTRI), which we studied all along this research work.

**Recycling**, touching every industrial activity when we consider the product end of life, is considered as a constraint rather than an opportunity for most industrials. Often, when there are potential economic benefits, industrials take calculated risks, within their industry, which may become a success or a failure. However, taking part of the "recycling industry" is still considered as a major industrial risk, the lack of organization, and the fact that it is not even considered as an industry of its own, the bad reputation telling that recycling means high processing cost and low quality, do not really attract potential investment in the first place. It also explains why industrials will rather contribute to an eco-tax[2] instead of developing internal solutions to improve their environmental impact, or the recyclability of their products, throughout their life cycle.

The French Government incites this recycling activity particularly using **regulation** as an action lever. Indeed, the regulation and the reinforcement of European and French law regarding Waste Management can be considered as a driver preaching for recycling. The Enlarged Producer Responsibility (Levillain and Fernandez, 2014), for the management of different waste types such as packaging, tires, electronic devices and textiles, helps the producer to consider the end of life of the products they put on the market. However, this system requires a financial contribution from the consumer when purchasing a new product: the eco tax.

Different reactions, **industrial behaviors**, are observed facing the evolution of the regulation. In a global way, manufacturers give more attention to the environmental impact as they are now aware of their activities' impact on the environment. The type of behaviors the companies may adopt depends on its maturity level (Rejeb, 2008). Less mature companies only react to avoid the eco-tax and/or financial penalties. They would present a reduction in CO2 emissions, as their way of considering environmental impacts. More mature firms will consider recycling as a business opportunity, for instance for a better

[1] Complexity: "it is generally used to characterize something with many parts where those parts interact with each other in multiple ways. The study of these complex linkages is the main goal of complex systems theory." Wikipedia

[2] Eco-tax : "(short for Ecological taxation) refers to taxes intended to promote environmentally friendly activities via economic incentives". Wikipedia

control of the raw material supply. If they can recycle their own product, they create a new supply of Recyclable Raw Materials (RRM) that could potentially be reintroduced in a product. This RRM control could induce a competitive advantage depending on its exploitation cost compared to virgin material's pricing.

In a way, recycling activities follow the **circular economic model** with the Cradle to Cradle concept (McDonough and Braungar, 2002). In this concept, the wastes of the ones become the resource of the others. However, the analysis work done on the French Textile Recycling Industry questions the opportunity to use RRM from End of Life (EoL) industrial textile wastes, to transform it, and design a new product satisfying a new market.

The French Textile Recycling Industry delimits the scope of our **industrial structural analysis study** for which we propose a specific analysis method using general analysis tools (Porter, 2008), but also considers our industrial observations to propose an original approach. Moreover, considering the specific business view angle of the industrial host of this thesis, Federal-Mogul System Protection (FMSP), an automotive product supplier, the aim is to understand the possible market opportunities in this new environment. In this respect, by analyzing this complex new industrial eco-system, we intend to highlight opportunities for a business such as FMSP until the definition of the projected Business Model that "describes the design or architecture of the value creation, delivery, and capture mechanisms it employs" (Teece, 2010).

Our hypothesis is that **driving innovation** enables to create opportunities and particularly in the recycling industry, with an adapted innovation process. The aim of this process formalization is to propose guidelines for a more proactive approach to develop the industrial activity. It uses new environmental trends, new recycled products, new recycling collaborative projects, new markets aware of the circular thinking model, to develop adapted offers. The study of **innovation** contributes in understanding the process of integration of a newness into a system such as described by (Rejeb, 2008). In this research, it corresponds to the development of the recycling activity which follows a specific innovation process. In order to run this project of developing a new activity in a complex eco-system, the actors need particular innovation management skills. This engineer's new role should be adapted to the associated innovation process.

Best practices in **Eco-design** and Design for Recycling (DfR) should be formalized and spread for engineers to use. However, more than following the ISO 14062 eco-design standard (ISO 14062, 2002), it is the consciousness of environmental impacts and knowledge of the product life cycle environmental impacts, that help designers, in a logical way, to introduce eco-efficient practices (McDonough and Braungar, 2002). But we observe that, when it is adopted by companies, it is done without communication on the reverse supply chain. Indeed, the product can be thought to have a better environmental impact on its use phase, but DfR as a limited propagation within the designer community today and errors can be done that generally penalize the recycling activity.

Considering the product **Life Cycle** in Design step, promoted by designers, the aim is to favor the design of eco-effectient products. However, here again, recycling is not always taken into account. Thus, for instance the LCA (Life Cycle Analysis) of the product on each phase (for example, the use phase; the disposal phase), considers the repartition of the environmental impact on the product life cycle. This consideration enables for the experts to have a hierarchical view of the impacts, to deal with the one causing the most damages. However, on a product such as a car, the use phase is the one causing most

of the environmental impact especially with the $CO_2$ and atmospheric pollutants emissions (see *Figure 14*), but the absolute impact of the disposal phase is also major if the waste is landfilled.

We consider, in this work, the Reverse Supply Chain as the **Recycling Supply Chain** (RSC), containing all of the activities from the EoL of the product to the introduction of RRM into a new product. The elaboration of an innovative RSC will then require the definition of each new activity. We understand, from this description, that the probability of the emergence of a new recycling activity in an autonomous way is low. In this sense, we want to study the potential enablers for the development of these activities.

The tactic used by the company FMSP to seek for business opportunities in the elaboration of recycling activities, is to become a partner of a **collaborative R&D (Research and Development) project**. It is a way to gain experience for possible new markets development. Our hypothesis also relays on the fact that a collaborative R&D project is an enabler and helps to drive innovation from R&D to the market. The fact that R&D collaboration enables to share risks and to develop market opportunity is not to be demonstrated as it has been a research topic since the 1980s. R&D work is an important expense for a company, and between the idea and the realization, time is being consumed. From one industry to another, time and a fortiori cost, of R&D work, change. It is what we can observe on the following diagram inspired from a presentation at the Colloquium (ADEME, 2014) (

*Figure **1***).

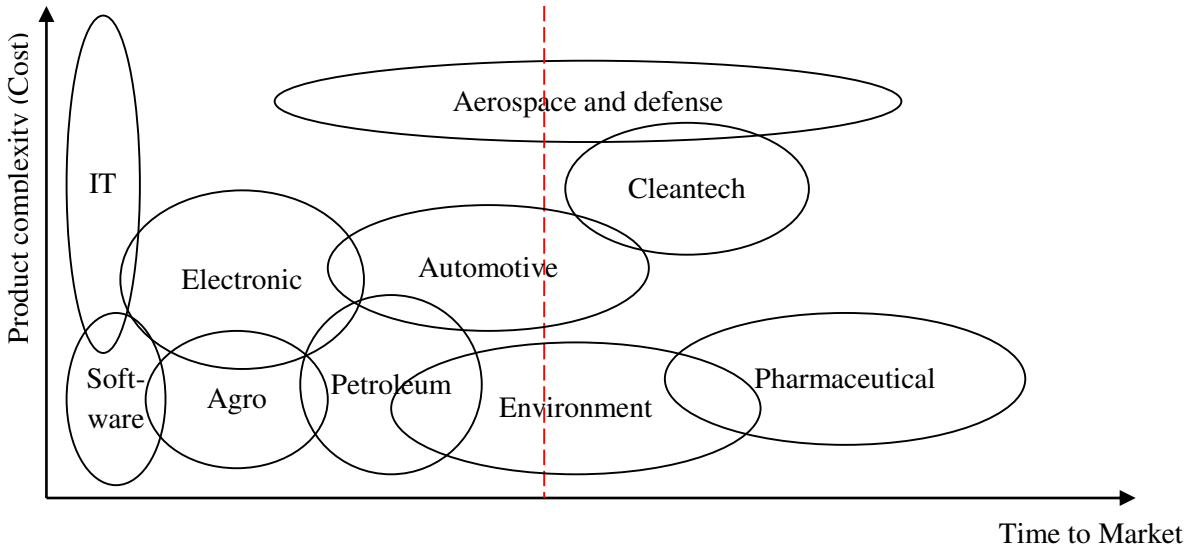



*Figure 1: Product time to market VS Product design cost*

Concerning the success or failure of **projects**, the general observation states that for 10 projects, 1 is a success, 2 just give a payback and 7 are failures that have been financed. We can also observe that new ideas come at 20% from scientific work and 80% from the market, however the ideas coming from scientific work are revealed to be 3 times more profitable. With these features, we intend to increase the potential success of a **recycling collaborative project**.

How to elaborate such a project in the recycling industry and in the same time provide an answer to the company initial questioning of potential market differentiation through this projects' type? Which **supports** are needed for such an engineering partner selection work? We position this work considering

these questions, enhancing the need for methods to design new RSC. But we also identified the need to take into account regulatory aspects. Considering these different inputs and our literature state of the art, we constructed a specific design process to be further developed and applied by industrials: a **Recycling Supply Chain Design Process** (RSCDP). This process is elaborated with the Stage Gate principles (Cooper, 2008a), already used by design engineers as an operational process. This eco-design process is an answer to the possibility to apply eco-design practices. The RSCDP integrates identified inputs, considered as best practices in our research context. At an early design phase, for a collaborative project definition, we describe the organization of each activity, from the initial business model elaboration to the product definition and the collaboration selection.

The RSCDP method enables to go from conceptual eco-design considerations to an **applicable design process** that we consider to be missing within our research field. We are convinced that the environment should be considered from the design phase (Eco-design) of a product, the only phase where the product life cycle can be projected and considered, but for engineers there is a lack of method and knowledge to integrate properly these eco-design tools. For instance, today, in the automotive industry we have seen that the use phase is the one that is the most focused by engineering, and decreasing the weight of the vehicle overall has become a fight for less $CO_2$ emissions. It means a cost saving for the end user and the manufacturer but also a marketing advantage for the original equipment manufacturer as it will require less gas for the same distance. In this respect metal sheets are changing to carbon reinforced fibers, for which the recycling process is technically not stable, and economically four times higher than virgin carbon (BMW, 2014).

Within this context, we focus on the justification of the design model proposal (RSCDP), which should satisfy industrial demands in a **simple and applicable way**, for a valuable and ecological RSC construction. In order to do so each stage of the design process is highlighted, and orientations for needed tools are considered, but it is not the aim here to develop a clear identification of each tool for each activity. We will give the description and links of each activity that should be considered by a recycling supply chain project manager, regarding the industrial experiences from which we could obtain feedbacks, and from a literature review (see *Figure 5: Our research methodology*).

A **specific input** is that a **pull market** must be identified. Indeed, one of the main inputs is that a recycling activity can only be developed if there is a business for the studied RRM, a project cannot be, only to study "virtually" the recyclability of the materials. In this sense, the market will potentially pull the RRM transformation and support its processing cost to be compared with virgin material for instance. This view angle was taken based on several project feedbacks.

Indeed, investments in R&D have been used to develop new technical recycled resources without considering a market application, and in the end this RRM could not find a use, so the investment was a lost.

Because this project should be led in a collaborative form in order to be integrated on a projected supply chain, we propose to develop a particular aspect of the project definition which is the **model of partner selection**. Indeed, in the field of Supply Chain Management (SCM), and in R&D partner selection, models and methods using **Multi-Criteria Decision-Making** (MCDM), have been developed in former research study. However, this particular application to R&D collaboration with partners identified on

the projected supply chain is not proposed in the literature. For the model elaboration, we consider jointly both research fields of SCM, for the design of RSC, and collaborative R&D work, for this original partner selection method. We firstly identify the criteria that should be used; we give a precise definition that we elaborated with experts. Then, because each project will have its own requirements, we propose a weighting method of these criteria using MCDM techniques. The result, obtained by the application of the model, helps the industrial to choose its potential partners, to increase the overall project success. Indeed, it has been related in the literature, that the initial choice of the partners is a crucial point for the project execution.

This work is realized in the Industrial Engineering discipline and combines the expertise of two French laboratories, ITECH ("Chemical and Textile Institute" in French "Institut Textile et Chimique", in Lyon) and ERPI ("Innovative Process Research Team" in French "Equipe de Recherche des Processus Innovatifs", in Nancy), supported by the doctoral school RP2E of the University of Lorraine. This PhD is financed by the industrial Federal-Mogul in the scope of a CIFRE ("REsearch Training under Industrial Convention" in French "Convention Industrielle de Formation à la REcherche") with the ANRT ("Association National de la Recherche et de la Technologies")

In regards of the different topics presented in this introduction, this PhD thesis will be structured as follows (*Figure 2*).

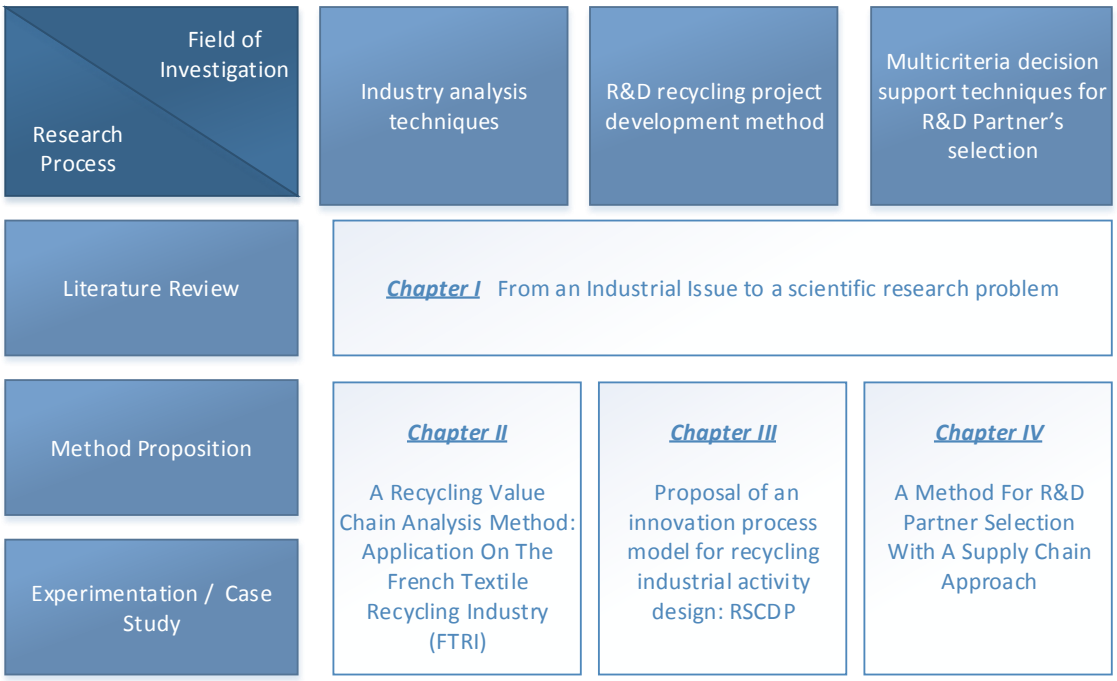



*Figure 2: Schematic structure of the PhD thesis*

CHAPTER 1: presents our research problem and the literature review in our different investigation fields. Industry analysis techniques, Innovation and Eco-innovation processes, Eco-design and Green Supply Chain Management practices, and finally collaborative modes in industrial R&D, are developed in this part. This literature review supports the chapters (II; III; IV) in which we present original methods.

CHAPTER 2: presents an original recycling Value Chain analysis method and the application to our industrial research scope, the FTRI. It also presents a way to transform an industrial context into a theoretical research study.

CHAPTER 3: proposes an innovation process model for defining a recycling value chain under R&D collaboration form and green supply chain vision. The aim of this contribution is to support design and project engineer work when collaborative strategy is undertaken by a company.

CHAPTER 4: is the most theoretical approach of this PhD thesis and presents a combination of MCDM techniques, for an adequate R&D partner selection to work on RSC design. In this respect a tree diagram model of specific criteria is highlighted and the techniques, AHP (Analytic Hierarchic Process), DEMATEL and TOPSIS, are combined to give an original selection method. This method can be used as a tool for recycling R&D partnership elaboration identified in Chapter III,.

# CHAPTER 1: FROM AN INDUSTRIAL ISSUE TO A SCIENTIFIC RESEARCH PROBLEM

This first chapter corresponds to the positioning of our problem taking into account the industrial environment and referring to the literature state of the art. In this respect it begins with the initial questionings (Bonaldi, 2013) of this research, especially regarding the regulation trends and the potential of collaborative projects, and ends with the description of the research issues. The research methodology performed during this work is also detailed along with the theoretical backgrounds.

## 1.1 Initial industrial questionings

This section presents the industrial recycling environment with its barriers and enablers: The regulation that both drives and inhibits recycling, the economic constraints that are particular to the recycling, and collaborative projects, considered as a new trend in favor of eco-innovation.

### 1.1.1 Strong regulation concerns: a business opportunity using the responsibility concept and its barriers

A business strategy follows the global trends, and also the regulatory context. The European regulations and their interpretations in each member state could represent a business opportunity through environmental behavior changes. The specific regulations toward wastes represent new RRM supply possibilities, but to which extent does the regulation promote this aspect?

Europe straightens increasingly its objectives regarding waste management and producers become more and more responsible for their products delivered on the market, when they arrive at their EoL. The first Directive on Waste dates back to 1975; it gives the first waste definition, not including recycling possibilities. Today, in the Waste Framework Directive (The European Parliament, 2008), includes the definition of waste: “substance or object which the holder discards or intends or is required to discard”. It is also new because it includes a recycling definition, as a waste management best practice. Moreover the Directive gives a hierarchy to respect for the waste treatment solutions (Prevention; recycling; other recovery; disposal), used in environmental studies (Lazarevic et al., 2012):

- Prevention: “before a substance, material or product has become waste”
- Recycling: “any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes”
- Other recovery, notably energy recovery: “any operation the principal result of which is waste serving a useful purpose”
- Disposal: Generally the wastes are landfilled

Specifically, Waste Management is defined as: “the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker” (The European Parliament, 2008). Wastes including cars, textile, batteries,

glass, plastics, deal with complex regulations based on the "polluter pays" principle (this principle gives a sense of responsibility to the actor who delivers products on the market, if it is polluting, he has to contribute economically to improve the environmental impact). However, as a consequence effect, the regulation also contributes in the organization of innovative recycling supply chains.

The way it is established is that Europe publishes Directives and the member states interpret and legislate the texts in their own laws. The directive fixes objectives and a delay to transpose the rules into the national legislation. Each state decides the way they will achieve the goals. Once in application, there is a control of effective results and improvements by the European Commission (Falkenberg and Director-General of DG Environment, 2012). If the delay is not respected, sanctions can be taken, penalizing the industrial sector. In France, the Waste Framework Directive was transposed by the decree n° 2011-828 of the 11th July 2011 (see *Annex 1: Description of the French law transposition from the Waste Framework Directive*).

For instance regarding the EoL vehicle directive, in Netherland it is mandatory to recycle EoL vehicle wastes, generating an eco-tax on new vehicles to satisfy the economic balance. In France, it is mandatory to recycle the glass from EoL vehicle since July 2013, the dismantling networks have to find a way to reach an economic balance to not engender an eco-tax. Thus states adopt different strategies.

Among the responsibility concept introduced by the regulation that should become an enabler for recycling activities development, other regulations can be seen as constraints and limit this development. In this respect, REACH (Registration, Evaluation, Authorization and Restriction of Chemical substances), supported by the European Community Regulation on chemicals and their safe use (EC 1907/2006) controls the composition of new products put on the market (see *Annex 2*). How can the conformity to the environment be proven to this organization with EoL wastes which have been submitted to different uses and eventually polluted during their life? How is it possible to demonstrate that new recycled products, dealing with heterogeneous RRM, are compliant to REACH or not? (See *Annex 3: REACH Study work – Engineering workAnnex 3: REACH Study work*).

Indeed, for instance an EoL vehicle is brought into the destruction center after an average of 20 years, car parts, from one car to another can be more or less polluted by the environment. REACH is only enforced since 2007. Considering the initial design and delivery on the market of a vehicle, 20 years ago, actual restricted substances could have been employed and put on the market. It is another difficulty that must be taken into account for the recycling of the materials. Moreover, as the vehicles are not commercialized anymore, it is not possible to access the security data sheets from the automotive constructor, there is almost no traceability of the material used into former cars. This traceability could have helped to understand the big changes in textile and foam trends used in the cars.

This short section has explained how regulation can drive the recycling industry, but also how it can be a barrier with the complexity of the recycled resource composition especially in regards to REACH conformity.

### 1.1.2 Focus on the economic barriers

What is observed in the industrial environment is that the recycling processes have the reputation to generate high costs compared to classic processes, which extract virgin materials. Indeed, the process of extraction of virgin resources is well known and it benefits of an economy of scale. It makes the economic equation not bearable for the RRM manufacturer initializing the activity on a competitive market. We have underlined how the regulation could favor recycling, especially using the solution of an eco-tax, to readapt this balance. However it is very controversial and its efficiency on the long term is not proven yet. Therefore, adopting an economic and business vision is the one we will focus on in our study.

In general, a final client will not pay a higher price for a recycled material or product than for virgin ones that could be at a lower price (subvention and/or fine included). Moreover, as a new potential supplier, the requirements from original equipment manufacturers are even stronger as they are looking for cost reduction overall (particularly observed in the automotive industry).

In the automotive industry, the cost aspect is essential, as we witnessed during our industrial investigations. Even if recycled projects are running, the final decision maker remains the purchasing department. The risk that the RRM be higher in cost than virgin materials, when initiating the RSC, is considered high. To spend time on R&D activities to study if it would be potentially acceptable is also a barrier to this kind of work and does not favor the development of RSC. It is also the reason why these activities search for external funding system to justify such expenses.

As seen in the previous paragraphs, today Europe gives environmental directions; each state member has to apply it. However we observe that materials are still landfilled and new RSC have difficulties to emerge. It is contrary to the Waste Framework Directive and common environmental best practices, but refers to economic barriers.

### 1.1.1 Governmental trend to favor recycling development

Europe promotes research and innovation programs with the aim to drive “great ideas from the lab to the market” (European Commission, 2015). It is the aim of the Horizon 2020, the biggest European program, with nearly €80 billion available between 2014 and 2020. Among the program roadmap and society challenges, two topics out of seven concern the environmental issue (“Smart, Green and Integrated transport” and “Climate action, Environment, Resource efficiency and Raw Materials”). Public-private partnership, to develop relative project can apply to the program, beneficing of the available economic resource and bringing additional investment to the study. Thus, Horizon 2020 is considered as a financial instrument which aims at securing Europe’s overall competitiveness.

In France, between 2005 and 2012, 1186 innovative collaborative projects have been funded by the Unique Interdepartmental Funds (« Fonds Unique Interministériel » in French) (dgcis, 2013). In addition, ADEME (« Agence De l’Environnement et de la Maitrise de l’Energie ») also favors the development of collaborative projects and particularly on green topics. However we can note a lack of

feedback study to understand the efficiency of such programs, confirmed by experts from the related agency.

## *1.2 Description of a collaborative project to favor the emergence of a Recycling Supply Chain: the case of ValTex*

As previously mentioned, the high cost for the design and implementation of a RSC is a barrier for companies which intend to address this question. This is the reason why, as collaborative approaches enable to share cost and use financial governmental helps on the topic of recycling, this system seems more relevant for the design of a RSC.

In 2011, a French research and funded collaborative project was launched involving 8 partners, supported by ADEME. The object of the project is to develop a new functional product with EoL recyclable fiber content, for the automotive industry. Since no such supply chain exists to treat this kind of wastes (which are today landfilled), the project aims at developing a new product as well as elaborating the associated RSC. The project focuses on specific EoL textile products, the ones provided by the project partners.

The companies and academic supports in the project collaborate under specific interests and motivations, bringing to the consortium their own competencies (*Figure 3*).

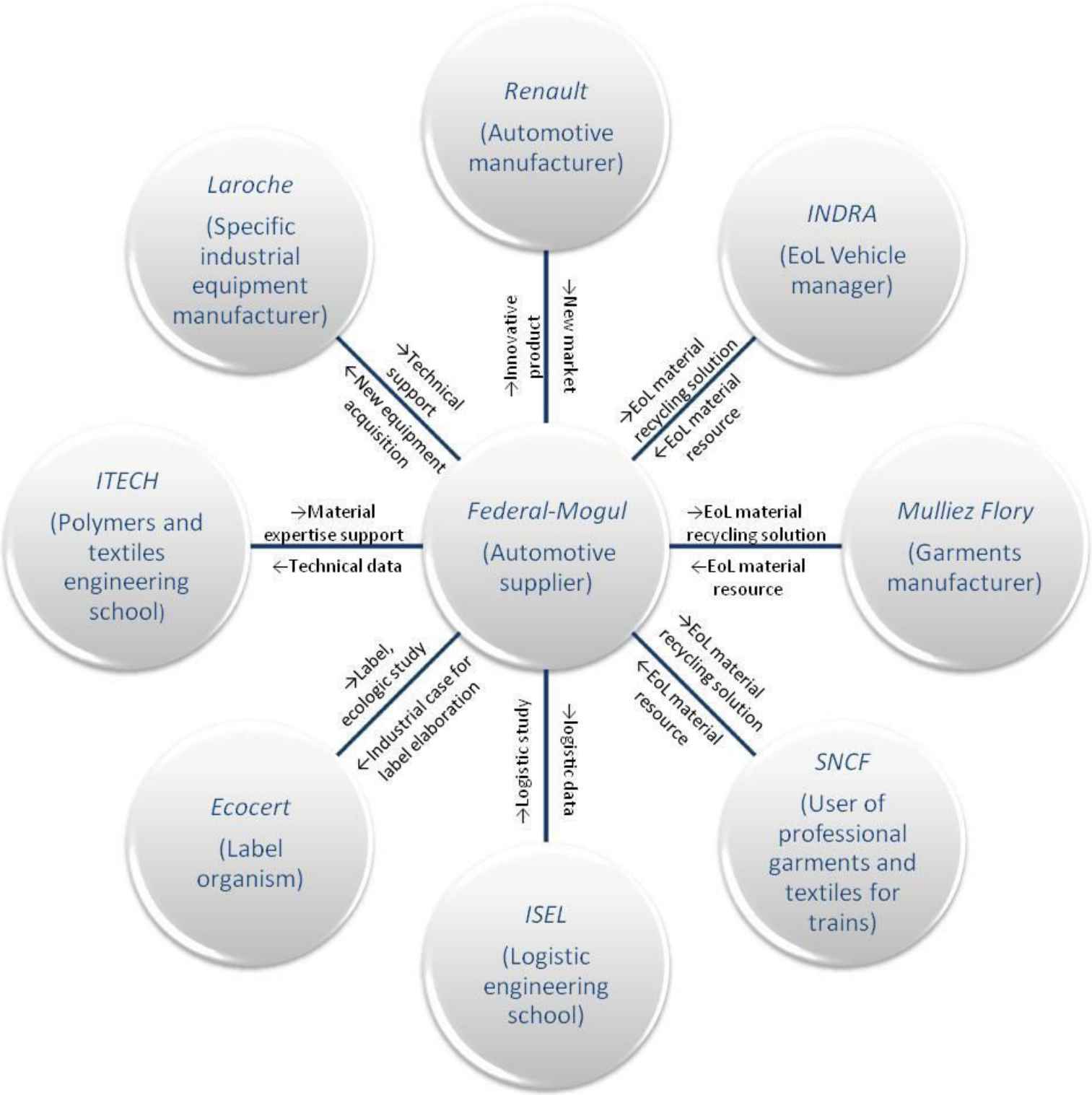



*Figure 3: Identification of project partners and links with the thesis host Federal-Mogul* (Bonaldi, 2013)

Nevertheless for most of them it represents a completely new topic and environment. Indeed, the recycling aspect of the project gathers partners that don't generally work together. In this respect, the understanding of this environment is a crucial point to define a compatible and competitive solution during the early design phase. But also, the project itself represents a learning opportunity, which enables

to refine the understanding of the partner's positions that also evolve with the acquired knowledge through the project itself.

The projected offer has to take into account the constraints of the involved companies that may belong to different industrial sectors. First of all, the automotive industry, for which the offer is intended to. It is a market already delivered by FMSP (host of our CIFRE), as an automotive Tier. However, the European market segment, where the projected product is positioned for, does not correspond to an existing supply. In this sense it represents diverse marketing investigations done during the project. On the other hand, the RRM manufactured from various EoL products and its potential market applications are fuzzy aspects of the project. Indeed, the recycling textile industry is itself emerging. The question that can be asked is why today this potential RRM are not recycled? If it is not the case in an autonomous way, is it because of the complexity of the elaboration of the recycling process, and can a collaborative, structured project favor this deployment?

## *1.3 Description of our research problem*

The increasing consumption of manmade goods, leads to an increase in the resource extraction. Today we aim at replacing non renewable material with recyclable ones, so that the resource can be exploited more than once and become a new supply opportunity. It is the aim of the regulation that intends to push industrials toward better environmental practices.

The study and evaluation of possible waste treatment and recycling processes are industrial challenges, long and tedious, requiring transversal competencies. Thus, the ratio time spent/benefit is not identified by businesses with low waste management skills. In this sense it becomes an endless cycles, there is no organizations to deal with the EoL products, and it requires long development studies to initiate this supply chain, with great risks for the producers under responsibility, as they are not confident with the success of this activity. Considering these features, industrials don't initiate any actions and relay on the existing offers from great EoL management businesses, and they financially contribute to an eco-tax (see §1.1.1). These industrials use the existing solutions, and are conform to the regulation with a defensive behavior (Gaucheron, 2000). With this behavior, the financial retribution goes to the company that manages the EoL products and this solution offers a poor vision of the EoL product fate.

During our observation we have pointed out that this consideration is increasing with more mature companies adopting cooperative or integrated behaviors, (see §2.3.1.2.1) which are evolving toward integrating eco-innovation practices (see §1.2.2.2) and circular thinking (see §1.2.3.4). However, the general industrial feeling is that until no best practice taking into account technical, environmental and economic aspects, is identified, this kind of development is considered too risky. There is a lack of adapted methods to study the opportunity of such a RSC elaboration and to define a specific collaborative project to design and implement this RSC.

Recycling is not always the solution, if it is worse for the environment, if it concerns high technical irreplaceable products (as in the medical industry) or if it is economically not bearable. Considering this context, our problem, **dealing with the new object of a recycling industrial process in an emerging industry, is to define a strategy and methods for the elaboration, development and optimization**

**of an innovative recycling process**. It will contribute to emphasizing recycling business opportunities (with an application in the textile and automotive industry).

Our aim is to understand how this recycling environment favors eco-innovation for proactive companies pursuing new businesses. **How can we study the structure of an emerging recycling industry?** Because recycling is a fuzzy environment, with strong regulation concerns and economic barriers (see §1.1.1 and §1.1.2), our first contribution presented in *CHAPTER 2*: is to propose an original method to help conduct this analysis. A short state of the art on industry analysis methods (§1.2.1), such as M. E. Porter (1985a)'s analysis techniques points out that this question has not been addressed in the specific case of the recycling industry. In the end, the application of the original method can be used by industrials to better understand a specific recycling environment for further strategic decision making.

Moreover, we are dealing with a business that is looking for differentiation opportunities and to adopt a more proactive behavior. **Considering that collaborative projects favor the opportunity to conduct R&D studies, for the specific objective to design and implement a new RSC, how should these projects be organized?** Because this approach is situated in a new environment, for the design of a new RSC, the second contribution proposed in *CHAPTER 3*: corresponds to an innovation process model for designing a new recycling supply chain which we call RSCDP (Recycling Supply Chain Design Process). This topic is concerned by different fields that a literature review will shortly present: innovation (§1.2.2), eco-design (§1.2.3) and supply chain design (§1.2.4). Our problem also leads to investigating collaborative aspects of R&D projects with a supply chain approach (§1.2.5).

This last consideration points out a lack of methods to favor collaboration especially considering the project partner selection. The research question is: **How to help the industrial to decide which partner is best suited for a R&D recycling collaborative project?** Because in a collaborative project, partner selection is a major industrial concern, *CHAPTER 4:* presents a specific criteria model, adapted to the focused industrial context, and a MCDM techniques' combination that ranks the potential partners. The ranking method helps the industrial to better choose its partners. To develop this aspect of the collaborative project, an investigation regarding partners selection and industrial collaboration is conducted (§1.2.5) and in §4.2.1 MCDM techniques are studied. The ranking method is also integrated as a tool, in the RSCDP method developed in the third chapter.

## *1.4 Our research methodology*

This research is conducted in an industrial environment with a specific research contract called CIFRE ("REsearch Training under Industrial Convention" in French "Convention Industrielle de Formation à la REcherche) financed by Federal-Mogul and the ANRT funds (National Research and technology association, in French: "Association Nationale Recherche Technologie"). This is the reason why, with this research-action positioning, our research process largely integrates our observation of the industrial environment, especially with industrial interviews.

However, a limit to this research method is the object of investigation itself. Indeed, the newness of the recycling industry, the changing of practices that are controversial today, and the secret features around these businesses, have limited the possibility of a large and systematic approach. Moreover, the field contribution on a specific recycling collaborative project, named "ValTex", has brought experience feedbacks but also limited our research area. Indeed, we are also positioned as an "Active Project Manager" (see Figure 5) on this specific collaborative project, the aim being to develop a new recycled product and its recycling supply chain. We summarize our industrial investigation field in *Figure 4*.

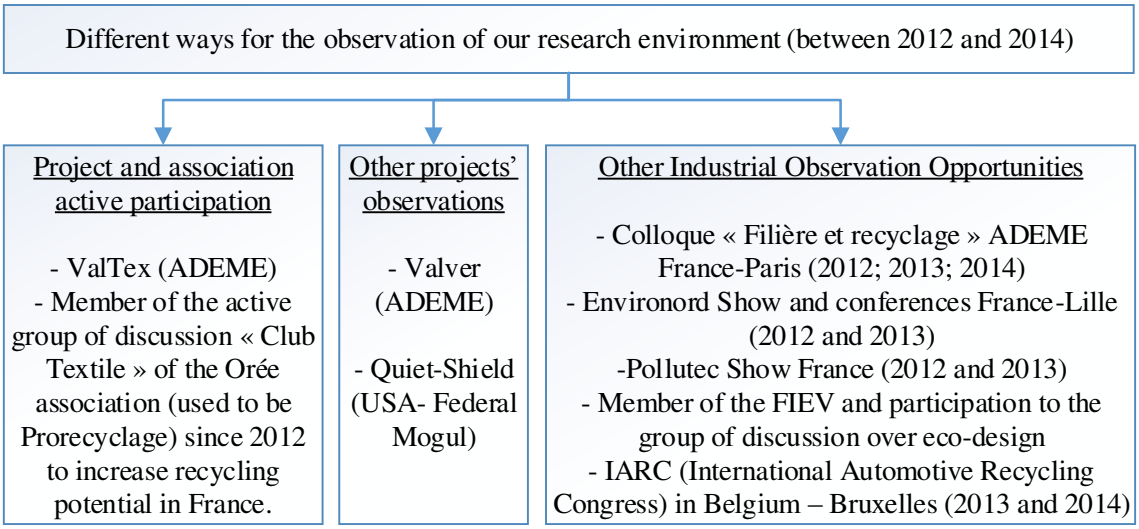



*Figure 4 : Observation of our research and industrial environment*

These observations are completed by systematic literature reviews about the different research fields (see §1.2). Our general research methodology is represented in *Figure 5*.

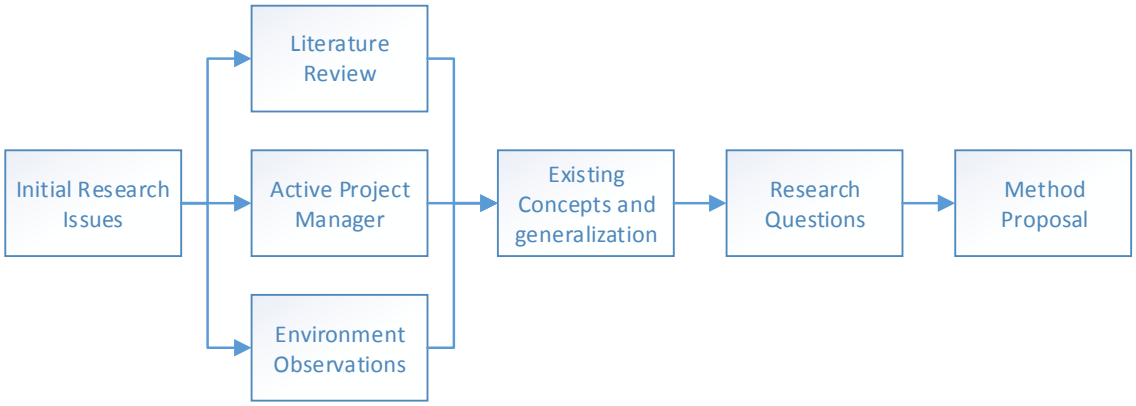



*Figure 5: Our research methodology*

From our initial research issues we use 3 materials, the literature review, our positioning as active project managers and our observations of the environment. In this respect we generalize and apply existing concepts to propose our research questions, addressed in the different chapters of this work. This research methodology leads us to the proposal of specific methods, detailed in this study.

## *1.2 Theoretical backgrounds*

This research is positioned in Industrial Engineering and leads to different research fields' investigations.

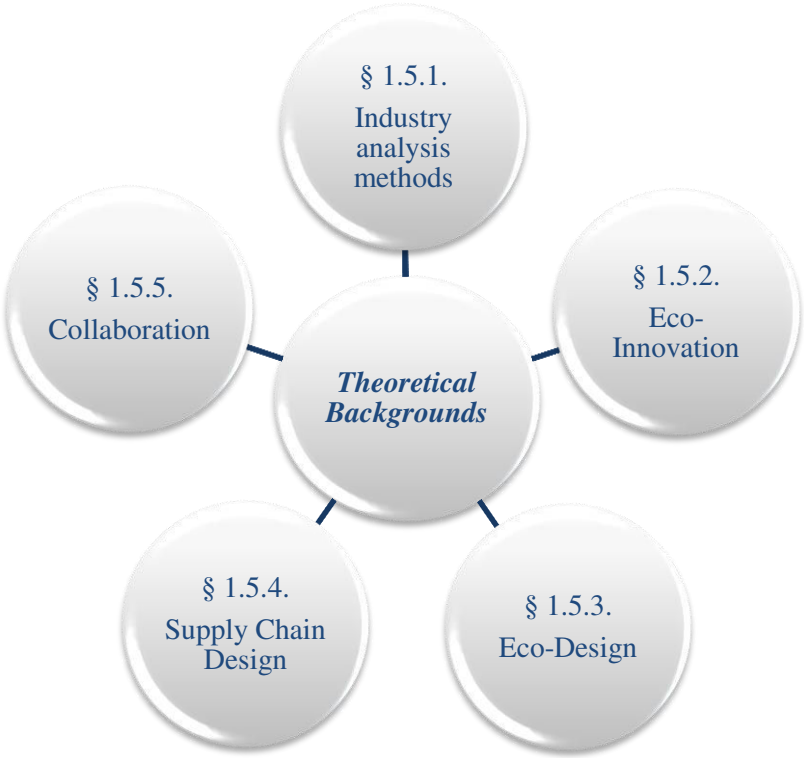



*Figure 6: Investigated Research Fields*

The presentation of the theoretical backgrounds (§1.2.1 to §1.2.5 see *Figure 6*) enables to position our research questions and later to discuss the interests of the proposed contributions.

### *1.2.1 A literature review of industry analysis methods*

In this section we describe the structural analysis approaches used for the analysis of industrial environments. Our objective is to justify the proposal of an appropriate method (§2.2) for the analysis of the French Textile Recycling Industry.

Porter's work (Porter, 1985) and his book "Competitive Advantage, Creating and Sustaining Superior Performance" explain the ground bases of his theory. According to Porter, strategic diagnostics have been developed by different authors who propose clear processes to conduct this analysis (Bidault, 1999; Johnson et al., 1998). The analysis of the industry is considered as a way to identify potential opportunities and understand the competitive environment. This study enables to anticipate and influence the evolutions of a business, and gives orientations for better strategic decisions making.

In the literature the strategic diagnostic is recommended to focus on two aspects. The first one is external with the study of the environment and its general dynamic functioning, the supply/demand balance, the value chain network with the organization of the added-value activities. The second one is more internal to the organization, in particular with the study of the strengths and weaknesses of a specific business in its environment and the definition of its strategy, such as "Differentiation" or "cost reduction". In our approach we are interested by the former aspect and we particularly focus on the analysis of the industrial environment structure.

#### *1.2.1.1 Primary analysis of the value chain*

The primary analysis of the market enables to study the dynamic of the supply and the demand (M. E. Porter, 1985a ; Bidault, 1999). This first positioning permits to organize the data from an initial observation. More than a static analysis it will help to appreciate the future potential of an industry. This analysis method is relevant for our research, as we are able to realize the state of the art of the industry and propose a first formalization. This study helps to understand the major variables of the industry, important for a company to better position its strategy.

First of all, the industry is described by a direct competitive market, for which the supply satisfies a demand with more or less equivalent products. The analysis of the supply and the demand is not an easy task, but approximations can be done in different ways to understand the availability of the EoL products and the size of the demand. The understanding of the existing influences in the relation between the supply and the demand, must be considered in the diagnostic.

Bidault (1999) explains the complexity of the strategic actions made by businesses, which influence the supply and demand balance, either in an autonomous or in a regulative way. In this respect, it reveals the importance to analyze the evolution of this relation, taking into account the simultaneous influences of the relevant factors, such as barriers, perspectives and constrains. They have the power to shape the

industry on the long term. For the demand, the factors can be regrouped in three categories: the quantitative evolutions in the environment; the buyer's perception and behavior regarding this market; and the commercialization policies. The analysis of the supply is based on the notion of availability; the end-product, the different inputs such as raw material evaluation; and the producer's profiles. Then it is possible to highlight a possible segmentation of the industry, especially regarding the applications projected and the technologies used.

#### *1.2.1.2 Analysis of the Industrial Environment and the intensity of the competition*

The industrial environment of a company is described by its actors, which can be organizations, companies, and its factors that influence this company decisions (Bidault, 1999). It can also be presented with different levels (*Figure 7*).

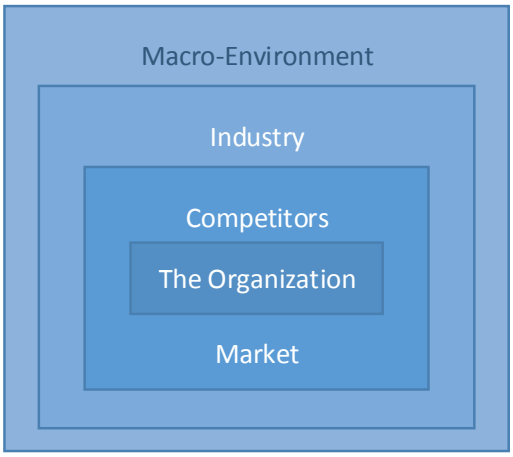



*Figure 7: The different levels of the environment* (Johnson et al., 1998)

The consideration of the most global level, the Macro-environment, enables to identify the pivot variables that create influences. The analysis of the industry with a dynamic approach uses the collected data from the primary analysis (§1.2.1.1), and with the 5 forces model (Porter, 2008), will enable to characterize the attractiveness of the industry on its competitive market (*Figure 8*).

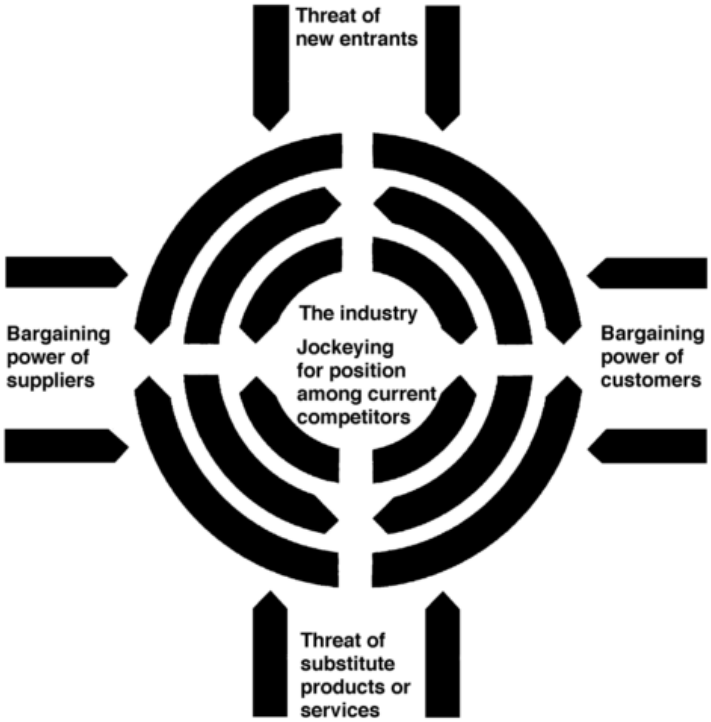



*Figure 8: Porter's 5 forces model* (Porter, 2008)

In *Figure 7*, the "competitors" and "market" define the market segmentation, and emphasize potential development opportunities. This diagnostic helps to propose a judgment on the performance of the organization in relation to its environment. Three predominant and complementary variables must be taken into account: the intensity of the competition; the dependency on this industry within its SC and the co-existing networks; the vulnerability of the industry facing potential substitutes.

Porter's strategic model includes the five forces which are Horizontal and vertical, but it also refers to the value chain and the generic strategy. The possibility to add a sixth force enables to represent the influence from the governmental authorities, which can disrupt the natural adjustments of the industry (the 5 + (1) model). The main purpose is the analysis of the profitability: « The forces reveal the most significant aspects of the competitive environment ».

In the domain of emerging industry, the concept of "blue oceans" has been developed (Chan and Mauborgne, 2005). Indeed, because the boundaries of the emerging industry are under construction, the market spaces are not defined, the demand is still fuzzy, "blue oceans" strategic thinking is adapted. Developing "value innovation" concept is one of the concepts used in the actions framework proposed by the authors. In their paper, Burke, Stel, & Thurik (2010) oppose the two models "the 5 forces" and the "blue ocean thinking", and conclude that it would be best for businesses "to consider a blend of the two approaches".

### 1.2.2 From innovation to specific innovative process

#### 1.2.2.1 General description of Innovation

Innovation, as a competitive impact for businesses, was introduced by (Dert, 1997; Midler, 1998). Indeed, beyond the triptych cost, quality and time, innovation produces the enthusiasm of the customers, which emphasizes the historical evolution of the competitive key factor for companies (*Figure 9*).

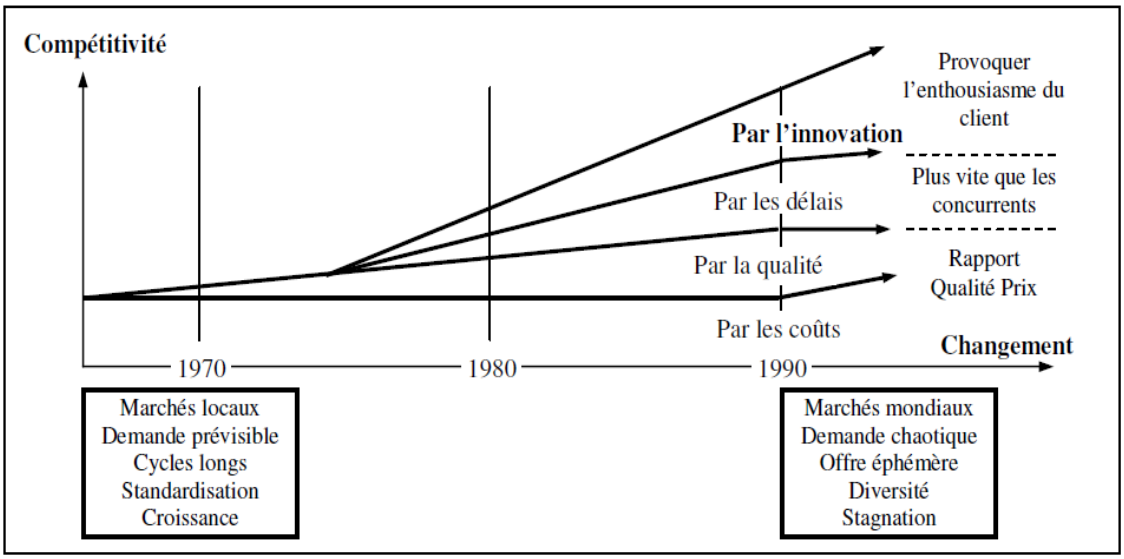



*Figure 9: Evolution of the triptych cost, quality and time, toward the introduction of innovation (Dert, 1997)*

Innovation is defined as the process of introduction of a newness into a system (Boly, 2004). The process is generally described from the innovative ideation phase to the commercialization of a product, with a long and complex design process with various stakeholders from a company and the environment. The process is uncertain, as stated by Tidd et al. (Tidd et al., 2009), "innovation is driven by the ability to see connections, to spot opportunities and take advantage of them". For instance, in our study, the idea of using recyclable raw material can be interpreted as a measure to prevent from the increasing cost of the virgin RRM, and act on environmental responsibility.

The management of innovative projects is complex because this kind of projects deals with new topics, the adequate knowledge and competency are not identified from the beginning of the project, and the success of the project is uncertain. Moreover, as observed by Boly (2004), the final project generally doesn't correspond to the initial idea. The innovative project being evolutionary, its management should be adapted to this evolution in order to develop a constructivist innovation approach.

The modeling of an innovative project elaboration and deployment is critical to drive innovation. In this respect, Rejeb (2008) presented different models such as the "platform product life cycle at Intel (Gao et al.,2007)", "the innovation funnel (Wheelwright and Clark;1992)", the "Crawford model, 1997", the

"PDCA (Plan Do Check Act), well known in quality management, the "Product life cycle from the standard NF X50-100", the "Fuzzy Front-End" and the "Stage Gate System by (Cooper, 2008b)". He also stated that the Stage Gate System model is the most used model in the industry with the example of multinational firms using it to manage their product design process, and this model has evolved with time as described by Cooper (Cooper, 2008b). This evolution permits even more to manage uncertainty with retroactive loops.

Because our contribution is based on the experience of the specific field of recycling supply chains and recycled product design, we will take advantage of the literature observations on innovative process to propose a specific innovation process.

#### *1.2.2.2 Introduction to Eco-innovation*

Eco-innovation is described as a key driver to tackle environmental challenges by industrials and by the Organization for Economic Co-operation and Development (OECD, 2010). It is presented as the "faster introduction of breakthrough technologies and for more systemic application of available solutions, including non-technological ones. It also offers opportunities to involve new players, develop new industries and increase competitiveness. Structural change in economies will be imperative in coming decades". In this sense, the manufacturing environment and major industries "have the potential to become a driving force to introduce efficient production practices" (Negny et al., 2012).

The difference with innovation is emphasized, with two particular aspects. The first one is relative to the reduction of the environmental impact and the second one gives a focus on social features (Cheng and Shiu, 2012). In this sense eco-innovation also integrates sustainability concepts (Boons et al., 2013) and sustainable manufacturing practices as recommended by the OCDE (*Figure 10*).

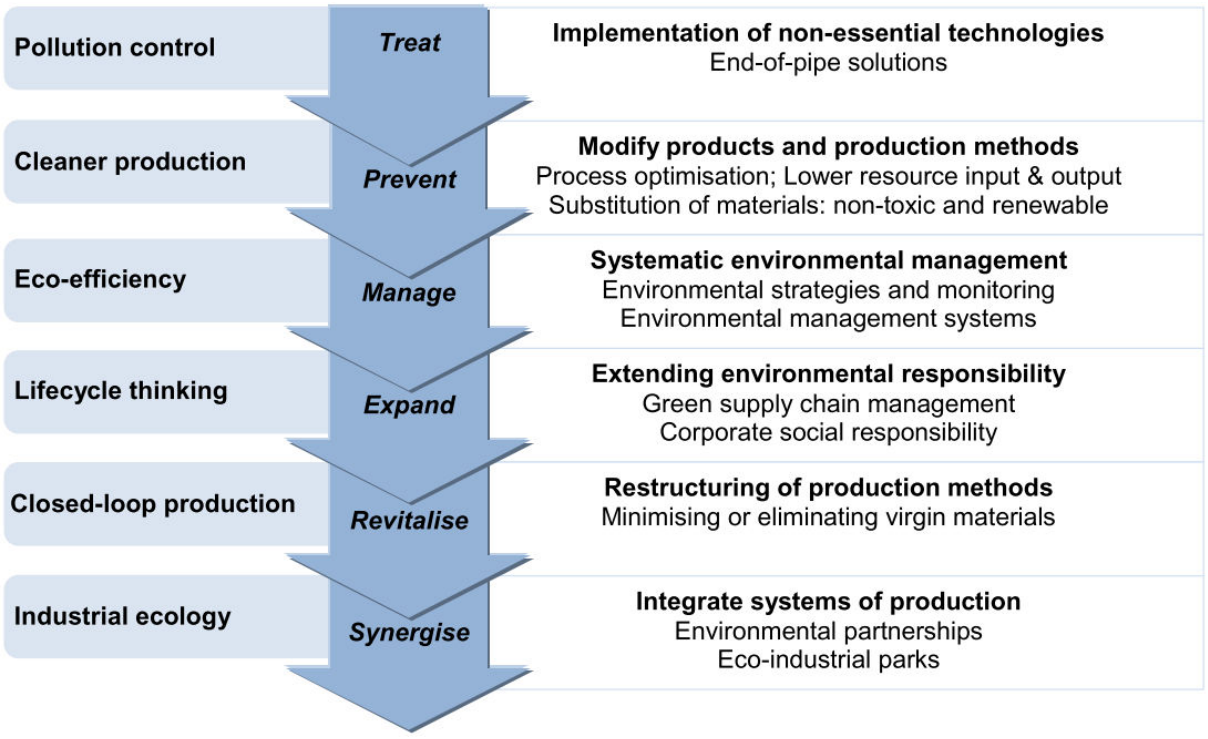


*Figure 10: Evolution of sustainable manufacturing practices (OECD, 2009)*

We can observe that eco-innovation is an existing practice among industrials. Indeed, Rennings (2000) stated that "in a German industry survey, about 80% of all innovating firms are involved in environmental-friendly innovation projects.". The management of eco-innovation is an increasingly important issue for many different businesses. Moreover, in the industrial environment we can witness the development of a consequence number of environmental friendly programs to better understand the new paradigm and analyze experience feedbacks. However, Rennings (2000) emphasizes that the methodological approaches for the evaluation of eco-innovation practices are poorly developed, making it uneasy to do this analysis.

With the definition of eco-innovation, firms develop "environmental innovation strategy" linked to business performances (Eiadat et al., 2008). Regulations don't necessarily succeed in inducing green strategy among firms, but "environmental partnership" could enhance the practice, even if further assessment studies should be conducted to confirm this effectiveness.

### *1.2.3 Integration of environmental concerns in Design*

Eco-innovation can also be seen as the activity for environmental new product development and is considered as a "product innovation process" by Pujari (2006). It can be achieved by environmental new product development projects, by integrating the environmental variable in early product and process design stages, which enables to prevent from higher environmental impact (Negny et al., 2012).

#### *1.2.3.1 Definitions and trends in eco-design*

The notion of eco-design appeared in the late 1980s (Roy, 1994), with a "green" and "environmentally friendly" product sector. It began with supply assessment and energy saving before heading to social responsibility and pressure to improve environmental performance. The definition of eco-design relies on the ISO 14062 standard, used by various authors such as Kengpol and Boonkanit (2011) or Lindahl (2006), and is presented as: the integration of environmental aspects for product development in order to reduce the total impact on the environment considering the product life cycle. *Figure 11* enables to illustrate this statement.

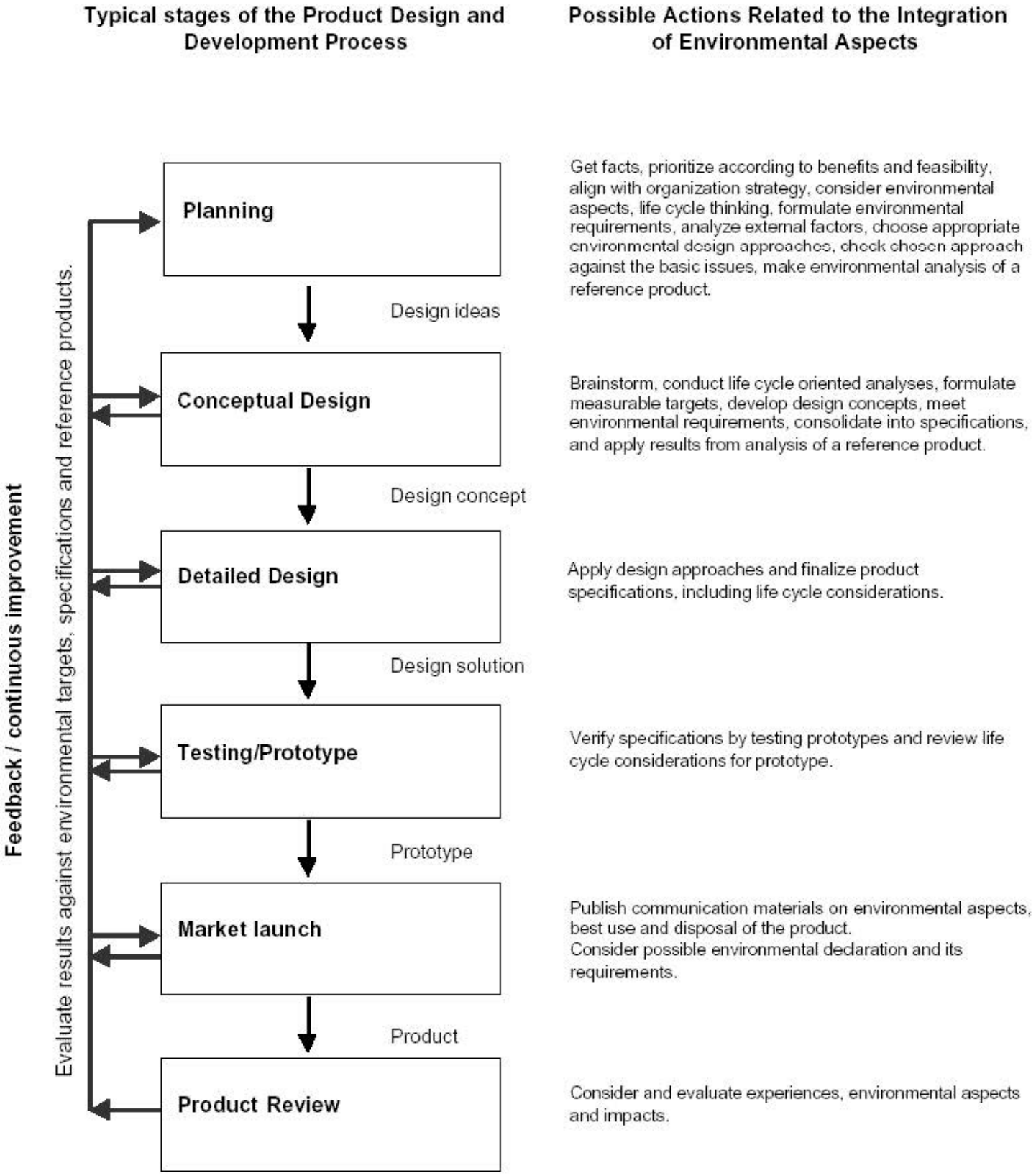



*Figure 11: A model for Eco-design (ISO 14062)*

However, in the literature it is possible to observe different definitions such as: " 'eco' in eco-design can refer to both economics (reflecting a business orientation) and ecology (reflecting the importance of environmental aspects)" (Borchardt et al., 2009). We understand that eco-design is considered differently among research fields.

Eco-design process is defined from the early stage of functional definition of the product, until the beginning of the final production. The formalization of the process leads the engineers to build the adequate product responding to the market. Eco-design is also a proactive environmental management approach, as defined by Pigosso et al. (2013) for product and process development.

A gap has been identified between the development of new design tools in detriment of eco-design process implementation, management models or roadmaps (Brezet, 2001). Many studies have been done to develop new DfX (Design for X) method. Lindahl (2006) shows that there is still a lack of industrial validation as there are few applications of these methods, performed in the industry. To the best of our knowledge, for the past ten years, this lack still exists. In this sense we can identify a gap between research studies and industrial concerns with the following statements:

- Too complicated to use
- Lack of diffusion of the method
- Method developed with a lack of interaction with industrials

Studies, such as research works (Kengpol and Boonkanit, 2011; Sherwin and Evans, 2000) or the ISO 14062, state that, in order to limit the life cycle impact, environmental concerns should be implemented as early as possible into the design process. Indeed, it has been shown by researchers (Kengpol and Boonkanit, 2011; Mascle and Zhao, 2008), that, because of major technical decisions made in an early design stage, it is also the period where around 80% of the economic and environmental costs are determined. It reveals the importance of the introduction of environmental concerns at this stage for cost efficient studies.

There is a lack of literature review focusing on this early stage, where the product designer has limited knowledge and when he has to make decisions, with no real best alternative decision (Lindahl 2006). In this sense, Lindahl (2006) explains the reason why DfE (Design for Environment) methods can be used by engineering designers and how it has received a growing interest, with a great number of published articles, to understand "what is required for successful integration of environmental aspects into product development". In their research, Mascle & Zhao (2008) define DfE as a "systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle. The main environmental implication that a designer seeks to control in a product will dedicate what strategy of DfE to pursue".

#### *1.2.3.2 Concepts used in eco-design: From sustainable development to eco-efficient and eco-effective models.*

The field of "process system engineering", as it adopts a holistic view, would be best positioned to "address the challenge of sustainability", with an adapted method to deal with the complexity of sustainability needs (Bakshi and Fiksel, 2003). The scope of sustainability is very broad. The definition

in the Brundtland Report (World Commission on Environment and Development: WCED) in 1987 is that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.". Bakshi & Fiksel (2003), propose a definition that would be more adapted for engineer to make decisions on the topic: “A sustainable product or process is one that constrains resource consumption and waste generation to an acceptable level, makes a positive contribution to the satisfaction of human needs, and provides enduring economic value to the business enterprise.” In respect of this definition, sustainability is a feature of the entire system.

According to the previous definition of sustainability we can ask ourselves what is an acceptable level of resource consumption, waste generation, in order to satisfy human need and provide economic value? To address this question, the notion of Eco-efficiency was defined by (McDonough and Braungar, 2002) as doing things in a “less bad” way, using a comparative approach. It was also defined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication, as a tool to improve environmental impact particularly with seven elements:

- Reduction of material intensity,
- Reduction of energy intensity,
- Reduction of the dissipation of toxic substances,
- Enhancement of recyclability,
- Maximization of the use of renewable resources,
- Extension of product durability,
- Increase in service intensity.

However eco-efficiency was defined considering a linear consumption model. This is the reason why when McDonough & Braungar (2002) introduced the “Cradle to Cradle” concept in opposition to the “Cradle to Grave”, they also presented the notion of eco-effectiveness more adapted to this model, which is “doing the right thing before doing it efficiently”. It is a regenerative concept rather than a draining one. G. Wang & Côté (2011), proposed a comparison between eco-efficiency and eco-effectiveness (*Figure 12*).

| | Eco-efficiency | Eco-effectiveness |
|---|---|---|
| Perspective | Less bad, reduce impact on Earth’s carrying capacity; slows contamination, destruction and depletion (or is less harmful) | Waste equals food; decompose or circulate in cycles, balance equity, economy and ecology; diversity, relies on solar income |
| Measures | Quantitative | Qualitative |
| Methods | Process-oriented | Eco-design, life cycle management |
| Character | Progressively reducing continual improvement | Revolutionary change |
| Tropism | Doing more with less | Regenerative with no dissipation |
| Features | Reduce material, energy and toxic substances and services; dematerialisation | Redesign, no harmful products and services for closing material flow systems; degradable or recyclable |
| Result | Doing better within a flawed system | Redesign whole industrial system |

*Figure 12: Comparison of eco-efficiency and eco-effectiveness*

After considering the best practices in the field of environmental engineering, we need to understand how it can be applied in practice.

### *1.2.3.3 Specificities and tools of Design for X concepts and Design for Recyclability: a close loop approach?*

In the literature, Design for X (DfX) methods have been investigated since the late 90', the number of article on this topic have grown consequently. X can be replaced by "Sustainability", "Environment", Recycling", Supply Chain", "Manufacturing", "Service", "Self-Repair" or even "End of Life" or "Innovation", using guidelines to help engineering decisions in design stages.

For example, DfI (Innovation) ("Design for Innovation," 2008), enables to create a Sustainable Competitive Advantage with continuous Systematic Customer-driven Innovation.

Regarding DfS (Sustainability), the methodology has the advantage to consider the whole product life cycle (Development phase; Production phase; Utilization Phase; Disposal Phase) and to engender sub DfX as presented in

Figure *13*.

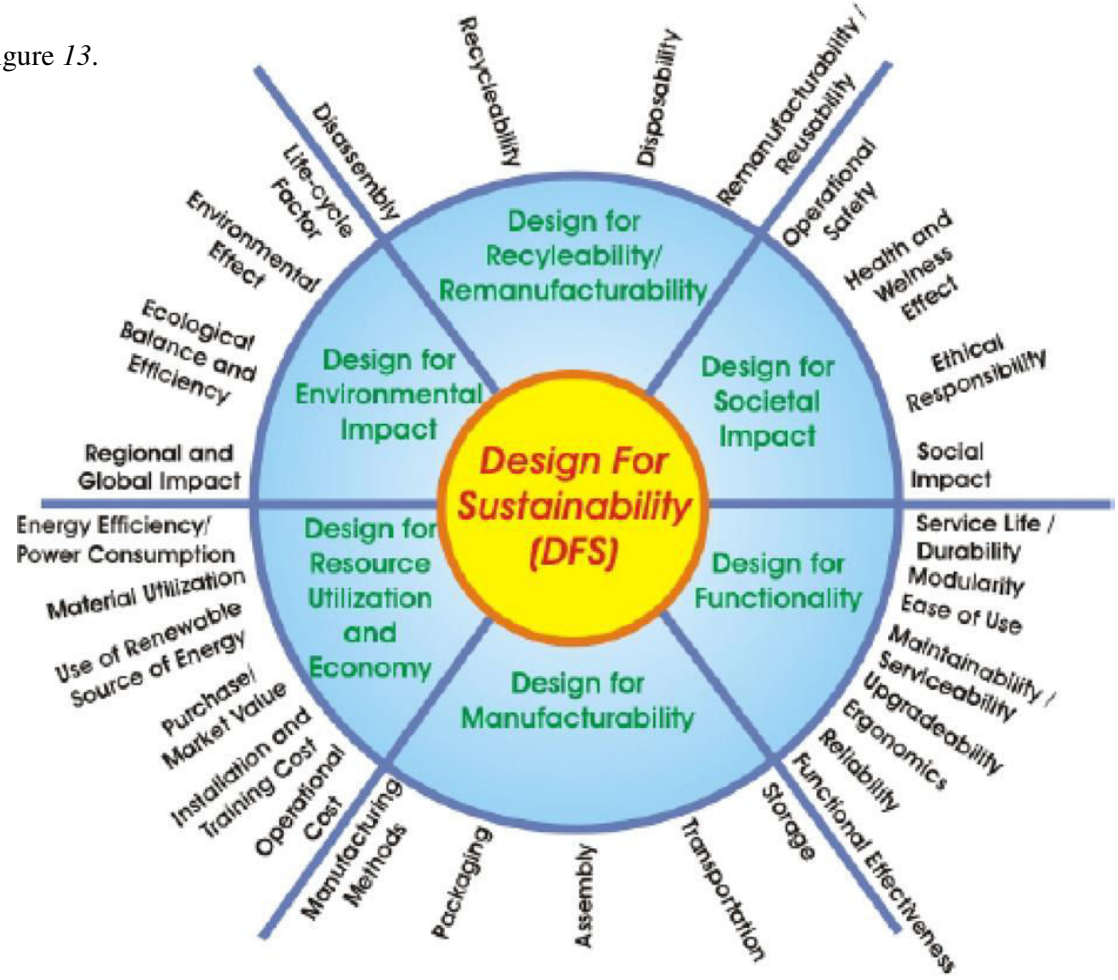



*Figure 13 : "Major elements contributing to design for sustainability" (Mayyas, Qattawi, Omar, & Shan, 2012)*

DfR (Recyclability) includes the DfD (Disassembly) and DfR (Remanufacturing). In the literature it is also called DfEoL (End of Life). In the article "Design for manufacture and design for ` X ': concepts , applications , and perspectives", Huang (2001) gives details about a hierarchy of disposal solutions for

EoL products: “From the top to the bottom, the hierarchy consists of re-use, remanufacture, recycle to high grade material, recycle to low grade material, incinerate for energy content, and dump in landfill site”. Mayyas et al. (2012) have the same thought and go from a linear disposal treatment to a “closed loop recycling”. However closed loop recycling systems are considered as an ultimate goal as they are technically difficult to achieve.

The DfX method should be put in perspective with the environmental impact on the product life cycle. For example, Mayyas et al. (2012) describe the energy consumption of an automobile life cycle (*Figure 14*).

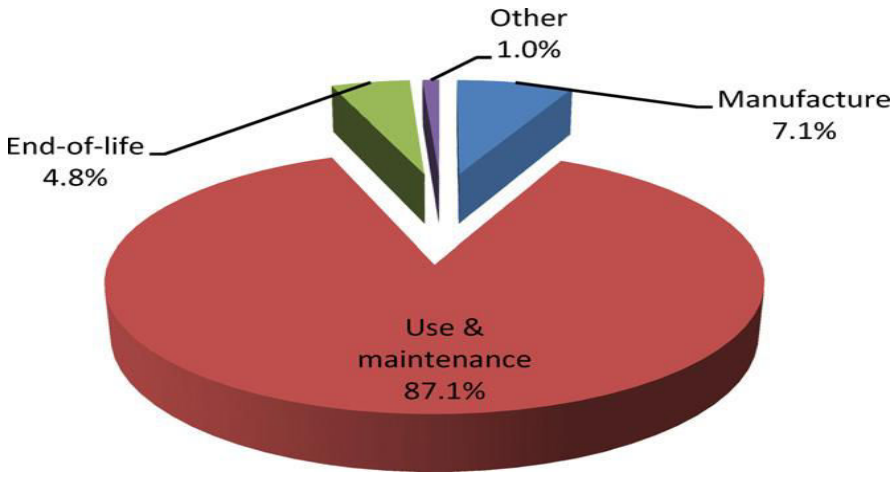



*Figure 14: “Energy consumption in auto life cycle (Mayyas et al., 2012),*

In this paper (Mayyas et al., 2012), dedicated to sustainability in the automotive industry, four main research areas are developed: “the life cycle assessment approach, the end-of-life perspective, the design for X, and the light-weight engineering and material selection studies”. We understand regarding the preceding figure that the Use phase is the most impacting on the environment.

However, qualitative and/or quantitative diagnostic tools to assess the environmental impact can be used. Yannou et al. (2011) described environmental assessment tools, and compared their relevance as presented in *Table 1*.

| | Qualitative diagnostics | Quantitative tools |
|---|---|---|
| MET (Material, Energy, Toxicity) Matrix | OK | |
| Simplified Life Cycle Assessment Methods (ESQCV)[3] | OK | |
| Partial Review *(carbon footprint, water footprint)*<br>*MIPS(Material Intensity Per Service)*<br>*SourceMAP* | | OK |
| Global Review (tool from ADEME) | | OK |
| Life Cycle Analysis (LCA) | | OK |

*Table 1: Eco-design tools (Yannou et al., 2011)*

The decision concerning which tool is appropriate depends on the objective of the study, the data available and the resource available. However it has been related in different studies that only the consideration of the impact on the product life cycle is relevant to understand the product environmental impact.

#### *1.2.3.4 Life cycle thinking, the only recognized model in eco-design*

The literature describes two consumption models: linear and circular.

The linear model of consumption called "Cradle to Grave" by McDonough & Braungar (2002), from resources extraction to the product EoL. With the consciousness that manmade goods come from limited natural tanks, the authors address the question of renewability. The focus on the recycling process is part of this global question. The objective is to use more virtuous consumption model, to stop impoverishing the natural reserve and still provide sufficient quantities.

[3] ESQCV in French for "Evaluation Simplifiée et Qualitative du Cycle de Vie "

In this respect, circular consumption model would be a copy of natural life cycles, where wastes are biodegradable and become nutriments over and over again (*Figure 15*).

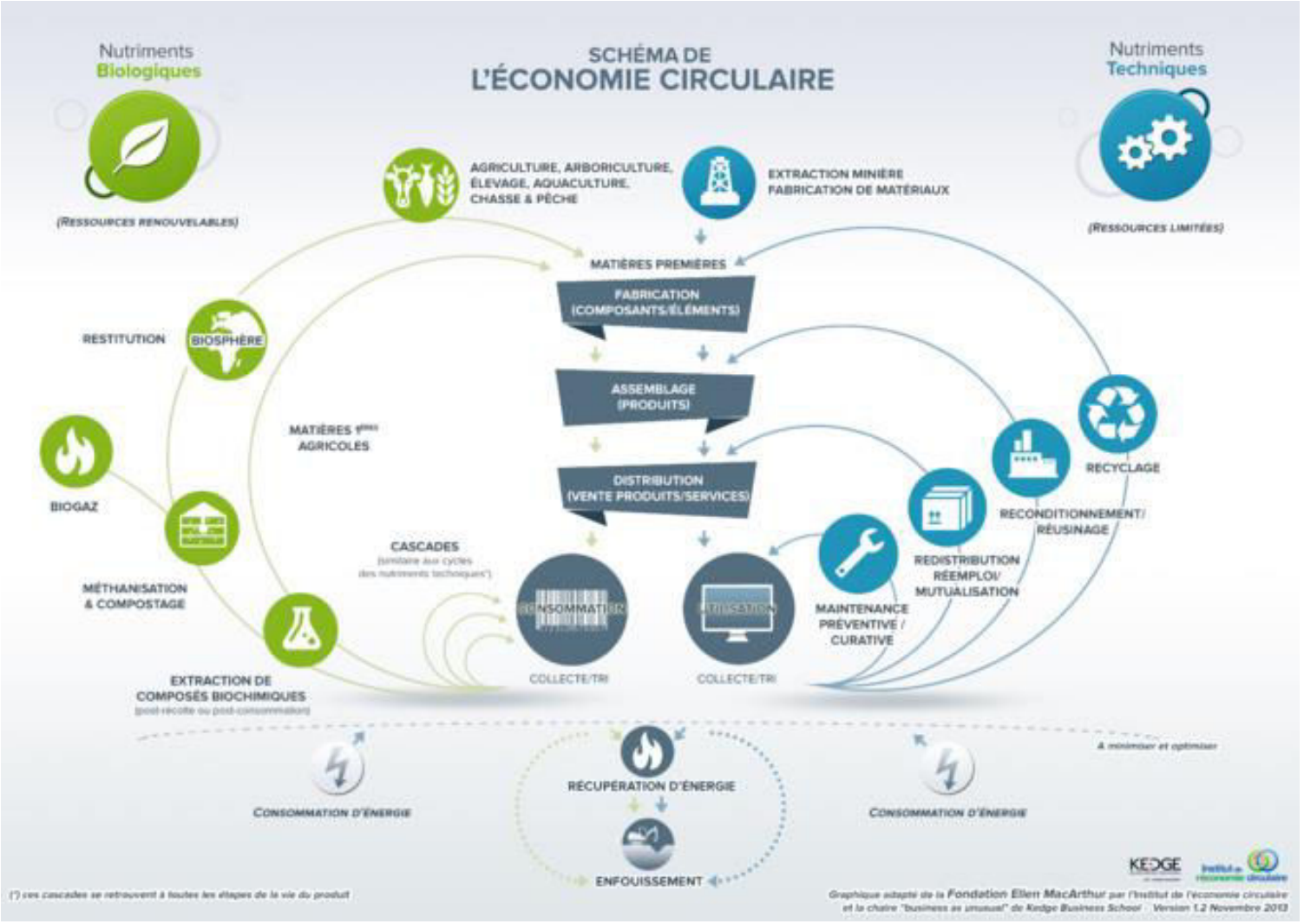



*Figure 15: The circular economic model in France (view by the French circular economy institute)*[4]

The most known tool used to assess a product environmental impact is the Life Cycle Analysis (LCA). This multi-criteria approach can be very tedious, but it is the most global and exhaustive approach that can be performed (see *Figure 14*, as a result of LCA application).

In 2013, in France, the consideration of the Circular Economy concept changed. The term was initially introduced in 2007, at the occasion of the "Grenelle de l'environnement". Despite critical arguments because of the ideality of the model, it is now taken seriously by the authorities. The actions and discussions around this concept prove it, especially since the French Environmental Conference (20 and 21 September 2013) dedicated one of its five panels on Circular Economy. For the occasion a Bibliographic study (Commissariat General au Developpement Durable, 2013) was presented by the General Intendance of Sustainable Development, tracing the last accomplishment on the concept. This

[4] The French circular economy institute: "http://www.institut-economie-circulaire.fr/Economie-circulaire-vers-un-nouveau-modele-de-prosperite_a277.html"

synthesis document relates the Ellen Macarthur foundation and its fundamentals, or the study from Braungart and MacDonough, among others.

Beyond the appearance of a new craze for the circular economy concept, it was initially introduced by David W. Pearce and R. Kerry Turner in "Economics of Natural Resources and the Environment" (Pearce and Turner, 1989). However, the architect and economic analyst Walter Stahel is the pioneer in the development of the concept with the term of "performance economy" in the 1970s especially with the recognized paper "the product life factor" in 1982, which highlights closed loop systems applied to production processes. This first theory also enabled Michael Braungart and Willian Mc Donough to develop their own philosophy of the "Cradle to Cradle", starting in 1987 but only published in 2002 in English and traduced to French in 2011.

To some extent "Sustainable Development" was clearly defined in 1987 at the Brundtland commission by the WCED (World Commission on Environment and Development) with the three pillars; "Economic, Environmental and Social", but the circular economy concept suffered from its lack of clearness, which explains the difficulty of the diffusion of the ideas to a larger public. Indeed, in her research, Charlotte Wang (Wang, 2014) proposes a quantitative approach of the scientific articles appeared on the circular economy topic, which shows that the number of studies dealing especially with the concept is relatively low. In this sense she deals with the communication of this concept with a comparison study between France and China in order to give key definitions for the adoption of the concept in the two countries. This article shows that depending on the region and the approach (generalist, economic, information science, philosophical), the definition can change, and that today there is no uniformity among territories. However she emphasizes, along with other authors (Hu et al., 2011; Su et al., 2013), that circular economy has already been accepted within the Chinese Central Government in 2002 "as a new development strategy aimed at environment protection, pollution prevention and sustainable development" (Bilitewski, 2005). In this sense circular economy plays a major role in China's economic development, but in France the regulatory framework is still under construction. It is considered as a new concept (Fernandez et al., 2014; Levillain and Fernandez, 2014). In her thesis work, Cerceau (2013), emphasizes the opportunity of 450 Billion Euro saving on raw materials on the European territory (Ellen MacArthur Foundation, 2012), by applying circular economy concepts. In this sense there is a need for change of the economic models toward circular virtuous models that enable value creation, from the wastes of one industry to a new product in another industry, or the same one.

Because fundamental concepts have been exposed starting with (McDonough and Braungar, 2002), we want to understand its practical implementation within today industries. Su et al. (2013) address this question in 'A review of the circular economy in China: moving from rhetoric to implementation". We can easily understand the importance of governmental targets in this process. However they show that the different studies over circular economy are not organized with "lack of visible integrative effort". The literature review focuses on the evaluation of the implementation performances at different scales, but suffers from "the lack of clear, standardized quantitative measurements and goals" and other lacks are listed by Su et al. (2013) such as: reliable information, shortage of advanced technology, poor enforceability of legislation, weak economic incentives, poor leadership and management and lack of public awareness. There is a gap within the implementation process itself. On one side we can find targets and goals from the authorities and on the other side we can find evaluation tools of the degree of implementation of circular economy, but there is very few focus on the actual, practical implementation, how do industrials deal with their duty facing regulation, how does it affect their business, their supply

chain, their organization? Can we find guidelines to practically implement circular economy in industrial environments?

### *1.2.4 Supply Chain Design*

In the literature, supply chains including environmental concerns are studied with different point of views such as design or operational management (Govindan et al. 2014; Mathiyazhagan et al., 2014; Zhu et al., 2012). In this research, we aim at supporting the creation of new recycling supply chains; we stand at a design phase.

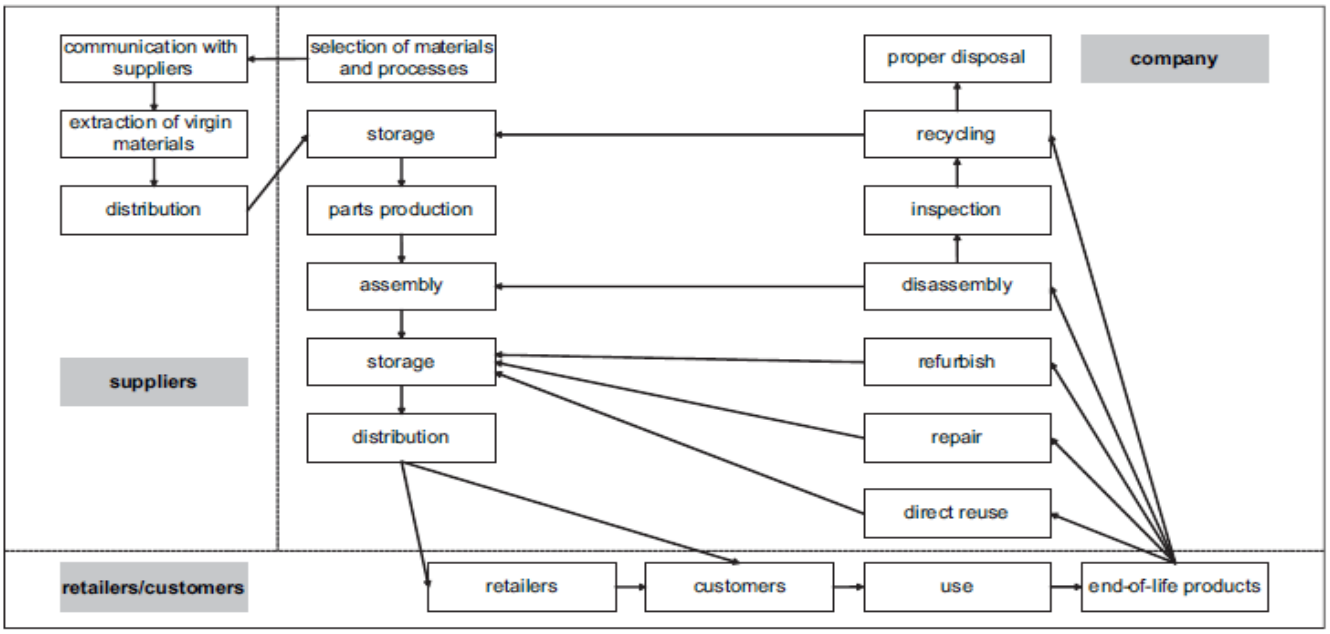
The Council of Supply Chain Management Professionals (CSCMP) in the "Journal of Business Logistics" has defined the supply chain as: a system, complex and dynamic, respectively because of the implication of organizations, people, activities, information, resources and the fact that it is in movement. In this study, we consider that the objective of a supply chain is to go from raw material extraction to the delivery of the product to the end user (Beamon, 1998). Because reverse logistic (that includes product recovery for the purposes of recycling, remanufacturing, and re-use) is increasingly investigated in the literature, another new phase can be added to the product life cycle which is the disposal of the product (Pagell et al., 2007).

By taking into account the environment in more and more research studies, derived supply chains have emerged (Linton et al., 2007), even if it is "still in its infancy". Due to growing environmental concerns, the optimization of environmental factors moved from local optimization to a consideration of the global supply chain.

Regarding the supply chain modeling, four dominant approaches have been identified (Seuring, 2013) which are the "equilibrium models, multi-criteria decision making (MCDM), and application of analytical hierarchy process (AHP)" but also life-cycle assessment models. However, as stated by Seuring (2013), there has been only "limited empirical research so far" and those modeling approaches are applied to supply chain management and optimization at an operational stage, and not specifically during the supply chain design phase. For example, green supply chain management generally involves green suppliers selection (Akamp and Müller, 2013; Hsu and Hu, 2009; Igarashi et al., 2013), understanding a screening of the suppliers based on their environmental performance (the focus of §1.2.5.3). It also takes into account transport logistic optimization issues (Pishvaee et al., 2009; Sheu et al., 2005; Vahdani et al., 2013), that focus on developing mathematical models. Other studies (Büyüközkan and Berkol, 2011) use decision making techniques to support the design of green supply chains.

We choose to present the one of Tsoulfas and Pappis (2006) that enables to justify the product approach in the Supply Chain. Indeed, linked to our issue, it is also stated that the first stage of Supply Chain includes the selection of materials and processes. As presented, the supply chain is driven by the product life cycle phases, from the recyclable raw material extraction to the product end of life (*Figure 16*).

*Figure 16: The material flow (Tsoulfas & Pappis, 2006)*




In their study, Tsoulfas and Pappis (2006) stated that because of the product manufacturing, transport, use and discards, it is the Supply Chain that causes impacts on the environment. This is the reason why the authors emphasize the importance of the material flow management with an environmental perspective.

### *1.2.5 Industrial Collaboration in R&D and in SC Management*

In our study one of the objectives is to develop a project partnership, supported by a superior authority agency that promotes innovative and/or environmental investigation. Indeed collaborative networks are promoted by public institutions to develop technologies and bring competitiveness in the country (Arranz et al., 2008). But it is also a potential competitive advantage for the companies themselves, the reason of this investigation.

A literature review has been done by Arranz et al. on the reasons why firms cooperate. The first benefit is that the externalization of the technologic study can lead to faster developments. Also, for companies for which innovation is difficult to manage, the externalization of the activity contributes in developing a new technology on a new market (Ding et al., 2013; Klette et al., 2000; Kotabe and Swan, 1995).

#### *1.2.5.1 Partnering, Partnerships and Virtual enterprises*

“R&D collaboration” or “R&D co-operation” is a model that has grown since the 1980s (Chen, 1997; Chesnais, 1988; Hagedoorn, 1990). It is also considered (Porter and Fuller, 1986) as a part of the global corporate strategy, as it is related to competition. In this sense, in the case it is driven by strategic aims, R&D partnership can be viewed as “strategic alliance or part of a strategic alliance, but it may also be an operational tactic.” (Chen, 1997).

In the literature authors have studied the exploration of “how strategic supply chain partnership contributes to environmental supply chain management”(Youn et al., 2011), meaning that “collaborative practice across supply chain participants” and successful partnerships reinforce environmental supply chain management, and competitive advantage, which gives a reason why firms are constantly looking at improving partnerships. Partnering is also considered “as a successful long-term relationships among trading partners in supply chain that are enabled by mutual trust, organizational compatibility, top management support, and information trading” (Youn et al., 2011).

However, Mentzer et al. (Mentzer et al., 2000), emphasize there is no “ideal” relationship that is appropriate in all situations. He also states that “no single, clear set of criteria exists that differentiates the nature of strategic partnering from other types of partnering”. However, strategic partnership is also defined with firms that “have a strategic mind-set toward the interfirm relationship”, they share values and believe in the partnership (Mentzer et al., 2000). Partnering also happens when the importance of the relationship is percieved by the company, considering the partner as a large part of the picture (Johnson, 1999). Also contextual pressures “encourage the formation of the partnerships: environmental uncertainty, global competition, and time and quality based competition” (Mentzer et al., 2000).

The concept of Virtual Enterprise emerged in the 1990s. Different definitions exist such as: “a Virtual Enterprise is a temporary consortium or alliance of companies formed to share costs and skills and exploit fast-changing market opportunities”. However, all the definitions contain the same base that “there is a tendency to describe a VE as a net-work of enterprises” (Camarinha-Matos et al., 1998). Industrials face through time major changes, such as globalization, which push them to adopt new structures to follow the evolution of their environment. Thus, the “emergence of the virtual enterprise paradigm comes in the natural sequence of these restructuring processes enabled by the “explosive” developments in the information and communication technologies” (Camarinha-Matos and Afsarmanesh, 1999).

#### *1.2.5.2 Overview of the R&D collaboration concepts*

We highlighted the definition of the strategic partnership from the literature as: "an agreement between two or more partners to share knowledge and resources, which might be beneficial for all the parts involved" (Trott, 20011). These alliances are as much intra-industry (alliances with competitors on the market) as inter-industry (alliances with other complementary companies on the market).

The power to handle successful alliances of collaboration is the major challenge within the current market. In fact, as competitive market environments create uncertainties that cannot be handled by a single firm, it is observed that companies subcontract research and development, to reach different technological areas, but also to accelerate the process of innovation and to diversify its technological strengths (Narula, 2004).

At a strategic R&D level, different types of collaboration exist, from close to open innovation, as proposed by (Chesbrough, 2003). In this sense, collaboration takes the organizational form of a project with outside partners who contribute to current or new markets. These R&D works are not risk free and the choice of partners plays a determining role in the cooperation mode (Arranz et al., 2008).

In 2012, Calamel et al. (Calamel et al., 2012) conducted a study on "The construction of collaboration" particularly in French innovative clusters, and states that there is a need to "pay more attention and invest more efforts in the initial stages of the project". The literature review on collaborative project highlights specific issues "such as trust building and managing cultural differences amongst different individuals" (Drouin et al., 2009), "coordination of members or inter-organizational cooperation between different partners (Gulati et al., 2000; Hoegl et al., 2004), "team autonomy" (Hoegl and Parboteeah, 2006), and "formal decision-making processes" (Bourgault, 2008).

Regarding R&D partnership, studies have focused on collaboration between technical research fields and industrial major groups which enable to finance advanced researches (Adeoti and Adeoti, 2005; Ben Letaifa and Rabeau, 2013; Link et al., 2002). The efficiency of such collaborations has already been demonstrated and shows that it facilitates development processes; however, the collaborative scope generally focuses on the relation between an industrial group and a research laboratory.

Sharing risks and development costs with a common aim to "boost competitive advantages" through collaboration was observed in the automotive industry with the Joint Venture Renault-Nissan (Sarasini, 2014). The combination of knowledge through these types of partnerships, induces creative interactions which bring new ideas, with well known benefits such as the "access to key markets, technologies, competences and skills that are useful for innovation" (Sarasini, 2014).

Regarding this research field, it is interesting to note that authors have already worked on the necessary criteria for the identification and evaluation of "strategic partners for collaborative R&D" (see *Annex 4*). Criteria such as "Technology strength" in (Geum et al., 2013), are relevant for this specific research issue. However they have to be reworked and adapted to the partner selection problem in recycling collaborative projects

Different forms of R&D partnership patterns exist, relevant to the openness of the collaboration. In this work we will focus on R&D collaborative projects as described by INPI (French Institute of Industrial Property), as joint consortium project.

#### *1.2.5.3 Partner selection in Supply Chain Management*

There are many papers about the process of supplier selection in the supply chain (Chai et al., 2013; de Boer et al., 2001; Ding et al., 2013; Lu et al., 2013; Sharma and Balan, 2012; Theißen and Spinler, 2014); nevertheless, they concern suppliers in the operational phase of a supply chain and not strategic partners in the design phase of the supply chain. For instance regarding the purchasing department, the selection of the best suppliers is one of the most critical topics in the competitive environment (Kannan et al., 2013). The management of the contemporary supply chain is focused on supporting long-term relations with the suppliers: their number decreases, but their relationships become more trustworthy. Therefore, the corresponding option of supplier selection implies more criteria than only information on negotiation, price and quantity (Ho et al., 2010).

On the other hand, the strengthening of the environmental legislation and the change of the population concerns for the protection of the environment have caused for the companies to change their politics and to include these new dimensions to support their competitive advantage (Andiç et al., 2012; Diabat and Kannan, 2011; Kubat and Yuce, 2010; Verdecho et al., 2012; Youn et al., 2011; Zhang and Wang, 2014). The increasing trend of the environmental worries also appears in the industrial development of logistic activities, green procurement (Appolloni et al., 2014), which leads to the emergent GSCM concept (Hsu and Hu, 2009; Kannan et al., 2014; Lee et al., 2009; Niknejad and Petrovic, 2014; Rizzi et al., 2013; Sharfman et al., 2009; Vachon and Klassen, 2006; Walker et al., 2008; Zhu et al., 2011). In this respect, new environmental criteria are proposed to be included in existing supplier selection process (Igarashi et al., 2013).

Concerning this research field, authors have worked on the identification of the selection criteria from the literature. For instance, in the work on the "Selection of the strategic alliance partner in logistics value chain" (Büyüközkan et al., 2008) we find relevant criteria such as "Technical expertise", "Similar values-goals". In other papers (Kannan et al., 2014, 2009; Wu et al., 2009), criteria such as "Reputation" ; "Previous alliance experiences"; "Quality"; "Willingness and Attitude"; "Technology Level"; "Flexibility of the Supplier"; "Environment Protection System Certification"; "Recycle"; "Green Design" have been proposed.

These criteria have been carefully analyzed and adapted to our specific issue. Indeed, because we are facing a combination of two research fields (R&D collaboration and recycling supply chain design) that have not been investigated together before, we have to build a new adapted criteria tree (CHAPTER 4:, §4.2.2.2).

## *1.3 Synthesis*

This state of the art highlights the best practices and the research gaps, relevant for the conduction of our research problem.

Regarding the industrial analysis methods, we found suitable tools that could help us to answer the question: **How can we study the structure of an emerging recycling industry?** However, we could not find any method or case study for the analysis of a recycling industry. *CHAPTER 2:* intends to fill this gap by proposing a method specifically for the analysis of recycling industries. Porter's Value Chain analysis concept helped us in the elaboration of this method, to understand the availability of the resource, the competitive environment and the supply/demand balance.

The study of innovation and specifically eco-innovation, also presents arguments for businesses to implement this practice. Driving innovation enables to adopt a constructivist approach and tackles the issue of innovative project management. In this respect it contributes to our research question: **Considering that collaborative projects favor the opportunity to conduct R&D studies, for the specific objective to develop a new RSC, how should these projects be organized?** However, even considering our investigation in eco-design processes, we have not found any adapted method to elaborate such projects. Conceptual models exist with the representation of typical stages (for example, see *Figure 11)* , but management models are missing (Brezet, 2001). Because our focus is on the design of a RSC, the investigation in supply chain design enables to propose a first identification of required steps. These steps would be reworked, for the development of our method (the RSCDP), especially with the consideration of reverse logistics (Pagell et al., 2007). But we also understand that when the product life cycle is considered from its design, the design of the supply chain is simultaneously considered.

We investigated the research field of industrial collaboration. It has already been demonstrated that it contributes to sharing R&D costs and risks, particularly interesting for long and tedious projects. This focus also enhances a critical aspect that is the importance of partner selection to favor project success. This statement contributed to the elaboration of our third research question. **How to help the industrial to decide which partner is best suited for a R&D recycling collaborative project?** It is a question raised by the identification of a research gap between R&D project collaborations and recycling supply chain design approaches. The existing models of criteria in the literature are not suited to support our problem. This is the reason why, this field of investigation with a focus on R&D projects and supply chain partner selection, with the identification of relevant criteria, contributes to the elaboration of a criteria model and a ranking method adapted to our research scope.

# CHAPTER 2: A RECYCLING VALUE CHAIN ANALYSIS METHOD: THE FRENCH TEXTILE RECYCLING INDUSTRY (FTRI)

The elaboration of the recycling fraction of textile EoL materials and its supply chain organization, for a recycled product development, requires an analysis of the value chain structure of the French Textile Recycling Industry (FTRI). Indeed, industrials who are not specialized in this domain and intend to take the responsibility of their wastes (application of the European regulation) and to develop innovative business opportunities are confronted to incumbents that are already positioned (waste collection networks and waste treatment companies), thus they need to analyze their environment. They are also confronted to a complex environment, in mutation. Coming from traditional businesses, the recycling activity is still under construction, which makes a fuzzy and unstructured environment, all the more tedious to analyze.

This is the reason why we use structural analysis guidelines, such as Porter's analysis techniques, with the Value Chain or the Supply/Demand analysis, previously presented in the literature review (§1.2.1). Indeed, it gives a primary method of investigation for the organization of the collected data throughout our study. However, even if we tend to make a general insight of the FTRI using these tools, the method is applied in the limit of the existing data gathered and highlighted during this research. Moreover, specificities regarding the recycling industry are highlighted. Our observations enable to make a generalization and propose an adapted method described in §2.2. Indeed, the importance of the recycled material features (composition; repartition; legal owning aspects; processing needs) but also the business strategies adopted, imply particular investigations. For instance, we highlight the need to focus on the initial/virgin industrial environments that we categorize. We also focus on the governmental regulation (especially on the enlarged producer responsibility with the generation of an eco-tax) on textiles wastes, which creates particular deregulation on the market. But also we highlight two potential approaches in step 3 and 4, to favor the use of RRM in new product design.

## 2.1 Organization of our Investigation

The study and observation of the recycling textile industrial environment, along with specific recycling collaborative projects, contributes to the elaboration of this analysis. Because of our research-action positioning with the CIFRE ("Convention Industrielle de Formation à la REcherche" in English: "Research Training under Industrial Convention"), we conducted various interviews on specific meetings such as the International Automotive Recycling Congress. We also participated in different discussions' group in industrial associations for the promotion of textile recycling. In *Figure 4*, we note the industrial materials used for our global research method (see §1.4), each industrial manifestation corresponds to different observatories, useful for the industrial data gathering. However, as we presented in §1.4, because of the newness of the FTRI, actors tend to protect their data, and reveal few information. In this context, industrials are not at ease with formal interviews, which were complicated to pursue consistently. The data have also been gathered by confronting conferences talks, from which, after two

years of attendance, major considerations are enhanced. These industrial expert interviews and information are feedbacks, to present our analysis of this environment structure[5].

## 2.2 Proposal of a recycling value chain analysis method

In the literature review, we have seen analysis approaches from (Bidault, 1999; Johnson et al., 1998; Porter, 1985), which aim to give methods to analyze an industrial environment for strategic decision making.

Inspired by these works and taking into account specificities of recycling supply chains, we propose the following overview of the industrial analysis method with five main studies (*Figure 17*):

Step 1. The "EoL resource study" for the analysis of the original value chains until the understanding of the potential EoL resource supply
Step 2. The "RRM Preparation Manufacturing activity study", with the analysis of the required process to transform the EoL materials into a usable supply (usable supply = RRM)
Step 3. The "Recycled Product Manufacturing activity study", with the analysis of the buyer needs and the demand
Step 4. The "Final uses and market study", with the analysis of the market demand (functionalities of the product and the potential volume)
Step 5. The "Synthesis Study", with the global understanding of the Supply/Demand balance and the competitive strategy to adopt

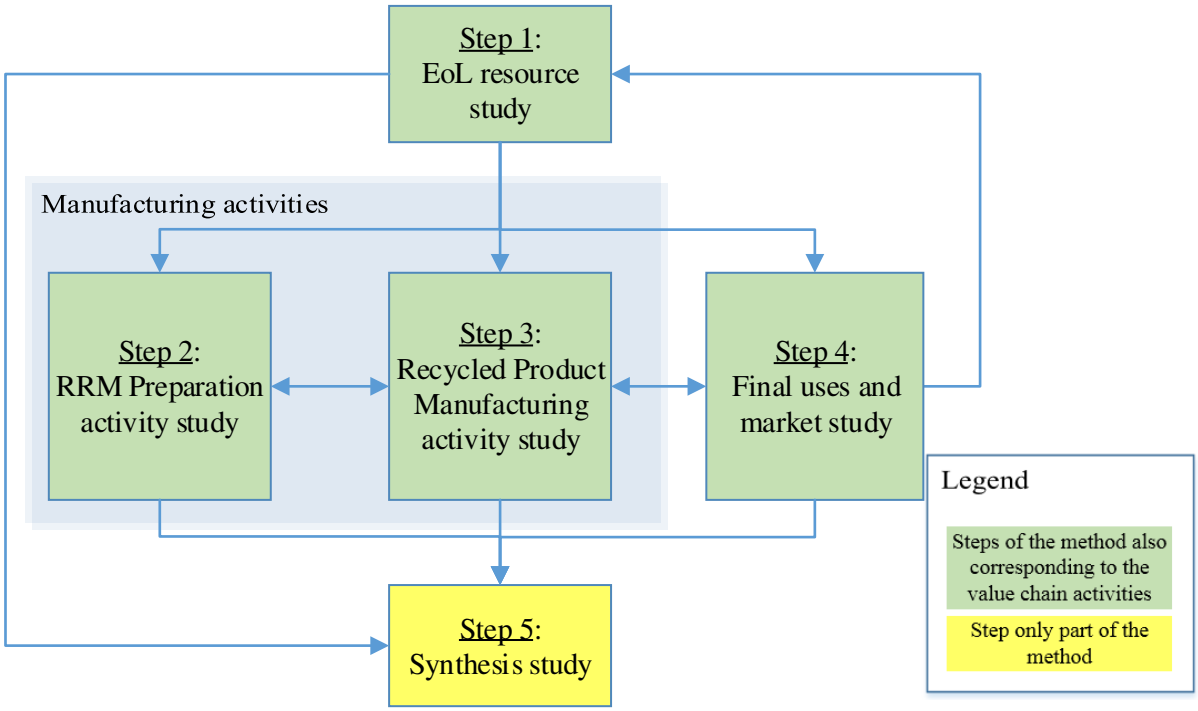



*Figure 17: The structure of the industrial analysis method*

[5] Some of our information are confirmed by press articles that focus on the recycling trends in the FTRI ("Envoyé spécial - Le recyclage des vêtements : de l'or dans nos armoires," 2014).

The presented detailed overview (*Figure 18*) also enables to visualize the new RSC with the black arrows representing the RSC material flows that link step 1, step 2, step 3 and step 4.

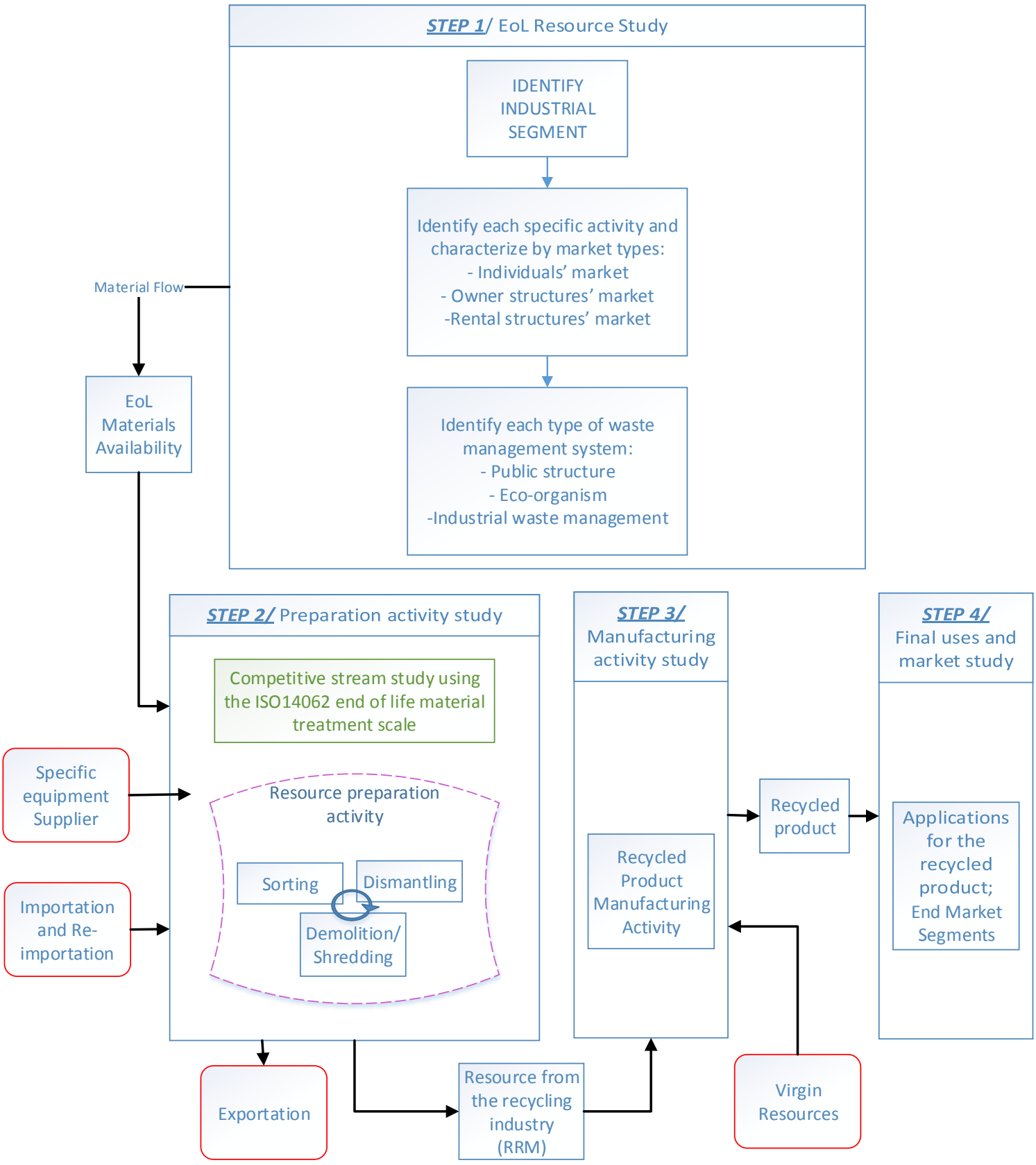


*Figure 18: Industry structure analysis generic method: Step 1 to 4*

*Figure 19* corresponds to the synthesis work, the fifth step, to understand the dynamic of the supply and demand.

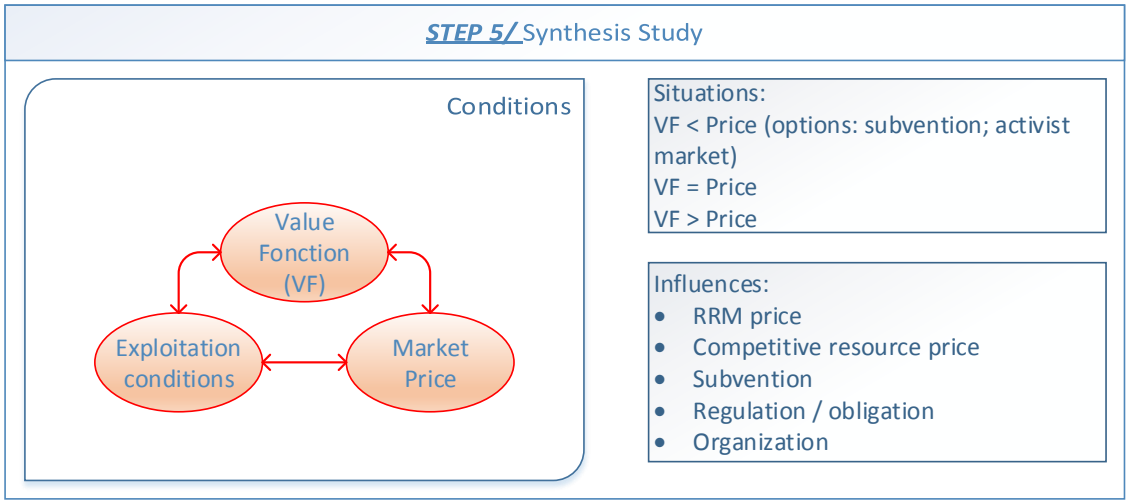



*Figure 19: Industry structure analysis generic method: Step 5*

Each step is described separately in §2.2.1 through §2.2.5

### *2.2.1 Step 1: EoL resource study*

The study of the supply requires investigating the EoL resource potential (also called the EoL product), present on an original market segment. We consider (what we call) an "original market" as a market that gives the scope of the investigated resource. The EoL products, considered as potential recyclable resources, are also associated to their own initial supply chains and are delivered to specific markets (or original market considered in this step 1). The identification of these original markets enables to understand the potential EoL material supply. Indeed, the competitive scope of the value chain must be defined as described in (Porter, 1985). Scopes such as the segment scope of the industry, but also the geographic scope must be defined. Then, within these scopes, the companies are identified and characterized by their original market types. This characterization enables to position the legal responsibility of waste management and understand which stream the wastes are destined to.

The first step is to identify whether the products from each specific activity go to the "individual market" (it corresponds to the public consumption market), to "industrial owner structures market" (the products are used by the employees of an organization but they remain the company's property) or to "industrial rental structures market" (the products are loaned by a company that put at disposition the goods for their employees). One specific activity can deliver different markets (of the three presented), so the volumes put on the markets are divided into different streams. This classification enables to understand the material flows, based on the volumes introduced on the market by each specific activity, where the data can be gathered. This identification and characterization are necessary to know where the products will be at their EoL.

Using this first identification, we are able to use the regulation to position the waste management responsibilities. Indeed, for instance, knowing which market is delivered by the initial product manufacturer (a specific activity), based on the presented features ("individual"; "owner structure"; "rental structure"), helps to understand by which structures the wastes are managed. Thus, it enables to better understand the characteristics of the EoL material supply, such as, its volume repartition on the territory, its accessibility, its availability (represented by the box "EoL materials availability", the information coming from Step 1).

The relationship between the identification and characterization of the specific activity, and the identification of the "waste management system" depends on the original market segment. Indeed, the evolution of the regulation creates particular wastes streams, especially introducing more and more the "polluter pays" principle (see *Figure 22: Evolution of the regulation*). In this respect, the EoL material flow is managed between the "Waste management by public structure", the "Waste management by eco-organisms[6]" and the "Industrial waste management organism". These activities collect and manage the wastes.

For instance, the "Waste management by public structure" aims at collecting and dealing with individual wastes, home garbage, for which the user (individual) contributes economically by paying his taxes. However, concerning specific waste streams (such as textiles or furnishing), the regulation, through eco-organisms, transfers the EoL material management responsibility out of the public structures: it corresponds to the "Waste management by eco-organisms". The objective is to withdraw the specific considered wastes out of the classic waste management network, in order to favor better environmental management. To achieve economically this model, the initial producer that delivers the product on the individual market, contributes to an eco-tax, defined by the eco-organism, to support the system.

The "Industrial waste management organisms" act for the treatment of industrial wastes. Generally, the industrial requires an external company, specialized in waste management depending on the type of wastes. In this case, there is no economic impact on the public structure. With this model, industrials economically contribute to the company that manages wastes. Through this stream, it is difficult to know if there is a valorization of the wastes or if they go to landfills and what is the engendered cost (logistics; processing cost) compared to the benefits of the valorization.

At the end of this first step, the understanding of the relations within the original markets and the analysis of the value chain structure, such as described by (Porter, 1985), enable to have an overview of the EoL resource availability and main characteristics which are:

1) Technical feature of the EoL material, main material composition
2) Potential EoL volumes based on the original market delivery of the first life product
3) Regulation impact on the waste management system
4) Dispersion of the resource on the territory and accessibility

In this study, these four features imply economic impacts, on the preparation process in step 2, and the manufacturing of the recycled product in step 3. But these impacts must also be balanced with the

[6] Eco-organism: An eco-organism is a society of private right, invested by the public authority of the mission of general interest, to take care, in the scope of the Enlarged Producer Responsibility, the End of Life Equipments delivered on the market in the scope of the assigned industry (see http://fr.wikipedia.org/wiki/%C3%89co-organisme).

possibility to penetrate a new end market (step 4), with potential economic deregulations (due to the regulation and potential eco-taxes). The degree of logistic optimization required is also impacted, depending on the dispersion conditions of the EoL resource. These features must be considered for the understanding of the availability of the resource.

### *2.2.2 Step 2: Preparation activity study*

The preparation activity is also a manufacturing activity; however, we separated it from the manufacturing of the recycled product, as it is specific to the recycling industry. This step corresponds to the transformation of the end of life products into Recyclable Raw Materials (RRM), which could further supply different markets for the manufacturing of different recycled products (ex: end of life cloth into recycled textile fibers to make a recycled yarn),.

Then, the study of the EoL treatment stream, based on the ISO 14062 (green box in *Figure 18*), shows how the RSC is situated compared to its competitive value chains. The analysis of the specific recycling industry induces the particular focus on the recycling process within the "identified value activities" as defined by (Porter, 1985). In the particular context of recycling, these main activities are: sorting; dismantling; shredding (but also activities such as logistics, storing or packaging that are more general to any industries). We can note that this second step uses the information concerning the "EoL material availability" but also "importation and re-importation" features. With this information the feasibility of the preparation activity can be evaluated and the process dimensioned. It may require the help of "Specific equipment supplier" engendering a machinery material flow into step 2.

This value activity is dependent both on the supply and the demand. Indeed, the EoL material available from step 1, possesses its own technical features, for which the adapted process must be elaborated (help with specific equipment supplier). But also the available volumes (risk of deregulation due to importation/exportation trends) and its localization (logistic costs), represent economic dependencies. The specifications from the recycled product and its end market (step 3 and 4), are also inputs that must be considered to decide on the adapted preparation process. These specifications can represent technological challenges to elaborate the adaptable preparation process, with the right exploitation costs for the end recycled product to be competitive.

At the end of the second step, we obtain the "Resource from the recycling industry (or RRM)". It corresponds to a new volume compared to the initial EoL product availability due to the wastes generated. Indeed, the preparation process, by treating the resource, eliminates a percentage of the initial available volume and it must be evaluated in order to define the quantity of RRM that can be used in the final recycled product, for instance to make design adjustment. Knowing the quantity of RRM used in the product, it is compared to the final market absorption capacity, to understand how it responds to the demand.

### 2.2.3 Step 3: Manufacturing activity study

The study of the demand (step 4) enables to propose a market segmentation of the RRM application fields. This analysis drives step 3, with the "recycled product manufacturing activity". Two approaches for this study can be conducted, an *analogical approach* or a *functional approach*.

The first *analogical approach* considers existing specifications from an identified market segment ("Application for the recycled product – End market segments" step 4). In this case, the conduction of step 3 (and by transposition gives inputs to step 2), is based on existing materials features (such as virgin materials). The use of RRM aims at replacing virgin resources already used in existing products. In this sense, during step 3, the design engineers would look for RRM that possess similar features compared to virgin materials. However, this achievement is generally compromised. Indeed, step 2, with technical-economic limits, might not be able to achieve the requirements. In this case, the flexibility of the product design in step 3 can counterbalance this issue. Indeed, the RRM impact on existing product design is not easily predictable and design work can be required to be able to use RRM and still meet the market specifications. This is the reason why the "Recycled product manufacturing activity" must also be based on functional product definition rather than looking for similar raw materials.

With a *functional approach*, we can imagine new design work in step 3 for the development of new products. On an identified segment, a "Buyer need" (Porter, 1985) can be translated into a new product functional definition. For a business, the strategy to use RRM and the first functional definition of a product, could bring to the development of a new offer, without analogy to existing organic products. However, this positioning by design engineers, out of existing material and their applications, are not easy to observe in the industrial environment. But it is a hypothesis in this research work that could favor the development and use of RRM.

In this step 3, and particularly regarding the *analogical approach*, the economic balance can be compared with the use of virgin resources engendering different situation presented in §2.2.5

### 2.2.4 Step 4: Final uses and market study

The study of the final uses and market drives to the definition of the specifications that must be considered in step 3 for the design, and further, the manufacturing of the recycled product. The motivations to use RRM can be different from one market to another. For instance, it may be mandatory (due to regulations) to have a percentage of recycled materials within a product. However, no better reason than economic sharing can favor this change, and the study of the competitive market, where the new recycled product is destined to, must be conducted. If the market is considered positively and the functional specifications are settled, the understanding of the target price is primordial to set conditions to the value chain organization. Then, the synthesis of the method aims at understanding these conditions (§2.2.5)

### 2.2.5 Step 5: Studies Synthesis

The aim of this method is to obtain an understanding of the conditions that are ruled by the triangle (Value Function; Exploitation conditions; Market price) (see *Figure 19*). Considering Porter's approach (1985), it corresponds to the *structural analysis of the value chain* with the Supply and Demand balance. From Bidault (1999), it corresponds to the determination of the influences in the relation between supply (technology push) and demand (market pull). In this respect, we identified five influences: RRM price; Competitive resources price; Subventions; Regulation/Obligation; Organization.

The RRM price is dependent on three situations satisfying or not the value function. It is also formalized based on competitive resource price existing on the market such as virgin resources, especially regarding the analogical approach described in step 3. Depending on the situation (see *Figure 19*), because we are in the specific environment of the recycling industry, supported by regulations, subventions and the application of taxes (in the situation "Value function < Price"), may contribute to the development of a business.

This value chain analysis approach from step 1 to step 4, focuses on the intensity of the competition with the study of co-existing networks (based on the ISO 14062 and other existing supply to satisfy the demand). From the Macro-environment (that defines the scope of the Recycling industry to be analyzed) and the EoL resource availability studies, to the identification of the actors that shape the industry, this "5 steps' method" is particular to the recycling industry. Indeed, the fact to focus on the EoL resource availability coming from "original markets", (including regulative aspects), is specific to the recycling industry. Moreover, the proposal to adopt a functional approach to obtain a performing product for an identified market, in step 3, is also an original contribution to this research work.

In fine, we can summarize the requirements and threats for the study of a new recycling value chain and for the design of a new RSC:

1) The exploitation costs and existing final market
2) The quality and performance of the recycled product
3) The regulation impact
4) The EoL resource availability
5) The logistic optimization due to the heterogeneous repartition of the resource
6) The technological barriers for the EoL resource treatments
7) The acceptation by the market of the recycling feature of the product
8) The flexibility of the recycled product design
9) The methodology required for the design of a new RSC

The formalization and combination of these different requirements are specific to the recycling value chain. Its design is also dependent on the cohesion of the different identified actors along the value chain. The third chapter, through collaborative design, presents an adapted methodology that creates this cohesion feature.

## 2.3 Application of the industrial analysis method on the French Textile Recycling Industry (FTRI)

Today, the standard (ISO 14062) recognizes a specific scale for the treatment of end of life material in order to limit the impact on the environment. The scale recognizes 5 complementary processes for the EoL product management. It starts with the Reuse (1) of the material, the Recycling (2), the Energy Recovery (3), the Incineration (4) and finally the Dumping or Land-field (5) of the wastes. From this scale, we observe different business models that are either existing or emerging, and competitive between each other's. The regulation favors the less environmental impactful solution, however, these directives are only followed based on economical values, and, in this sense, wastes management activities are positioned on a competitive market (refer to §1.1.1).

In this respect, the price formation depends on each step of the RSC process. The complexity and costs of the recycling processes are not necessarily balanced by the product value in the end, observed with the 3 possible situations depending on the Value Function. In step 5, the influences that favor the development of the RSC are highlighted and the conditions are analyzed.

### *2.3.1 Step 1: EoL resource study, from textiles garments, complex textile systems and regulative aspects*

Each segment corresponds to its own regulatory context (Garments; Technical industry using textile ratio). In this respect, we can note how the wastes are managed, either by public structures; or by eco-organism; or by waste management systems for professionals done in an autonomous way (see *Figure 18*). The French Statistic and Economical Study Institute (INSEE), publishes features on every industrial sectors. INSEE presents specific sectors in the industrial combination of "Textile, Garment, Leather and shoes". In this study, we only focus on two of them, defined by this organization as:

**1/ Clothing or garment:** "The process of cloth's and accessories creation, with the confection mode (custom made, ready-made …), the raw materials (fabrics, furs, leathers …), or the type (man/woman/kids, sport/work, underwear …)". In our study, this sector is relevant for the analysis of the professional clothing segment, and by necessity, of the individual garment industrial segment. It corresponds to an average of 720 000 tons of material put on the market in France per year.

**2/ Textile:** "Regroups the activities of spinning, weaving, finishing, and the manufacturing of textile products that are not sartorial (housing textiles, carpets, cordage …)". This group corresponds in our study to the Technical Textile products that are present in complex systems, and we limit the study to the technical textiles present in the automotive industry. For the total industry of Technical Textiles it corresponds to an average of 408 000 tons of materials put on the market per year (DGE and UBIFRANCE, 2006).

*Figure 20* gives the overview of the application of the first step of the method. Examples of existing organizations are proposed and the network flow is represented in this particular case study.

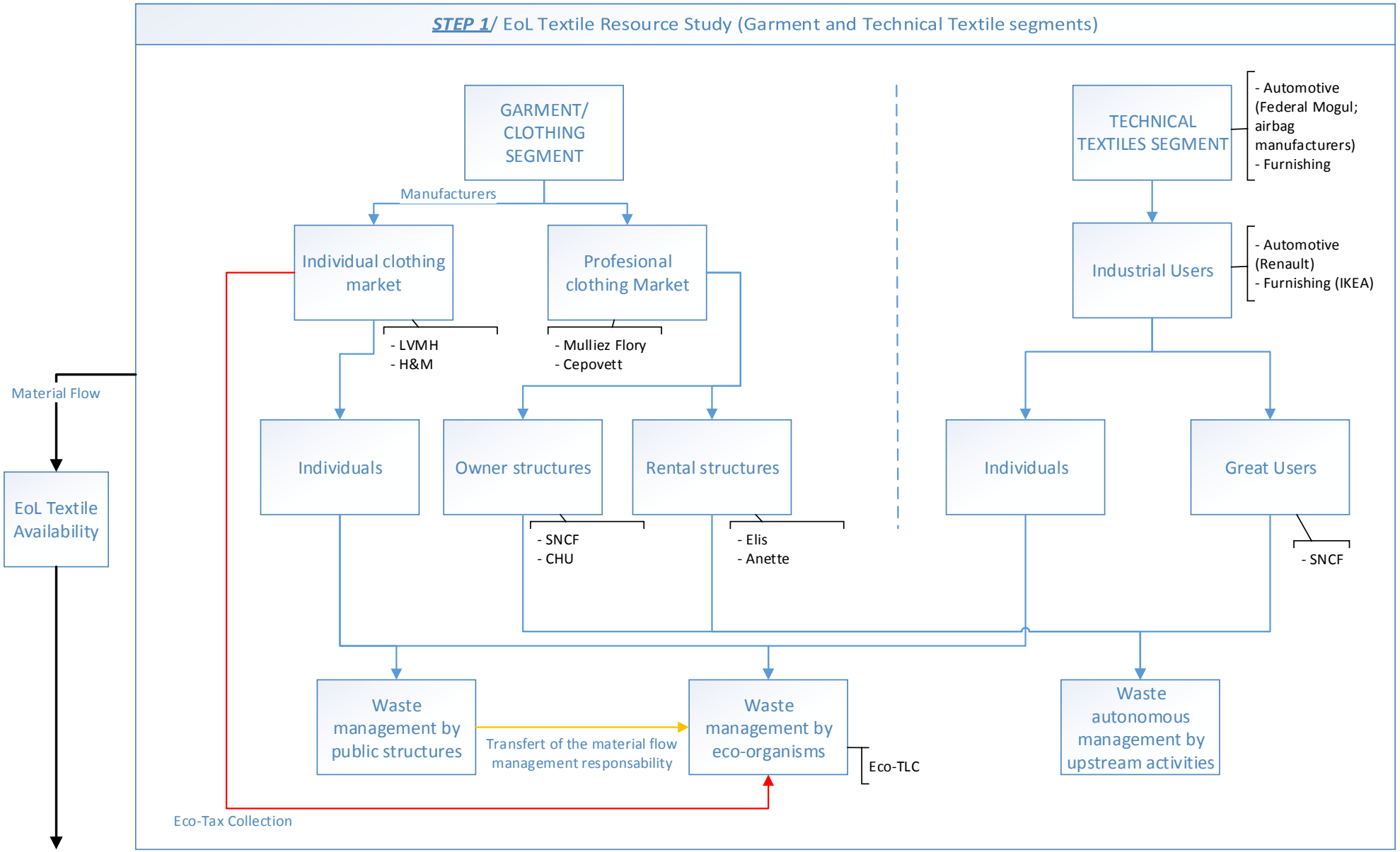



*Figure 20: First step of the method*

Between the two activities, in France, in 2010, the number of companies and the personnel effective repartition were respectively of 64.1% and 48.2% for the Clothing industry (1) (35.9% and 51.8% for the Textile (2)). In both sectors, in 2010, companies have been highlighted as part of the top ten, based on their turnover. In this classification we can find firms such as DIM, Petit-Bateau, Faurecia, Hexcel Composites. These top industrials make by themselves 4 Billion Euros (20% of the market).

Because (1) and (2) are completely independent markets, we perform separate focuses of both areas in the next sections.

#### *2.3.1.1 The clothing industry: Influences, regulation and availability study*

Regarding the clothing industry, the volume of textiles distributed on the French market is composed of two major potential resources; the "professional clothing" industry and the "individual clothing" industry. In our research, we are confronted to industrials from the professional clothing industry: it corresponds to the resource supply we want to focus on. However, this resource is not recycled today, but technically close to any kind of textile garment (pants; shirts) and governmental regulative pressures could be extended to this type of wastes. Thus, we also focus on the analysis of this waste stream.

##### 2.3.1.1.1 Individual clothing industry

- Regulation aspects

Today, in France, in order to respect this mandatory rule for individual clothing, a non-profitable eco-organism, Eco TLC ("Textile Linge et Chaussures"), was designated by the French authority in 2009 (designated again in 2014), to favor the application of the regulation. However, the companies, responsible for the textile products put on the market, have the choice between, either treating themselves their wastes with a collection system, or joining the eco-organism. In both cases, it should be certified by the public authority. If Eco TLC is the solution chosen by an industrial, the organism should take in charge the recycling operation treatment and participate to the development of the activity using different supportive actions.

- Supply availability and main features

The "individual clothing" market segment corresponds to products put directly on the market for individual users. This part of textile represents between 600 000 and 700 000 tons (Laperche, 2013) put on the market each year. In this stream, the garment is the property of the individual user and he has to deal with the product end of life. There are no mandatory rules for individuals to bring their end of life clothes into a specific stream. Thus, this waste can go in the same waste stream as unspecific garbage, and in this case, be managed by public funds. In this environment, the owner can keep the good on various time scales that change from an individual to another. These are observations highlighted by the IFM (French Fashion Institute) to understand the potential returns of the textiles initially distributed on the market. This evaluation is primordial because of the issue that the textiles, thrown in the public

garbage, can't be further extracted from it for a recycling activity (due to cost, pollutions, and contaminations issues). Another stream is also highlighted, with historical charitable associations, such as Emmaüs or the French Red Cross, which have the reputation to propose the discarded product for its reuse to underprivileged social class population.

Regarding this situation, we understand that the difficulty to gather the EoL cloths is an important issue and these tons could potentially enter in specific waste streams such as reuse or recycling. The change within the regulation could contribute to the development of the recycling activity, limit the environmental impact, and relieve the collectivities of this management toward autonomous businesses. However, today, only 143500 tons enter this specific textile waste stream. The objective is to recycle 300 000 tons in 2019 (Eco-TLC).

The intention of the French government is to develop this activity. Indeed, the European Directive, with environmental best practice's principles, gave an initial lead for each state to transpose the guidelines individually. In France, the government introduced the principle of the Enlarged Producer Responsibility for the textile industry in 2007 (ADEME, 2011), applied for individual clothing (http://www.developpement-durable.gouv.fr/Textiles-usages,12042.html). On the "polluter pays" principle, the objective is to transfer the economic impact of textile waste management from the collectivities to the producer (as observed on the overview of the FTRI with the red arrow). A way to do so is to internalize the EoL treatment cost directly on the initial price of the product, with the so called eco-tax. In this sense the producer becomes economically responsible for its products all the way through the entire life cycle, until disposal phase, for which the contribution is made upstream.

In order to manage the eco-tax, the public authority appointed an eco-organism and defined the objectives and agreements for the implementation of the plan. In France, the textile industry submitted to an Enlarged Producer Responsibility, is managed by the accredited organization, Eco-TLC (certified since 2009). However, a company can avoid the eco-tax payment by setting its own recycling program and collection network: the added value should then be balanced with the retribution to the eco-organism. *Table 2* presents the evolution of the financial contribution, to give an overview of the economical implications.

| Year | Sorted articles (in T) | Financial eco-contribution (million €) |
|---|---|---|
| 2007 | 76500 | 5.7 |
| 2008 | 85700 | 6.5 |
| 2009 | 96700 | 7.4 |
| 2010 | 112800 | 11 |
| 2011 | 128000 | |
| 2012 | 137 000 | 12.9 |
| 2013 | 143500 | 13.8 |
| 2019 | 300 000 (objective) | |

*Table 2: Volumes of EoL garments treated since 2007* (Eco-TLC, 2013; Intertek et al., 2012)

For instance, in 2010, the contribution to EcoTLC represented 11 Million Euros, with 4000 adherents and for 2.3 Billion pieces distributed on the market.

The contribution is calculated annually, based on the previous year volume of textile introduced on the market, and considering four "product types" (

*Table 3*).

| Product type | Contribution/piece (€ HT) |
|---|---|
| Very Small Piece | 0,0011 |
| Small Piece | 0,0044 |
| Average Piece | 0,0066 |
| Large Piece | 0,044 |

*Table 3: eco-tax contribution per product type (Eco-TLC, 2013; Intertek et al., 2012)*

Moreover, if a company uses recycled fiber content from post-consumer textile (at least 15%), a 50% discount is applied. This measure tends to favors the introduction of RRM.

However, the system is much criticized, specifically because the value generated by the reuse or recycling industry is difficult to evaluate[7]. Even if it enables to make a transfer of the responsibility from the industrials to the eco-organism, the capital generated is only managed by one organization, which can have a different point of view than the eco-tax contributors. In this sense, we understand that the contributor has no way to participate in the effective management of the EoL products, and is not aware of the EoL products fate.

To give an idea, in 2010, we highlighted that the eco-contributions generated 11 Million Euros; on the other hand, if the same quantity was to be land-filled at an average price of 100 Euro/ton it would also cost around the same amount; in this sense, we could say that the cost of End of Life is transferred from the community to the producer, and the new stream cannot cost more than the land-field cost. However, we can suppose that a part of the recycling industry (reuse, fiber recycling for automotive) generates value from the textile that can be sold to a third part, does it imply the necessity of the tax to reach an economical balance? To what extent is this tax necessary for the recycling industry to be sustainable? Today, the fact is that these recycled fibers can be used by third parts, such as in the automotive industry (historically recycling textile activities are implanted in France, such as Moncorgé or Minot Recyclage), and generate benefits. In this respect this aspect should also be introduced in the economic equation. Because of these questions and facts, textile producers could be looking for new business opportunities, as they are, with the eco-tax today, economically concerned by the issue.

For example, in 2013, the sorted quantity that found a valorization stream, represented 94% of the quantity collected (6% went to elimination) (*Figure 21*).

[7] This note has been confirmed by a TV report (Envoyé spécial - Le recyclage des vêtements : de l'or dans nos armoires, 2014, https://www.youtube.com/watch?v=x5iKiOjhPI0)

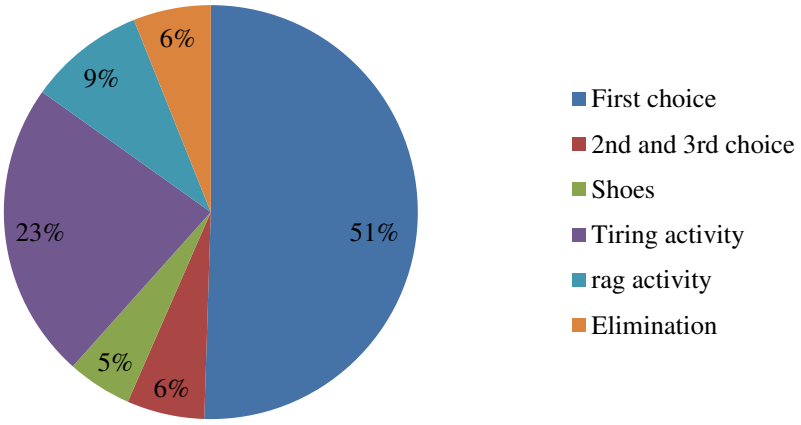



*Figure 21: Destination of the sorted cloths (Eco-TLC, 2013; Intertek et al., 2012)*

We can note that half of the volumes go for the reuse segment. The recycling industry benefits of 23% of the total volume. This corresponds in 2013 to an average of 33 000 tons, without considering exportation features.

#### 2.3.1.1.2 Professional clothing Industry

The "professional clothing" segment gathers actors such as Mulliez Flory or Cepovet who deliver products for an industrial use to companies, such as SNCF, La Poste, and other public or private organisms. It represents an average volume of 20 000 tons put, each year, on the French territory (estimation done through interviews). Today, the industry of professional clothing is not concerned by the eco-tax, compared to the individual clothing industry, even if the products are technically similar. However, the governmental trends and public concerns about environmental impacts drive these actors to consider potential regulatory evolutions. For instance, SNCF, as a public organism, made the decision, without constraints, to manage its End of Life textiles, and would require to its suppliers to have a recycling solution for the product they deliver. It is a new and increasing situation that professional clothing producers are facing. For example, today, Mulliez Flory (professional clothing market part 7,5% in 2010), witnesses an increasing demand for end of life solution when they deliver their product on the market (50% of the call for offer present this particular demand).

The situation of this market segment is quite different than the individual clothing industry. The volumes are more concentrated and are delivered at strategic logistic places. It is the case of the textile loaners, such as Elis, a leader on the French market. These companies provide a cleaning service for textiles, clothing or bedding, so they have facilities dedicated to this activity, strategically located on the territory; this means that there is a concentration of the waste before they are eliminated. However, based on industrial observations, these textiles are today, for the most, land-filled, reason why industrials are seeking for new possibilities, and cost effective solutions. This market is also very different from individual clothing, as it is much more based on mass productions, with lower product prices, and there is much less incumbents to share the market. It implies that if an eco-tax was defined, it could not be on the same bases than for the individual clothing industry, because for the same quantity of production, the margin cannot be compared, and the average eco-tax per company would be very high.

### 2.3.1.2 *Technical industry with complex system including textile ratio*

Depending on the specific industry that puts on the market complex assembled system, the European Union Directives and national regulations define particular targets for waste management, always in the mindset of the polluter pays principle. The following frame shows the various European and French waste categories supported by different types of organizations (such as eco-organisms or autonomous organizations). In order to limit the scope of this study, we will focus on the EoL vehicles in the automotive industry, but we can find categories such batteries, tires, furnishing (ADEME, 2011), on which we won't focus (*Figure 22*).

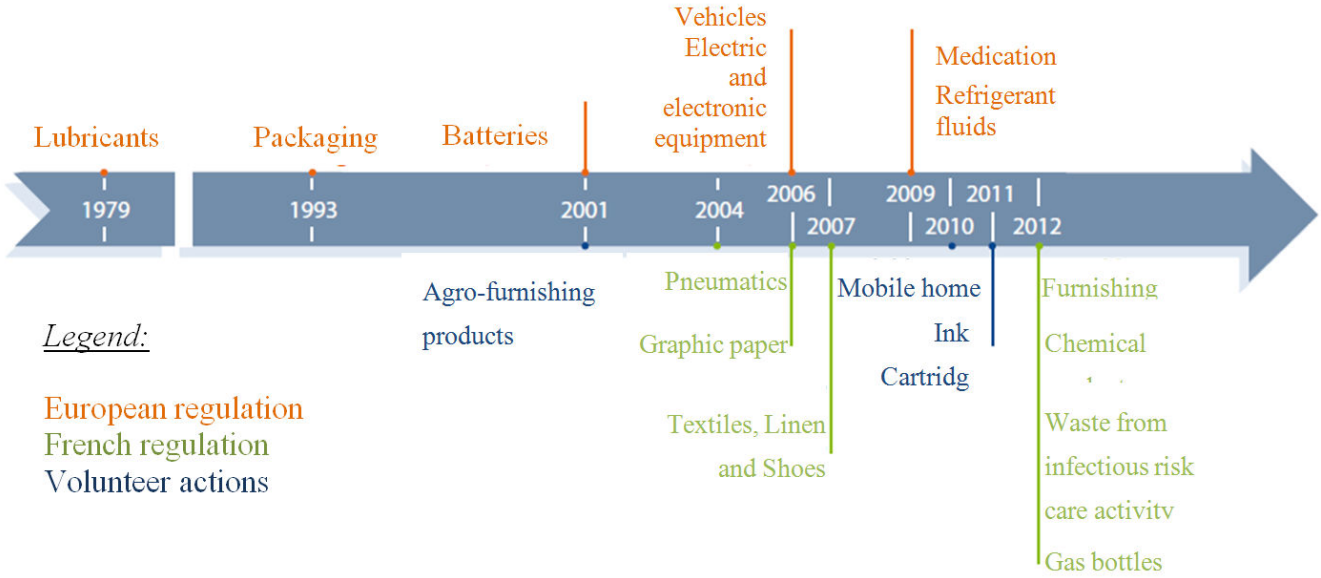



*Figure 22: Evolution of the regulation (ADEME, 2011)*

#### 2.3.1.2.1 EoL Vehicles: An European Directive

In Europe, annually, between 8 and 9 Million tons of wastes are coming from EoL vehicles. The first European Commission directive specifically on EoL vehicles was published in 2000, as the "EoL vehicles directive" (Directive 2000/53/EC). Before, it was the European directive on waste, of 1975, which was used. On the European Commission Web Site, we can find the following statement concerning the aim of the directive: "making vehicle dismantling and recycling more environmentally friendly, set clear quantified targets for reuse, recycling and recovery of vehicles and their components and push producers to manufacture new vehicles also with a view to their recyclability". The quantified target is 85% recycling and a 95% recovery (potential of 10% for energy recovery) for 2015.

In France, ADEME runs shredding campaigns to present the results of the EoL vehicles management system. In 2008, this report presents the rates of EoL vehicles wastes valorization: 79, 6% and 81%, respectively for recycling, and recovery (1,4% in energy recovery).

The art.2 of the Décret n°2003-727 (1st august 2003), defines the meaning of "producer" and states his obligations toward the supply chain. This article also points out that the main producers such as Renault and PSA, but that importers such as Fiat, Volkswagen, are as much concerned by the regulation. It is stated that each producer has to counterbalance, for the vehicles of his own brand, the cost encountered

by the waste management facilities, as the EoL vehicles taken back shall be free of charge for the consumer. It is also mandatory for the producer to work with the other economic key players in order to put in place EoL vehicles waste treatment supply chains. The legal order of the 27 June 2011 reinforces the previous laws, stating the responsibilities and obligations of the producer who is mandated to reach, with the recycling network implantation, the 85% and 95% on the required time scale (2015), otherwise there is a financial penalization by the authority.

We only propose here a short text in the scope of our study, focusing on EoL vehicles waste stream. However, it is important to keep in mind that all of the rules, obligations, information, in the domain of regulation, are complex, as much as their applications, in an environment for which the structure remains fuzzy. In fact, in his study, Gaucheron (2000) said that for a car to be commercialized, 85 European standards and regulations should be taken into account. Adding to that, he also highlighted the ambiguity of the regulations, as for instance, the automotive constructor has to put on the market a vehicle with a defined recycling rate, but on which basis? Indeed, a car model can be declined in various personal designs for which the material repartition is variable.

In response to the regulation, Gaucheron (2000) listed different behaviors that can be adopted by the companies concerned:

- Hostile behavior: ecological preoccupation is anti-economic, denying the issue
- Defensive behavior: recognize the environmental impact as a constraint and will assure prevention on a legal point
- Benevolent behavior: recognize the environmental issue as legitimate to the society and acts on its environmental impact
- Cooperative behavior: the wish of the company to pursue environmental targets and join voluntary action and communicate on its behavior
- Integrated behavior: the environmental requirement with the development of a competitive offer

For instance, Renault started its environmental consciousness in the beginnings of the 90', with a detached specialized department. It was also the time of the first public communications, and brought the key players around the environmental question and industrial engineering issues. This first step was concretized by the "framework agreement" of 1993, which, on a voluntary basis, encouraged EoL vehicles supply chain deployment, with a collective responsibility. The objective was to keep an economic freedom from the government mandatory measures, such as eco-taxes.

Today, Renault is still contributing to the EoL vehicles treatment supply chain reinforcement. The company created a joint venture with SITA (a company specialized in waste management), in order to meet the Waste Framework Directive requirements. The LIFE ICARRE95 (Innovative CAR REcyling 95%) project is also an important example of Renault ecological implication. The aim of the project is to review technical solutions to reach the Waste Framework Directive requirements, for EoL vehicles management.

In order to answer these objectives, projects are initiated by Renault to develop potential waste treatment solutions. For instance, ValVer (Glass Valorization, "Valorisation du Verre" in French) was a project focused on EoL vehicles glass valorization. Today, the project ValTex (Textile Valorization "Valorisation du Textile" in French) considers out of the light weight fraction of EoL vehicles; textiles and foams. With this description of Renault's action for the environment, we identify that the company

has global targets and develops competitive offers on specific project, so could be in both cooperative and integrated behavior classification.

#### 2.3.1.2.2 The reality of the EoL vehicles management system

Today, the automotive constructor is responsible for the vehicle put on the market. However, the textile products used in the vehicle (an average of 20kg per vehicle, 2 to 3%), come from their tier suppliers, who design these parts, based on strict specifications. Today, considering the vehicle as an assembled system, from our observations, the EoL consideration is not the priority of the constructor. However, they still need to be in accordance with the regulation and put on the market compliant vehicles.

In order to be able to claim the accordance with the regulation, the criteria should not be only based on technical recyclable material such as steel, PET, or textile, but it is also required to prove that it is economically feasible. Those economic studies are conducted by constructors, shredders or dismantlers, with ideal scenarios, which don't take into account the reality of the EoL vehicles market. For instance, Toyota tested the EoL scenario on 165 identical vehicles, and they presented a positive result (Presentation Comet/Toyota at the IARC). However, we understand that this 165 vehicle batch is not representative of what would really enter in an EoL vehicles center. Thus, in approximately 15 years (average life time of a vehicle), 80% of the EoL vehicles would represented at least 20 different kinds of models and brands (based on actual data). In this respect, the study on one single vehicle type is not accurate, nor representative of the EoL vehicles management reality.

Another fact; in Germany, not in the scope of the French market study, but highlighted because of its interesting illustration and transposable consideration to France, 80% of the vehicles are exported, legally or illegally in foreign countries. In this respect, even if the vehicles present on the territory could be recycled in the mandatory quantities (85%-95%), the affected result would have to be balanced with all of the EoL vehicles that would come out of the European recycling control, in Africa, Eastern Europe, and Asia, where recycling technologies are not developed.

From these two examples, we understand that automotive constructors are looking for justifications, but the studies pursued are not always representative of the reality. Today, we observe that the activities of vehicles dismantlers and shredders, are profitable activities (Presse et al., 2008), and that it is a growing market as the life time of the vehicle decreases as the number of vehicles sold increases. These activities are profitable especially because of the value from the steel or precious metals from catalytic conveyers that only require a shredding activity. However, the recycling of plastic (mainly polypropylene), or rubber is more complex, as it requires specific dismantling, sorting and chemical processing activities, that induce costs, that can be higher than the disposal cost of the material or the extraction cost of virgin resources. In this sense, except the Directive (that is today interpreted and justified by each constructors in his own way), nothing incite the EoL activities to put effort in reaching those requirements effectively and economically balanced, as their activities are, in the current state, profitable.

#### 2.3.1.2.3 EoL management for a car

Depending on the localization, the way to recycle a car is different. Indeed, there are 2 main strategies, supported by their industrial militants.

First of all, we can find what we call, the *all shredding strategy*. It is a way pushed by innovative shredding technologies and shredding companies (Comet, Ecore, Galloo) to reach the end of life European requirement (95% valorization in 2015). We can find an example with the ARN (Auto Recycling Netherland) organization, which proposes a complex shredding facility (IARC), economically balance using the eco-tax system in place in Netherlands. However, the results of those facilities are discussed and the output materials, from the light weight fraction of EoL vehicles, are low quality resources, eliminated by incineration, or used in the cement industry as a combustible (energy recovery).

The second trend is a balance between dismantling and shredding. It is still a question raised by the automotive constructors and the dismantlers. Some remain confident and others don't believe in the solution. But in both cases no relevant data can contribute to the objective answer to this question. Renault (IARC renault_fournier.pdf, 2014) with the French Dismantling Network, INDRA, proposed a presentation on dismantling studies on going. However, no relevant data were given on the economic balance between Post shredding treatment (Incineration/Land-field) and sorting the materials at the dismantling stage. However, we understand that these kinds of data are of interest for the constructors. Indeed, if shredders push toward "all shredding" solutions (the industrial tools are massive and required consequent investments), constructors are more open to these comparative studies, especially regarding their EoL recycling index.

For instance, BMW did a recycling comparative study on its new 100% electric I3, with a carbon composite vehicle structure (IARC). The use of carbon composite enables to decrease the global weight of the vehicle. The issue with the replacement of the steel parts, (higher percentage of recyclable raw material in a vehicle), is that the overall EoL vehicle recycling ratio decreases. To tackle this issue, and prepare the recycling of the future (carbon composite products), different studies on carbon composite recycling technologies are in progress (ITA presentation at NHPA). Today, the economical demonstration shows that the actual cost of carbon composite recycling (processing cost) is 5€/kg, against 2,5€/kg for aluminum raw material cost. BMW presented the project as a high challenge.

#### 2.3.1.2.4 Availability of the resource and comparative cost structures

Nowadays, there is no recycling of textile from EoL vehicles, except from marginal, low volume and non-industrial examples. The objective of the regulation is to recycle the highest possible percentage of textiles coming from vehicles. A vehicle weights in average 1,5 tons and there is between 2 % to 3 % of textile material. However, all of the textile materials are not reachable in the dismantling phase or the effort, and by extension, the cost would be too high. Moreover the identified materials should satisfy the specifications of the preparation process.

It is important to identify and categorize the textiles from EoL vehicles, based on adapted recycling stream. For the fiber opening process (see *Annex 6*), textiles such as airbags, seatbelts, acoustic pads, seat fabrics, have been identified to technically be recycled in order to make a RRM. However, the economic study and the available volumes, demonstrate that only the airbags and seatbelts could be valorized with the present state of the art technology.

We present, in *Table 4*, the example of the airbag dismantling.

| | France | Germany |
|---|---|---|
| **Deregistered vehicle / year (M)** | 1.8 | 3 |
| **Dismantling centers** | ≈1500 | 200 |
| **% going into dismantling streams (ADEME report)** | ≈85% (second-hand/ illegal exportation) | <20% (second-hand/ illegal exportation) |
| **Average quantity of airbags/vehicle (kg)** | 2.5 | 2.5 |
| **Average total potential quantity/year (tons)** | 3750 tons | 1500 tons |
| **Dismantling time (min)** | 1 | 1 |
| **Labor dismantling + packaging cost/vehicle (20€/60min)** | 0.33€ | 0.33€ |
| **Total material cost/kg** | 0.132€ | 0.132€ |
| **Land-filled cost (€/k)** | Between 0.06 and 0.12€ | ? |

*Table 4: Airbags dismantling in France and in Germany (From interviews)*

The comparison between France and Germany is relevant to understand specific influences on the value chain and the potential volume features. For instance, a great difference is based on the number of dismantling centers. In Germany the 1500 tons would have to be extracted from only 200 localizations, whereas in France, a logistic is required for 1500 localizations. This fact enhances the important issue of logistics versus volumes potentials.

### *2.3.2 Step 2: Fiber preparation study, the Tiring activity in France*

In the resource preparation study, we observe five possible waste management processes based on the Regulation Waste Management Scale (From Reuse to Dumping). Indeed, depending on the waste stream, the activity of Preparation of the resource in order to obtain the usable resource (the RRM in the case of the recycling stream) is a combination of different sub-activities that will be specific for each stream. We can find, for instance, the sub-activities of dismantling, sorting or shredding, which are the most common. But we could imagine an activity of cleaning, drying, in order to obtain the usable resource for the manufacturing of the recycled product. All of these successive sub-activities should be optimized by the study of the preparation activity cost structure. This study corresponds to the analysis of the Exploitation Conditions, considering also new machine investments that bring another player in the game: the "Specific equipment Supplier" (see *Figure 23*).

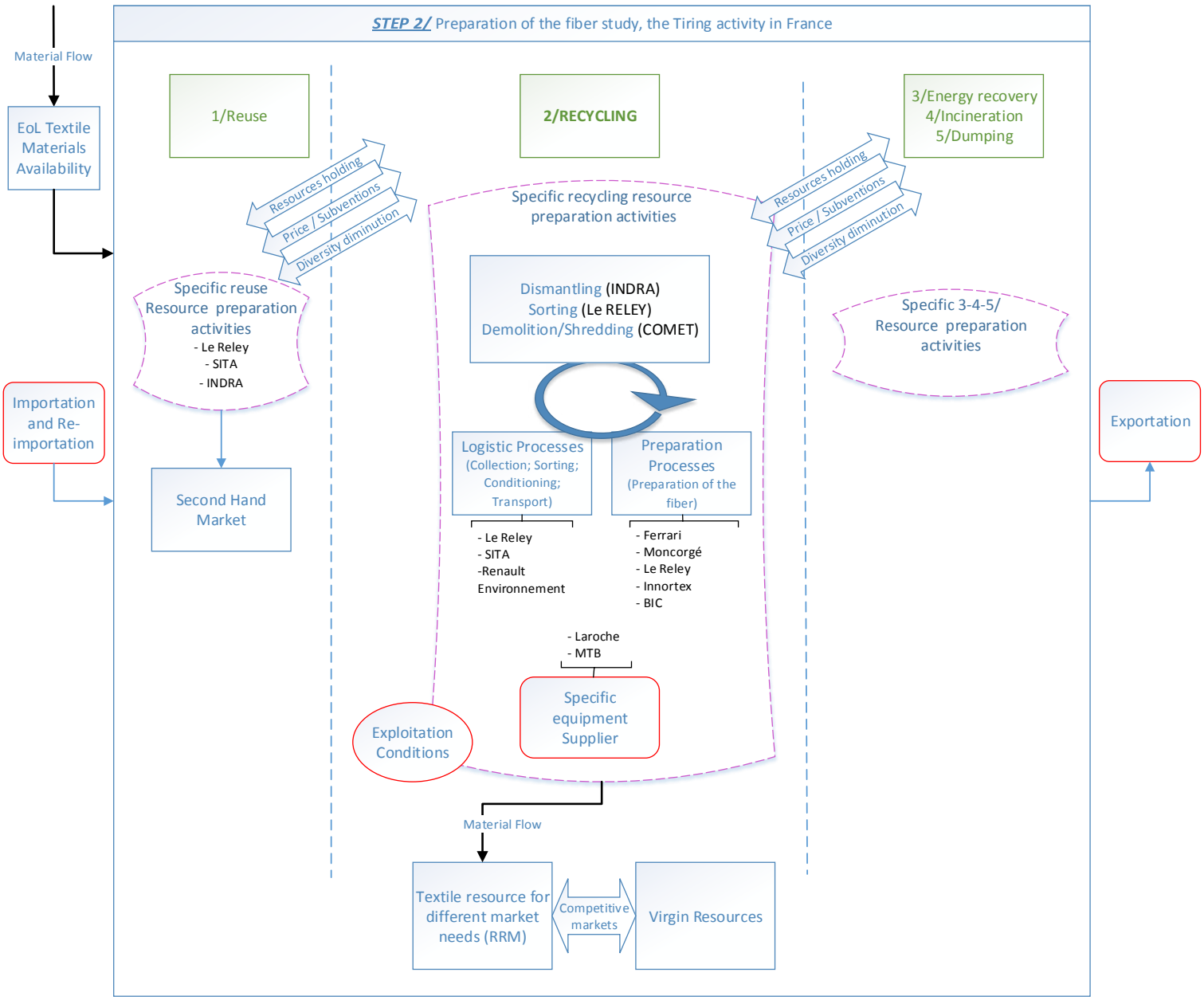



*Figure 23: Preparation activity study*

We have already noted that the EoL textile material availability for the personal clothing industry represent in 2013, 143 500T. However, only 23% (see *Figure 21*) of this total volume is treated by mechanical opening, which is to say 33 000T. But only 35% stays in France to be recycled which makes a total of 11 500T (due to exportation).

The tiring activity is an old and historical activity. Even if the evolution of the machinery enables to obtain better production, the basic technology remains the same. Two principle actors and competitors are present on the market, one near Lyon and one near Lille. The quantity they can produce per day varies per machine between 3-5T/h. With these data we understand that the recycling in France requires no more than 2 tiring machines, for which we can estimate the investment cost between 2-3M€.

Nowadays, these existing activities recycle production residue, coming from jeans or other fabrics with mainly cotton fibers. Depending on the opening process (see *Annex 6*) the production cost varies between 0.3€ (garments) and 0.7€ (seatbelts) per kilogram.

### *2.3.3 Step 3 and 4: Applications for recycled fibers, the product manufacturing activity study and the market study*

Studies have been done on the volume used in the recycled products. We have seen that in 2013, 11 500 tons of post consumers garment textile products were destined to the mechanical recycling industry in France through the tiring industry. This type of material is commonly used in the production of nonwoven products through 2 main technologies (Airlay and Carding machines, see *Annex 7*). It can be applied to different sectors such as the automotive industry (potential of 10 000 tons/year RRM absorption by the automotive industry in France; Intertek), but also for habitation isolation materials (to replace fiberglass), or in geo-textile products. *Figure 24* highlights the technological solutions and the identified actors (step 3) to manufacture the textile recycled product. Step 4 presents the application fields where these solutions can be applied. For instance, Federal-Mogul, as a nonwoven manufacturer, could apply its technology to different market defined by applications, such as in Insulation, Composite, or Geotextiles use.

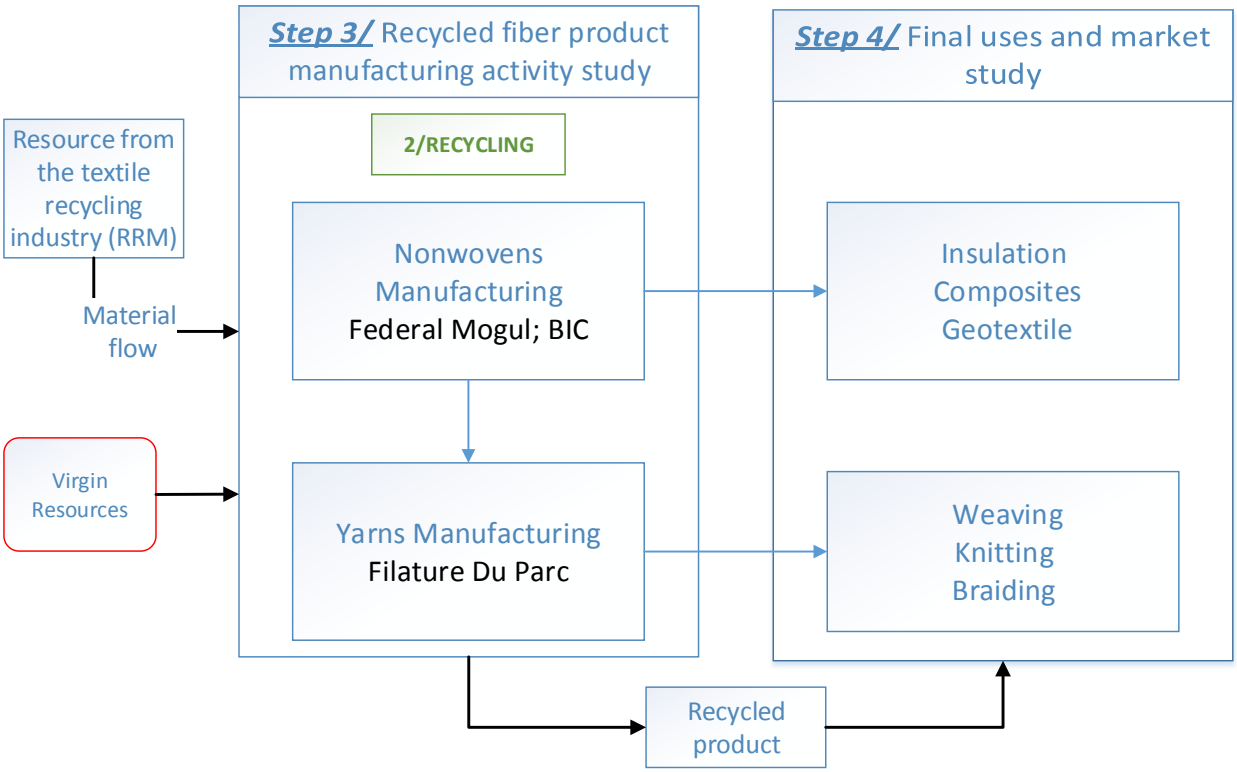



*Figure 24: Specific feature of step 3 and 4*

In the housing sector, the eco-organism (Eco-TLC) supports the development of an application. However, we understand that the price for the resulting product (4€/m²) is 3 times higher than a regular fiberglass insulating products, which makes it difficult to compete on the market based on the only

economic stand point. However, new constructions could absorb a great part of the recycled resource. The volume produced in 2012 is situated between 1500 tons and 2500 tons (between 14% and 23% of the available resource).

In the automotive sector, we observe contradictory behaviors. When interviewed, automotive constructors seem reluctant to use post-consumer textiles because of hygiene and health issues, but also because of heterogeneity issues, such as the material structure or color. However, it is an historic activity in Europe to use recycled fibers for sound insulating products in cars (*Figure 25*). For instance, a main actor, Autoneum (formally Rieter), an automotive Tier, possesses his own fiber reference for the automotive insulating product from recycled textiles.



*Figure 25 : A Photo of a Megan-Renault under-carpet trunk, a sound insulating application*

### *2.3.4 Step 5: studies synthesis*

Steps 1 to 3 enable to follow the potential RRM flow that contributes to the textile RSC definition. Each step possesses its own exploitation conditions, with, in step 1 the extraction cost of the RRM, in step 2 the preparation processing cost and in step 3 the product manufacturing processing cost. Each step should be cost down with the evaluation of each activity needs. But also, the value function to achieve by design engineering for the manufactured product should be high enough to support all of these aggregated costs to be compared to the market price. In the other way, the early definition of the market need (volume; functional specification of the product) can lead to an early supply identification, which, at an initial stage, would be considered as adapted to the need. Further design work, such as presented

in §2.2.3 that requires a flexibility of this activity, can be pursued to adapt the initially selected RRM to the product specifications. The design technical limits enable to present the final cost structure of the new recycled product and analyze how its economical equation behaves on its new market.

## *2.4 Discussion and Conclusion of the chapter*

The aim of the FTRI structure analysis is to highlight a new environment. Driven by environmental objectives, we highlighted the evolution of the consciousness considering the need to recycle more in an eco-effective way (see *Figure 12: Comparison of eco-efficiency and eco-effectiveness* in §1.2.3.2). Thus, for industrials, understanding the functioning of a recycling industry becomes primordial when willing to adopt greener practices. Independent on its RSC positioning, the business should understand how the recycling environment is ruled.

The overall conclusion is that this industry, because of its emerging character, is quite tedious to analyze. However, the conducted observations based on our research method (see *Figure 5*) present a general photography of the specific FTRI structure, with the main recognized inputs. Although, because it is a dynamic mechanism, with its different parameters (regulation; virgin raw materials costs; technologies; waste land-field costs), it remains a punctual visualization. Moreover, as observed, because businesses intend to position themselves on this new RSC (example: garment loaners such as Elis), this competitive environment remains secret. The difficulties to understand these businesses vision of the FTRI, refrain the conduction of such an analysis.

In this research, we presented how to understand the conditions for a RSC development (Value Function; Exploitation conditions; Market price). In our research scope, we are particularly looking for the development of EoL textile recycled product and its associated RSC. We believe that existing applications could enable to replace post production textile waste (historical known activity for the automobile, using mainly cotton jean fibers) by EoL textile waste, prepared by specific tiring activities. However, this use of EoL RRM remains secret among industrials, and this supply is generally not presented as coming from wastes when commercialized. Thus, EoL still has a bad reputation, and is considered as a risk to use in new products. This is the reason why such new RSC success is complicated to witness. The new RSC observed, based on this model from EoL individual garments, supported by Eco-TLC, proposes a product that is not competitive if only the economic equation is considered (situation VF<Price see *Figure 19*). Only activist markets or subventions, which promote ecologic behaviors, could counterbalance this situation.

The 5 steps' method we propose is based on Porter's value chain analysis concept; however, it is adapted to the specific recycling industry that highlights its originality. We can observe how each step is linked to another (see *Figure 17*), which emphasize the iterative aspects that contribute to the emergence of the value chain. We understand now the complexity of such studies, recycling environments are fuzzy, unorganized, thus difficult to analyze. But regarding growing environmental consciousness, we believe that such studies should be more and more undertaken by businesses. Indeed, they may find their motivation in sustainable development and specify it in their strategies, in this respect looking for "green" solutions might bring them to more frequently consider recycling as part of their activities.

# *CHAPTER 3: PROPOSAL OF AN INNOVATION PROCESS MODEL FOR RECYCLING INDUSTRIAL ACTIVITY DESIGN: RSCDP*

The literature review over Eco-design and Supply Chain design, shows that the only phase, where the entire supply chain is considered, is when the product is designed (Tsoulfas and Pappis (2006). A new RSC (Recycling Supply Chain) and the new product, manufactured by this RSC, should be designed simultaneously. However, we observed that there is no existing method enabling to guide industrials in the definition of such a "recycling collaborative project" that could open new business opportunities in the recycling industry.

Our focus is on the definition of both the innovative RSC and its product. Hence, the RSC is designed with a "product driven" approach. Indeed, the object of our study is not only attached to the development of an innovative recycled product but also to develop a new industrial RSC.

Borchardt et al. (2011) relate that "the relationship between eco-design and reverse logistics practices for the reuse of material and packaging must be investigated as well." It is what we will intend to do by taking into account EoL materials (Pagell et al., 2007).

In this study we consider a specific eco-design strategy that is the introduction of Recyclable Raw Materials (RRM - from end-of-life products) in a new recycled product. We propose to implement this strategy with the concurrent design of the recycled product and its recycling supply chain, by considering the environmental aspect. Regarding our different observations, we highlight the guidelines that should be implemented in a specific concurrent design process.

New regulations, in competitive environments, bring organizations to work on common recycling collaborative projects and to introduce differentiated products on the market. Indeed, the European Union straightens its objectives regarding waste management (The European Parliament, 2008). For instance, producers become now responsible for the products they deliver on the market, until the end-of-life (disposal phase of the life cycle) of these products. A control of effective results and improvements is conducted by the European Commission (Falkenberg and Director-General of DG Environment, 2012) that enhances the enforcement of the regulation and the industrial preoccupations. In this context, guidelines are given to companies to improve their environmental impact, with, for instance, the standard ISO 14062, for Eco-Design (Grisel and Duranthon, 2001), or the new Circular Economy thinking trend (Commissariat General au Developpement Durable, 2013; McDonough and Braungar, 2002).

The consideration of these guidelines by industrials, communicated by governmental institutions, favors, in the scientific area, the study of new eco-design tools. Indeed, the number of publications on the topic of eco-design considerably increased between the year 2000 and today, which reveal the new growing scientific interest (Reyes et al., 2013). Luttropp et al. (2006) also enhance the implication of environmental concerns into New Product Development (NPD), and provide the "Ten Golden Rules". These guidelines, or rules, remain general features, with no practical implementation method (procedure or process) that could be applied by industrials.

In this respect, a gap remains between the development of eco-design tools, and the implementation of environmental design processes (Brezet, 2001; Lindahl, 2006). This implementation issue has been addressed by Le Pochat et al. (2007), proposing that environmental assessment and improvement tools should be integrated in the product development process both during the conceptual design phase (also referred as "early design phase") and the detailed design phase.

Moreover, even if regulation is considered by many authors as a direction for the industry, industrials consider that "no external factors other than economic or legal could influence the implementation of eco-design in a company" (Borchardt et al., 2011). Subramanian et al. (2014), points out that in China for instance, that "firms are unlikely to embark on reverse logistics operations without external factors such as strict government legislation". To face economic challenges of applying environmental regulations, in competitive environments, organizations work on common recycling collaborative projects to share development costs and risks linked to major industrial changes (Calamel et al., 2012; Sarasini, 2014). For instance, the 7th Framework Program (2007-2013) of the European Union, dedicates funds for such collaborative projects.

In the literature, "Environmental Assessment" and "Environmental Improvement" (Le Pochat et al., 2007), are integrated in the Product Development Process at the Conceptual and Detailed Design phases. However it is done from a theoretical viewpoint, it remains a conceptual model, meaning that it only gives directions for the use of environmental tools and presents the main features, but not how they are organized. In another study, Luttropp et al. (2006) illustrate the implication of environmental concerns into new product development, even though this "piece of cake" (Luttropp et al., 2006) enables to consider new product development with environmental concerns and gives guidelines; it does not show the way to achieve the implementation of environmental practices.

We define an operational model, as a support for project managers, which should be followed step by step and with iterative feedback loops, each step being supported by specific environmental tools. The most used model to support innovative processes in an operational way is certainly the Stage to Gate Model developed initially by Cooper (2008b). It enables to define the project orientation and deliverables, and to structure the project phases, from idea to product launch.

In this respect, we studied three specific recycling collaborative projects, to identify the best industrial practices. Two of the projects were supported by the "French Agency of the Environment and the Energy Management" (with dedicated funds) called ValVer (for the end-of-life vehicle glass recycling) and ValTex (for the end-of-life textile recycling). The third studied project was performed in the USA, considering end-of-life cardboard for the development of a new recycled product. Regarding these successful projects, we pointed out that not only new recycled products were developed, but also their associated recycling supply chains (see *Figure 4*).

## *3.1 Proposal of a method*

For our contribution, we propose to model the specific Recycling Supply Chain Design Process (RSCDP) using the stage to gate principles. This process is developed, based on industrial feedbacks, active collaborative project participation and a literature review about environmental best practices (see *Figure 5*).

The analysis of the literature review and the industrial feedbacks study lead to determine the key guidelines that should be used for the design of a RSC. These guidelines will be implemented in the proposed Recycling Supply Chain Design Process (RSCDP). These guidelines are:

| Guidelines for a recycling collaborative project construction | Sources |
|---|---|
| A supply chain approach from the RRM extraction to the Disposal of End-of-life products (with the particular consciousness of a complex logistics) | From the literature: (Linton et al., 2007; Pagell et al., 2007; Tsoulfas and Pappis, 2006)<br>Industrial feedbacks from the observed projects and meetings (ValTex; ValVer and the congress attendance) |
| The importance of the early design phase, where many product features are positioned. | From the literature: (Kengpol and Boonkanit, 2011; Le Pochat et al., 2007; Mascle and Zhao, 2008; Sherwin and Evans, 2000) |
| A collaborative project for sharing industrial skills and technologies | From the literature: (Calamel et al., 2012; Sarasini, 2014)<br>Industrial feedbacks from the observed projects and meetings |
| A recycled product oriented approach for the design of a RSC, which corresponds to an innovative recycling activity (market pull and technology push approach) | Industrial feedbacks from the observed projects and meetings |
| Consideration of the environmental regulations and more specifically the toxicity of the RRM | From the literature: (Borchardt et al. 2011; Luttropp et al. 2006)<br>Industrial feedbacks from the observed projects and meetings |
| Emphasis on the importance of the project partner selection | From the literature: (Akamp and Müller, 2013; Fahimnia et al., 2015; Hsu and Hu, 2009; Igarashi et al., 2013)<br>Industrial feedbacks from the observed projects and meetings |
| Opportunity to seek for financial helps from governmental funding systems, which support environmental challenges | Industrial feedbacks from the observed projects and meetings |

*Table 5 : Guidelines included in the RSCDP construction*

To put these guidelines into practice, we propose an original guide for a recycling collaborative project definition.

*Figure 26* represents our overall approach considering concurrent design of the Product (P.) and the Supply Chain (SC.), on the 3 stages (Strategic study; Project opportunity study; Project management). Moreover, the first two stages are considered at a conceptual design phase, whereas the third phase corresponds to the detailed design phase.

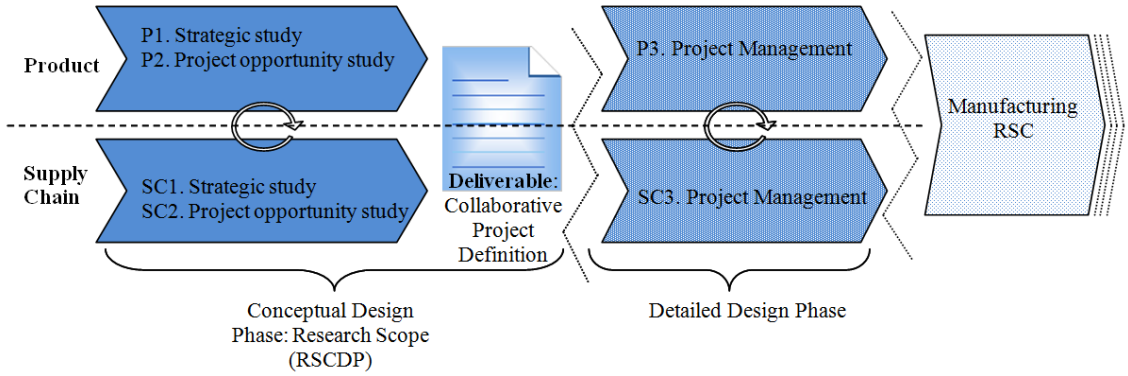



*Figure 26: Positioning of the research scope based on the RSCDP stages*

In this sense we propose a RSCDP for the definition of a recycling collaborative project. This collaborative work aims at designing an innovative RSC and its associated recycled product (the products are designed with recyclable raw materials issued from end of life products). In the following sections we define the project definition process, which should open the way towards a new recycling activity and responds to a company strategy.

### *3.1.1 Overview of the model*

This research enables to analyze the elaboration of an innovative Recycling Supply Chain (RSC), for which every strategic decision is made. The objective is to take into account the environmental best practices in order to propose a green RSC. This innovative RSC is designed by considering experience from green supply chain management and the eco-design practices using the stage to gate process principles (Cooper, 2008a). Our study focuses on EoL products that should provide Recyclable Raw Materials (RRM) that can be used in the composition of the new product. At the beginning of the project, the pre-identified RRM are land-filled, no organization is in place to recycle them, and the projected RSC does not exist.

A main strength of the RSCDP is that it is developed in parallel of a complex industrial recycling collaborative project (ValTex; see *Figure 4*), taking into account each step of its deployment. In this sense we were able to analyze the degree of success of various actions during the project deployment, and to analyze the project backgrounds and elaboration. In this respect the model relays on the identified best practices that must be taken into account, to go from, one stage to another, and adapted to the selected project. The industrial objective is to obtain an adequate and simple method and tools in order to facilitate the elaboration and management of such projects. The aim is also, by this method, to favor, this project type, success potential. The success could be than measured, considering the value that is created and the environmental solutions proposed. For the formalization of the model, the software Microsoft Visio is used. The process terms such as “go”/”no go”/”rework”, is the semantic employed in new product development and appropriated to this model.

The process is decomposed into stages, steps and activities. We propose to give details about the RSCDP, continuously as a step by step method with its five activities, organized in three stages:

- Stage 1: Strategic study

This first stage is divided into 2 steps and is initiated by the industrial strategy of a business. The first step is the study of a collaborative project opportunity study [1.1], identified as strategic by the company. Afterwards the product opportunity study [1.2] will initiate predefining the architecture of the collaborative project.

- Stage 2: Project opportunity study

The architectural definition of the project continues but in an external oriented study with step [2.1] and the formalization of the preliminary RSC scenarios. When both the Product and Supply Chain studies are finalized, the step [2.2] allows elaborating the collaborative project document of work.

- Stage 3: Detailed Supply Chain Design

The document of work obtained in stage 2 will enable to start the project and present a roadmap for the project coordinator. In this step various specific studies are organized such as: the detailed toxicity study considering REACH European Union Directive (REACH / Regulatory Framework for the Management of Chemicals, Regulation N°1907/2006 of the European Parliament and of the Council of 18/12/2006); detailed process definition; recyclable raw material selection and characterization; development of mathematical models for logistic optimization; Life Cycle Analysis study.

In the scope of our study, as a matter of focus, we did not go into the details of this stage of the RSCDP that we consider rather as usual engineering activities. The innovative and risky part of this project that is not supported by any structured method relies on the early design phase that is the focus of our research work. However during the PhD period, we have led studies concerning the detailed SC design phase (see *Figure 4*). The RSCDP is supported by 4 figures and 4 tables to follow the process. The figures organized as following ( *Figure 28*):

*Figure 27: Overview of the RSCDP*

**(2nd Stage)** *Figure 31: RSCDP second stage: Project opportunity study*

**(1st Step of 2nd Stage)** *Figure 32: RSCDP 1st step 2nd stage: a recycling supply chain approach*

*Figure 28: Organization of the figures*

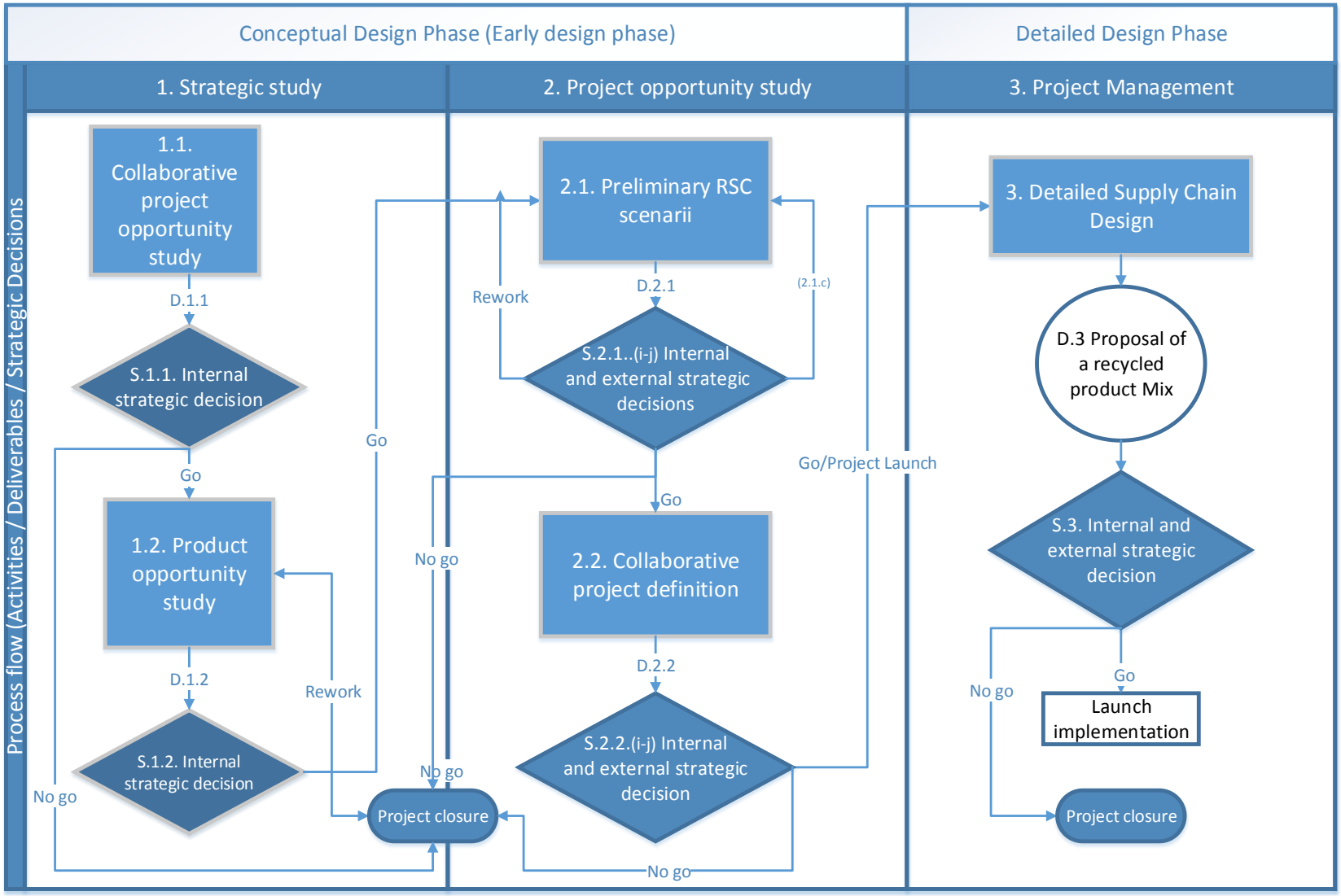



*Figure 29: Overview of the RSCDP*

At different levels the details of the process are proposed. Especially for the 2nd stage, we present the details of the first step for a matter of understanding the organization between the activities. The

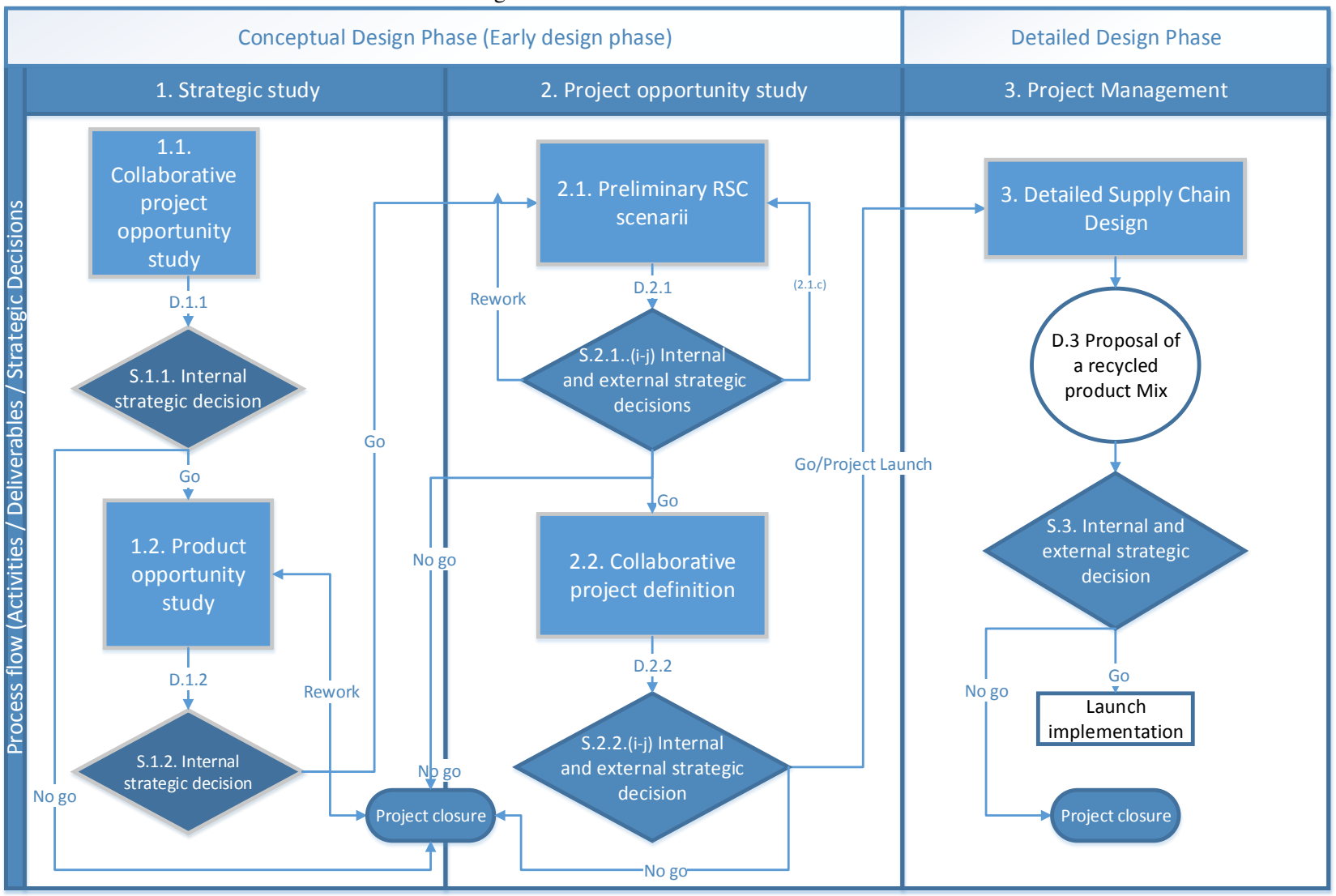



*Figure 29* presents the overview of the model:

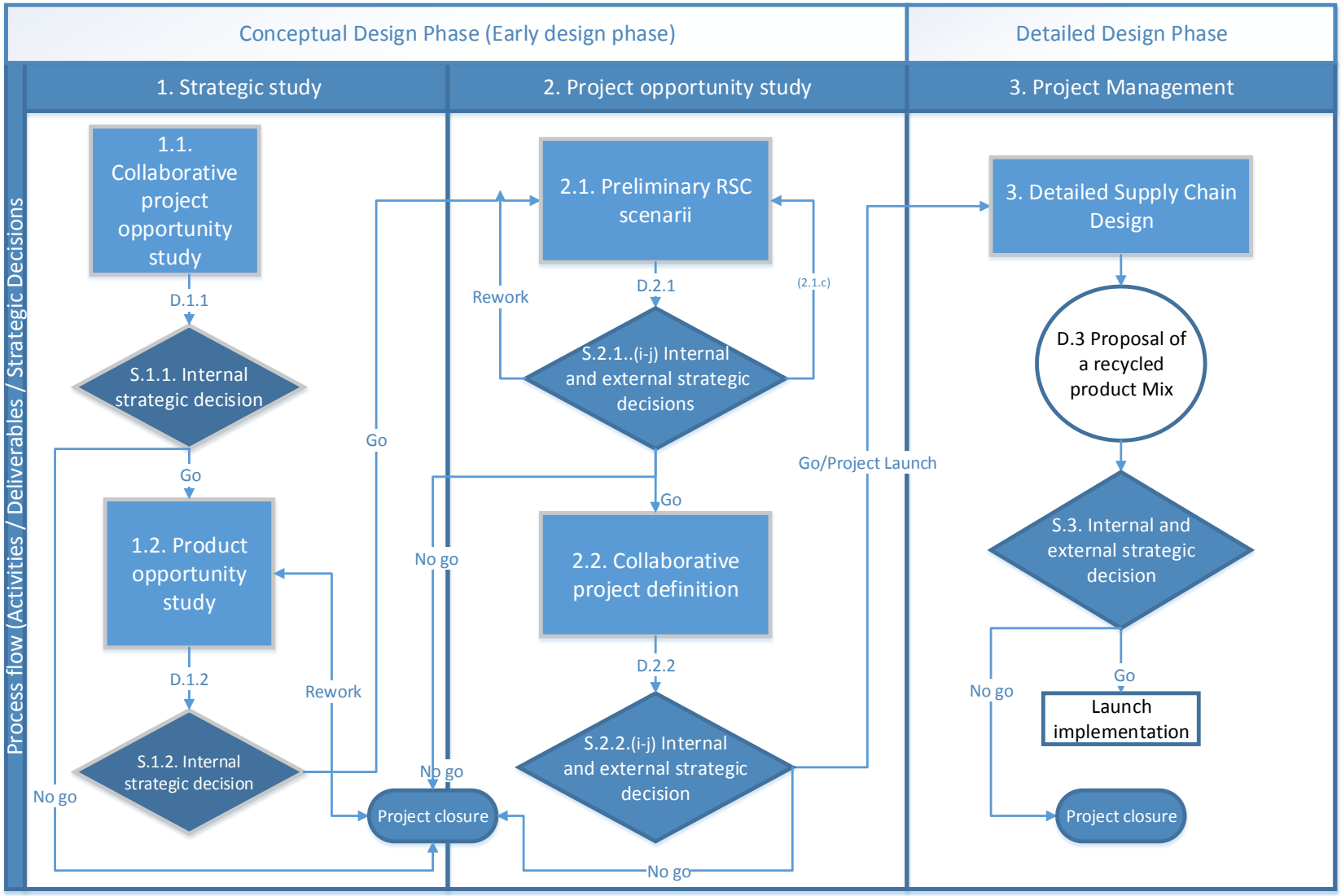



*Figure 29: Overview of the RSCDP*

### 3.1.2 First Stage [1]: Strategically assess the company industrial plan

Stage [1], "strategic study", is divided into 2 steps: "collaborative project opportunity study" [1.1] and "product opportunity study" [1.2]. In this sense the decision to elaborate a collaborative project is made at a strategic level of the organization, as well as the decision to design a recycled product (part of the eco-design strategy to pursue).

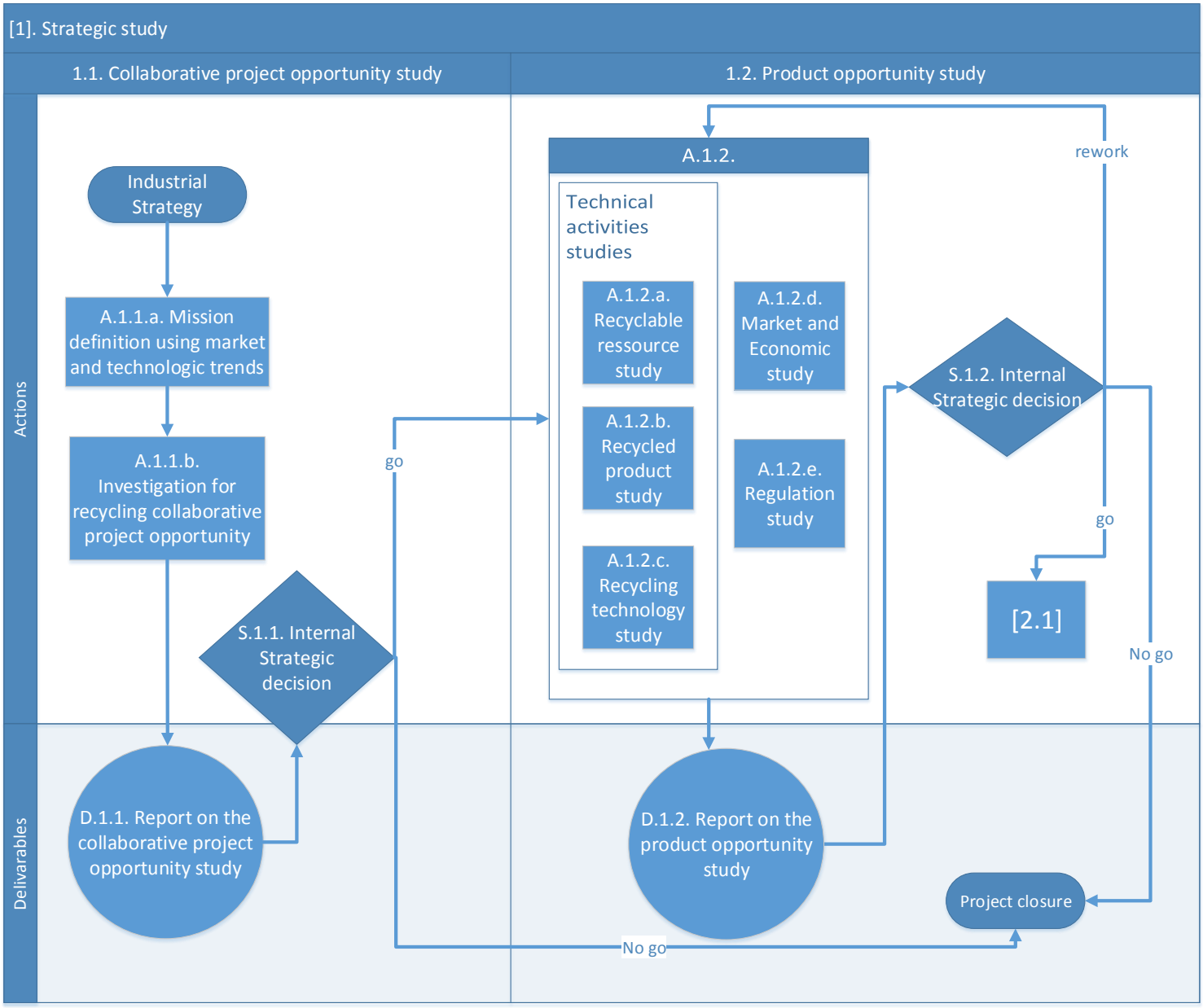



*Figure 30: RSCDP first stage: Strategic study*

### 3.1.2.1 First step [1.1]: Collaborative project opportunity study

The step [1.1] is composed of two activities (*Table 6*).

| Step | Activity | Deliverable | Strategic Decision | Title |
|---|---|---|---|---|
| [1.1]: Collaborative project opportunity study | [A.1.1.a] | | | Mission definition using market and technologic trends |
| | [A.1.1.b] | | | Investigation for recycling collaborative project opportunity |
| | | *[D.1.1]* | | *Report on the collaborative project opportunity study* |
| | | | **[S.1.1]** | **Internal Strategic Decision ("go" to next step [1.2]; "no go")** |

*Table 6: Stage [1]: Strategic study – First step*

The first two activities "mission definition using market and technologic trends" [A.1.1.a] and "investigation for recycling collaborative project opportunity" [A.1.1.b], included in this first step [1.1], enable to assess the opportunity for a recycling collaborative project (see *guideline n°3)*

The initial activity [A.1.1.a] ("mission definition using market and technologic trends") comes from the industrial strategy, meaning that [A.1.1.a] is a tactic, from the strategy, to favor innovation and alternative solutions. [A.1.1.a] is the activity of elaboration of the mission, with its definition (mission definition), considering a collaborative approach in perspective with the market and technologic trends. The strategic (or steering) committee elaborates this mission definition with its given scope, and assigns the mission to the suitable department(s) (R&D; Sales…). The decision to lead this activity means that a first idea, impulsion, has been identified and requires more investigations. The conduction of this activity means that there is a potential interest in using RRM (Recyclable Raw Material) into innovative products as a way to answer the company strategy, but neither the product, nor the RRM are precisely identified yet.

[A.1.1.b] ("investigation for recycling collaborative project opportunity"), is the conduction of the mission defined in [A.1.1.a]. The selected actor (or department) in [A.1.1.a] achieves the mission by an initial market opportunity study. This actor also initiates discussions with potential partners, with a collaborative project mindset and an approach of RRM use, for new product development.

In the end, this activity leads to the "Report on the collaborative project opportunity study" [D.1.1], with the identification of potential markets and technologies. [D.1.1] should propose arguments of interest to pursue the RSCDP, for a presentation to the strategic committee. [S.1.1], the "internal strategic decision", corresponds to the decision made by the strategic committee, either to continue ("go") the process (the RSCDP) to the next step, or to close the project ("no go" that means "project closure").

#### *1.1.1.1 Second step [1.2]: Product opportunity study*

The second step regroups five activities (*Table 7*). If the decision is to initiate the step [1.2], the strategic group will assign each activity to the appropriate department(s) (R&D; sales; marketing…) depending on the internal organization of the company.

| Step | Activity | Deliverable | Strategic Decision | Title |
|---|---|---|---|---|
| [1.2]: Product opportunity study | [A.1.2.a] | | | Recyclable resource study |
| | [A.1.2.b] | | | Recycled product study |
| | [A.1.2.c] | | | Recycling technology study |
| | [A.1.2.d] | | | Market and economic study |
| | [A.1.2.e] | | | Regulation study |
| | | *[D.1.2]* | | *Report on the product opportunity study* |
| | | | **[S.1.2]** | **Internal Strategic Decision ("go" to next step [2.1]; "no go"; "rework" this step [1.2])** |

*Table 7: Stage [1]: Strategic study – Second step*

This step simultaneously considers three domains which are: technical, marketing and regulatory (see Activities [A.1.2.a-e] in *Table 7*). These activities aim at providing the initial chosen product definition, with Recyclable Raw Material (RRM), recycling process, potential market demands and regulatory concerns. The conclusions of these activities are reported in [D.1.2] "report on the product opportunity study".

The technical aspect is divided into three activities: [A.1.2.a] the "recyclable resource study"; [A.1.2.b] the "recycled product study"; [A.1.2.c] the "recycling technology study". [A.1.2.a] focuses on the potential end-of-life products that could be used as recyclable resources (or RRM) and be introduced in a new recycled product. [A.1.2.b] is the study of potential products that could use the RRM potential supply, but considering also the global company's new product development strategy. The activity [A.1.2.c] links the first two ("a" and "b") by the study of the potential recycling technologies to transform the end-of-life products into RRM. This activity focuses on the feasibility to recycle end-of-life products, in order to satisfy the new recycled product material specifications. The three activities are transverse and must be approached with a simultaneous engineering vision. If a potential RRM is identified (from end-of-life products), both the question of the use for a new recycled product development and the feasibility of recycling activity must be considered.

The activity [A.1.2.d] (“market and economic study”) stands for the preliminary marketing study. [A.1.2.d] is run simultaneously with the technical studies previously described. If the product has no potential market (neither existing, nor innovative), it is not advised to pursue a long study. The conduction of this activity may contribute to the identification of an application (and a potential recycled new product definition) for the use of RRM.

This simultaneous approach (technical / market) is proposed based on industrial feedbacks (mainly from the active group discussion “club textile”). Indeed, an observation, that enables to justify *guideline n°4* is that for end-of-life waste valorization, a company must consider jointly the potential market and a potential new recycled product. Running a long study on the recyclability of the end-of-life products into RRM, without marketing targets and specifications, is not recommended, as the new RRM might not find an application. The question that should be raised for the activities is: which product can be manufactured out of the waste and under which specifications the RRM must be prepared? In this respect, the simultaneous approach in the RSCDP we propose, aims at avoiding useless studies.

In parallel to the previous considerations, regulatory issues should be taken into account at an early stage (conceptual design phase) with the activity [A.1.2.e] (“regulation study”). Indeed and especially observed in Europe, the waste management is at the time of our study, a primary issue. The company which initiates the RSCDP (that we call in the paper the “initiator company”), must understand the waste strategy (in Europe for instance), be aware of the global directions and potential funding helps to run studies on the topic.

At the end of the five activities of this step [1.2] (“product opportunity study”), the “report on the product opportunity study” [D.1.2], is delivered to the strategic committee. The “internal strategic decision” [S.1.2] presents whether the conclusions of the joint studies are favorable (“go”) to pursue the RSCDP or if the opportunity study requires more work (“rework” to the beginning of the step [1.2]) or if the conclusions are definitely invalidated (“no go”).

A validation (“go”) by the strategic committee implies that both a collaborative project and a new recycled product development are considered as potential opportunities, for the company, to develop the environmental strategy. The stage [2] “Project opportunity study”, is then engaged. During the meeting [S.1.2], the strategic committee assigns the activities that compose stage [2]. At this point the company has a functional specification of the product to be designed and first market orientations to sell this product.

### *3.1.3 Second Stage [2]: Project opportunity study*

The second stage [2] concentrates on the “project opportunity study” and is divided into two steps, the “preliminary RSC scenarios” [2.1] and the “collaborative project definition elaboration” [2.2]. We present a general view of [2] with *Figure 31* and focus on *Figure 32*, on the decomposition of the step [2.1] that concerns the definition of the preliminary RSC scenarios for a better presentation of the activities’ articulation.

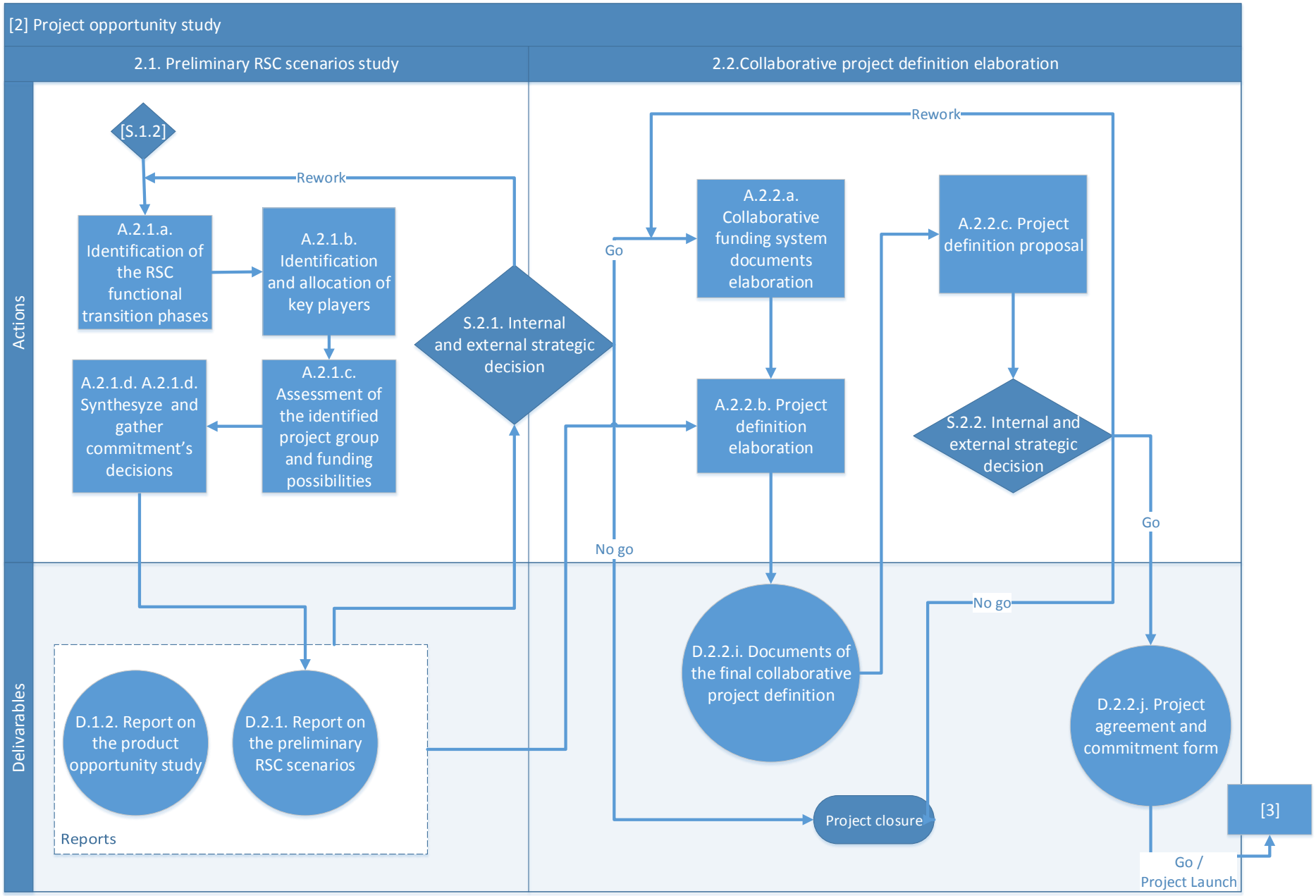



*Figure 31: RSCDP second stage: Project opportunity study*

After the decision [S.1.2], from the previous step, to follow the RSCDP, the first step [2.1] concentrates on the RSC collaboration approach study. This step is composed of three activities, detailed in §3.1.3.1 and delivers a "report on the preliminary RSC scenarios" [D.2.1]. Based on this report [D.2.1] and on report [D.1.2] (from the previous step [1.2]), the strategic committee (internal strategic decision) and the potential project partners (external strategic decision) decide on the direction to follow, represented by the arrow "rework" back to the beginning of step [2.1], the arrow "no go" to the project closure, or the arrow "go" to the step [2.2] ("collaborative project final definition elaboration"). The step [2.2] with the activities "collaborative funding system documents elaboration" [A.2.2.a] and "project definition elaboration" [A.2.2.b], permit to elaborate the collaborative project proposal with the report [D.2.2.i]. This report is considered by the strategic committee of the initial company and by the external partners. If the proposal is accepted (arrow "go") the process leads to the signatures by all parts to a "project agreement and commitment form" [D.2.2.j] and the recycling collaborative project is launched. But at this point the proposal can be rejected (arrow "no go") or reworked (arrow "rework").

#### *3.1.3.1 First step [2.1] of the stage [2]: The Preliminary RSC scenarios*

The step [2.1] ("Preliminary RSC scenario study") aims at focusing more on the recycling supply chain aspects in order to define the preliminary RSC scenarios (*Figure 32* and *Table 8*).

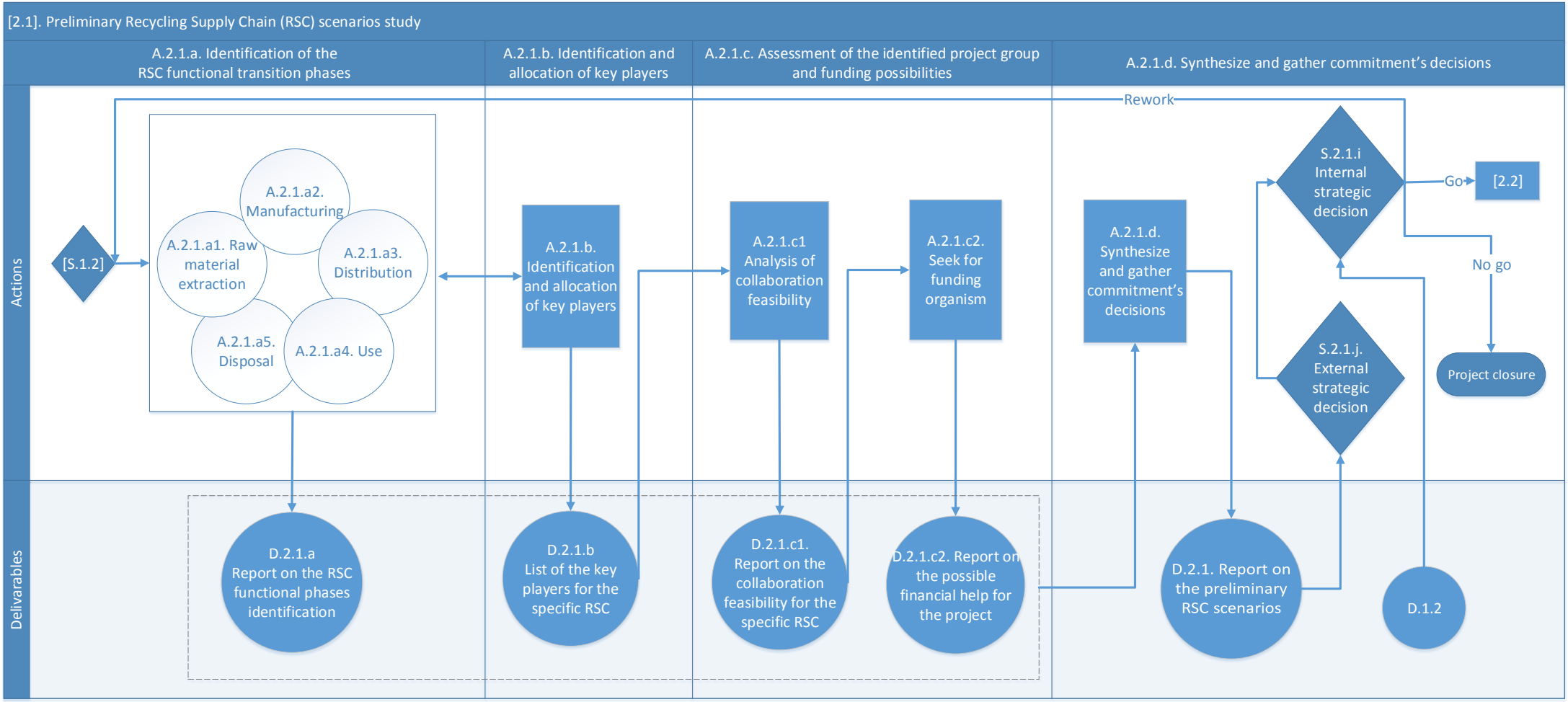



*Figure 32: RSCDP 1st step 2nd stage: a recycling supply chain approach*

| Step | Activity | Deliverable | Strategic Decision | Title / Description |
|---|---|---|---|---|
| [2.1]: Preliminary RSC scenarios study | [A.2.1.a] | | | Identification of the RSC functional transition phases (including a1 to a5) |
| | [A.2.1.a1] | | | Raw material extraction study |
| | [A.2.1.a2] | | | Manufacturing study |
| | [A.2.1.a3] | | | Distribution study |
| | [A.2.1.a4] | | | Use study |
| | [A.2.1.a5] | | | Disposal study |
| | ↳ | *[D.2.1.a]* | | *Report on the RSC functional phases' identification* |
| | [A.2.1.b] | | | Identification and allocation of key players |
| | ↳ | *[D.2.1.b]* | | *List of the key players for the specific RSC* |
| | [A.2.1.c] | | | Assessment of the identified project group and funding possibilities (including c1 and c2) |
| | [A.2.1.c1] | | | Analysis of the collaboration feasibility |
| | ↳ | *[D.2.1.c1]* | | *Report on the collaboration feasibility for the specific RSC* |
| | [A.2.1.c2] | | | Seek for funding organism |
| | ↳ | *[D.2.1.c2]* | | *Report on the possible financial help for the project* |
| | [A.2.1.d] | | | Synthesize and gather commitment's decisions |
| | ↳ | *[D.2.1]* | | *Report on the preliminary RSC scenarios* |
| | | ↳ | **[S.2.1.j]** | **External Strategic Decision** |
| | | | **[S.2.1.i]** | **Internal Strategic Decision ("go" to next step [2.2]; "no go"; "rework" this step [2.1])** |

*Table 8: Stage [2]: Project opportunity study – First step*

This step [2.1] includes five of the guidelines (1, 3, 5, 6 and 7).

Indeed, a hypothesis is that a company cannot run a RSC development project by itself; it requires collaboration with other key players (*guideline n°3* "A collaborative project for sharing industrial skills

and technologies). In order to facilitate the development it is important to create a R&D collaboration that involves, on a timescale, these key players (future partners) in the project. Moreover, another hypothesis included, is that a RSC approach with the identification of each life cycle stage of the product favors the development of the project (*guideline n°1* "A supply chain approach from the RRM extraction to the Disposal of End-of-life products (with the particular consciousness of a complex logistics)").

- Activities [A.2.1.a]: identification of the RSC functional transition phases

The identification of the transition phases of the RSC is run by activities [A.2.1.a] ("Identification of the RSC functional transition phases"). It is based on the recycled product life cycle, from the raw material extraction to the disposal phase (Tsoulfas and Pappis, 2006), and is illustrated by the 5 activities [A.2.1.a1 – 5] in

*Table 8*. The "report on the RSC functional phases' identification" [D.2.1.a] corresponds to the deliverable of these activities and presents the RSC potential scenarios.

- ✓ [A.2.1.a1]: Raw material extraction phase study

In the "report on the product opportunity study" [D.1.2], potential RRM have been identified for the recycled product design and manufacturing. In this respect, the activity [A.2.1.a1] ("raw material extraction phase") aims at identifying potential RRM more precisely. It also introduces the issues of the material composition and toxicity (see *guideline n°5*) of the potential RRM. The analysis of the previous "use phase" concerning the end-of-life product may contribute to this understanding. This study enables to initiate the elaboration of a RRM database; the aim is to give a general idea of the RRM availability.

- ✓ [A.2.1.a2]: Manufacturing phase study

At their end-of-life, products must be prepared into RRM (sorted / cleaned / restructured…) in order to answer the new recycled product material specifications. This study is also based on the "report on the product opportunity study" [D.1.2], in which the potential recycling technologies have been identified.

- ✓ [A.2.1.a3]: Distribution phase study

This study responds to the first guideline in "with the particular consciousness of a complex logistic" in a RSC approach. It requires an initial understanding of the distribution organization, from one industrial activity to another, until the use by the final client. Logistic issues have to be identified, such as:

- The localization of potential customers and how they would be supplied.
- The localization of the end-of-life product
- The type of transport required,
- The density that can be transported into one lorry after each industrial activity and its evolution

At this stage, the relative precision of the answers to those questions only aims at giving a general idea of the RSC process.

- ✓ [A.2.1.a4]: Use phase study

The use phase is linked to the application and it must be characterized with general features such as:

- How long will the product last and in this case, are RRM suitable for this application?
- What will be the environment of the product?

For instance, if the environment includes the users for a specific period, the consideration of toxicity issues (*guideline n°5*), to guaranty a healthy product, must be carefully taken into account.

- ✓ [A.2.1.a5]: Disposal phase study

After the use phase, the user disposes the product that enters into its end-of-life. Because the initiative of the RSCDP is to recycle EoL products, the project's general mindset leads to the consideration of environmental best practices and recognize the benefits of eco-design and design for recycling.

- ➢ Activity [A.2.1.b]: Identification and allocation of key players

The activity [A.2.1.b] aims at identifying the potential partners for each stage (defined by [A.2.1.a]) of the RSC. In

*Table 8Figure 32*, the activities [A.2.1.a] and [A.2.1.b] require simultaneous work and the project activities enable to identify and allocate potential partners. The commercial department may contact interested customers and exhibitions are interesting fields to meet the potential partners. The report of this activity [D.2.1.b] presents the "list of the key players for the specific RSC".

- ➢ Activity [A.2.1.c]: Assessment of the identified project group and funding possibilities

The activity [A.2.1.c] corresponds to the assessment of the interest of each potential partner into a collaborative project, and to seek for financial helps for the project feasibility. We divided the approach into two specific activities.

- ✓ Activity [A.2.1.c1]: Analysis of the collaboration feasibility

This activity aims at proposing a judgment on the partners, previously allocated (see [A.2.1.b]: Identification and allocation of key players) to the RSC activities. To pursue this study, the competencies and motivations are assessed. Indeed, it is necessary to understand how each partner would contribute to the creation of a valuable RSC. The objective is to present an objective assessment in the "report on the collaboration feasibility for the specific RSC" [D.2.1.c1].

- ✓ Activity [A.2.1.c2]: Seek for funding organism

The activity [A.2.1.c2] follows the guideline n°7 with the aim to assess the possibility to use financial helps to support the project. Indeed, the project possesses an eco-innovative approach and follows the sustainable directives coming from the European Union, which makes a good candidate for financial supports. The conclusions and identified financial help possibilities, are reported in [D.2.1.c2] ("report on the possible financial help for the project").

- Activity [A.2.1.d]: Synthesize and gather commitment's decisions

The activity [A.2.1.d] aims at proposing to the potential partners a recycling collaborative vision, in a written form. The documentation is elaborated using the deliverables from the previous steps of the RSCDP and the potential partners requirements. [S.2.1.j] ("external strategic decision") corresponds to the decisions from these potential partners, to pursue a collaborative project. This way, the initiator company can make a decision, using all of the previous deliverables (gathered in [D.2.1], the "report on the preliminary RSC scenarios" and [D.1.2], the "report on the product opportunity study"), on the direction to take ("go";"no go";"rework") for this recycling collaborative project proposal [S.2.1.j]. If the opportunity studies are validated by the strategic committee ("go"), the RSCDP engages the last step [2.2] ("collaborative project final definition") of stage [2] ("project opportunity study").

#### *3.1.3.2 Second step of stage [2]: Collaborative project final definition*

In *Table 9*, the step [2.2] is composed of three activities.

<table>
<tr><th>Step</th><th>Activity</th><th>Deliverable</th><th>Strategic Decision</th><th>Title</th></tr>
<tr><td rowspan="6">[2.2]: Collaborative project final definition</td><td>[A.2.2.a]</td><td rowspan="3">[D.2.2.i]</td><td rowspan="3">[S.2.2]</td><td>Collaborative funding system documents elaboration</td></tr>
<tr><td>[A.2.2.b]</td><td>Project definition</td></tr>
<tr><td>↳</td><td>Documents of the final collaborative project definition</td></tr>
<tr><td colspan="2">↳</td><td>Internal and external Strategic Decision ("go" to project launch; "no go"; "rework" to [2.2])</td></tr>
<tr><td>[A.2.2.c]</td><td rowspan="2">[D.2.2.j]</td><td rowspan="2"></td><td>Project definition proposal agreement</td></tr>
<tr><td>↳</td><td>Project agreement and commitment form</td></tr>
</table>

Table 9: Stage [2]: Project opportunity study – Second step

Activity [A.2.2.a] corresponds to the final "collaborative funding system document elaboration" (see *guideline n°7*. With this input, the potential partners and the initiator company can work on the "project definition" [A.2.2.b], using [D.2.1], the "report on the preliminary RSC scenarios" and [D.1.2], the

"report on the product opportunity study". The deliverable coming from this activity is the "documents of the final collaborative project definition" [D.2.2.i], it is then presented to the initiator company and to the potential partners for a final "internal and external decision" [S.2.2] (to "go", or to the "rework" of this form, or to the "project closure"). This last decision leads to the activity [A.2.2.c], "project definition proposal agreement" that correspond to the signature of the "project agreement and commitment form" [D.2.2.j]. This written commitment form represents the contract between partners (obligations, time frame…), and protects intellectual properties of each partner during the development work.

When the document is accepted, the project is launched, and starts stage [3], not detailed in this study.

## *3.2 Application of the RSCDP to our case Study*

The RSCDP has been applied, step by step, to illustrate the definition of an innovative recycling collaborative project, from the company's strategy definition, to the project launch. This case study enabled to verify the applicability and relevance of the RSCDP.

### *3.2.1 General context*

In the scope of our study the company global strategy was defined in four points: leading technology; differentiation; client satisfaction; globalization. Until 2006, the textile company used three main technologies which are braiding, knitting and weaving, and supplied different markets but mainly the automotive market. A few years back, in regards of the strategy, the North American R&D department invested in a new technology (for non-woven manufacturing), because of a commercial opportunity. The commercial opportunity was very specific. Indeed, the business model was to propose to the client (an automotive constructor) to take care of his wastes and to manufacture out of it, a recycled product. In respect of the strategic drivelines, the technology aimed at expending to Europe, although with specific tactics. Indeed, the RRM used in the USA were not applicable to Europe, as they already benefit of a mature recycling stream.

### *3.2.2 Stage [1]: Strategic study*

The general context met the condition to start the RSCDP, with an environmental strategy to use RRM for a new recycled product development.

#### *3.2.2.1 Step [1.1]: Collaborative project opportunity study*

The first activity [A.1.1.a] (“mission definition using market and technology trends”), was assigned by the strategic committee to the sales department according to the context knowledge (§4.1) related to the technology and market.

The activity [A.1.1.b] (“investigation for recycling collaborative project opportunity”) was then carried out by the sales department. The first interest was to understand the market in Europe of the same recycled product made in North America and seek for alternative RRM. The objective was also to seek for potential customers and obtain feedbacks on the possible interest regarding the initial proposal.

The initial proposal is defined by: the manufacturing of a recycled product, using the customers’ RRM, analogically to the initial American business model. In order to do so, customers in Europe have been interviewed, the environmental departments were particularly targeted and this is how the first potential partner to a collaborative project was identified.

At this point, a “report on the collaborative project opportunity study” ([D.1.1]) of the mission was given. This report pointed out that the requirement for the limitation of the transports was an important environmental concern, with the need to manufacture locally. The study also confirmed that the North American model could not be applied unchanged, but that the circular economic concept was of interest for the customers. The RRM types were not identified at this stage.

From this report, a strategic decision from the strategic committee presents a positive interest to develop the collaborative project (“go”). This strategic decision leads to step [1.2].

#### *3.2.2.2 Step [1.2]: The product opportunity study*

The “product opportunity study” was engaged [1.2]. Regarding the “recycled product study” [A.1.2.b], the company environmental strategy was clear, the North American functional product must be implanted in Europe in order to present a global offer (also based on the axis “globalization” of the company internal strategy). In this respect, at this stage, the recycled functional product (a nonwoven acoustic protection for car interiors), was defined.

Based on this first product definition, an initial “market and economic study” [A.1.2.d] was done by the sales department, in order to give an overview of the market and identify the first potential targets. The environmental department of a French automotive constructor (the client) was contacted in order to expose the North American business model and understand the possible transposition in Europe. This first contact led to a first meeting at a national exhibition.

The “study of the recyclable resource” was predominant [A.1.2.a], as the RRM present in North America did not and could not exist in Europe. The technical expertise of the company, enabled to identify potential RRM, EoL textile parts from cars (such as seatbelts and airbags or seat-covers). Because these RRM come from automotive constructors the business model is respected and corresponds to the company environmental strategy. This potential solution was identified during the meeting at an exhibition with the environmental department of the automotive constructor. At this event, from this

first meeting, the “market and economic” [A.1.2.d] vision was raised. The issue identified from the beginning concerned the potential volume to supply the European market. With the identified EoL automotive textiles, the volumes wouldn’t be enough to support the model. In this respect another RRM potential supply source was identified at this same exhibition: a professional garment manufacturer, which opened another potential RRM supply. Indeed, the fibers used to produce the textile pieces for clothes were able to be studied [A.1.2.a].

The EoL textiles have been identified as potential RRM also based on the “recycling technology study” [A.1.2.c] conducted by the engineer of the initiator company. Indeed, the transformation of textile product (such as a garment piece), is an industrial activity present on the French territory. The initial idea and question relies on the possibility to transpose this technology to diverse EoL products such as airbags or seatbelts.

In parallel, the “study of the regulation” in Europe [A.1.2.e] for recycling was led. One of the European directives is the requirement to recycle up to 95% (10% can correspond to energy valorization) of an EoL vehicle for 2015. This regulation corresponds to a motivation for the automotive constructor as, based on the directive, he is responsible to elaborate solutions to satisfy the environmental target. For the professional garment producer, the calls for offers require more and more EoL solutions, to provide to their clients.

With these first studies, the “report on the product opportunity study” [D.1.2] was elaborated. The “internal strategic decision” [S.1.2] by the initiator company was to continue the RSCDP which leads to the next stage [2.1].

### *3.2.3 Stage [2]: Project opportunity study*

#### *3.2.3.1 Step [2.1]: Preliminary RSC scenarios study*

For the “identification of the RSC functional transition phase” [A.2.1.a], the initial core group (the initiator company, the automotive constructor and the garment manufacturer) sketched the projected value chain and made sure to agree on this initial projection. At this stage, the initiator company reinforced its position of a fiber recycled product manufacturer, willing to conduct the “manufacturing study” [A.2.1.a2].

In parallel the activity is conducted on the “identification and allocation of the key players” [A.2.1.b] with a RSC mindset, integrating also the need for external technical supports. At this point, these two first studies go back and forth, reinforcing the “report on the RSC functional phases’ identification” [D.1.2.a] by the identification of potential partners. During this step, a professional association was contacted and helped to initiate relations with other potential partners. The experience of the project managers also played a determining role in this identification and allocation of the potential partners, with the knowledge of fiber treatments and existing recycling technologies in order to elaborate the preliminary RSC scenarios.

Regarding the need for external support, an engineering school of textile was contacted, to obtain a research and technical support (and to include an academic entity that can be required by financial help organisms). Again, based on the project experiences of the managers, a critical point was identified regarding the logistic. In order to study the distribution channels, a specialized company, met through the same professional association, permitted to cover this aspect of the supply chain [A.2.1.a3] ("distribution study"). Another logistic support specialized in logistic studies and an engineer school, were also identified. At this stage, the use phase was briefly investigated ("use study", [A.2.1.a.4]). The idea was that the product should be included into a vehicle, thus using the automotive product specifications, which guaranty the quality of the recycled product. The disposal phase ("disposal study" [A.2.1.a5]) was discussed as the notion of a close loop was pointed out by the automotive constructor; in this respect design for recycling (DfR) was considered at this stage.

Considering these initial features the "reports on the RSC functional phases' identification" [D.2.1.a] and the "list of the key players for the specific RSC" [D.2.1.b] are completed. Using these reports, the "analysis of the collaboration feasibility" [A.2.1.c1] can be conducted. It implies the understanding of the potential partners' motivation to be involved in the collaborative project. The objective is to assess the potential conflict of interests that could disfavor the future project. At this stage of the RSCDP, the potential partners are identified on the RSC which permits to deliver the "report on the collaboration feasibility for the specific RSC" [D.2.1.c1].

In parallel, the activity [A.2.1.c2] "seek for funding organism" was done to support financially the development work of the collaborative project. The identified organism that could deliver funds was the French environmental and energy management agency. The requirements of the agency have been investigated, with the main need to present an innovative project. These conclusions are then reported in [D.2.1.c2] ("report on the possible financial help for the project"). In this respect the project potential partners proposed the idea to obtain an environmental label for the projected new recycled product. In this respect, another partner was required: a certification organism, which incremented the "list of the key players for the specific RSC" and the "report on the collaboration feasibility" respectively [D.2.1.b] and [D.2.1.c1].

The last activity of step [2.1] enabled to "synthesize and gather commitment's decisions" (materialized by the "report on the preliminary RSC scenarios" [D.2.1]) and the potential partners agreed on a recycling collaborative project first definition ([S.2.1.i-j]). The last step was engaged.

#### *1.1.1.1 Step [2.2]: final Collaborative project definition*

The following activities were conducted simultaneously. The potential partners worked on the "collaborative funding system documents elaboration" [A.2.2.a] to answer the requirement of the identified funding organism, in particular the financial sharing part elaboration. They also wrote the project definition ("project definition" [A.2.2.b]) and obtain from these two activities the "Documents of the final collaborative project definition" [D.2.2.i] for submission to internal and external strategic decisions [S.2.1.i-j]. Once the project definition was accepted by the potential partners (which have required some rework in order to obtain this definition, the final "project definition proposal" [A.2.2.c] was sent to the potential partners to gather their signatures in the "project agreement and commitment form" [D.2.2.j]. At this stage the project was launched and the potential partners became partners. The

project definition presented a 3 years project, with 9 partners to share development work during all of this timeframe (3 years corresponding to stage [3] "the project management" in the detailed design phase).

## *3.3 Discussion*

In France, between 2005 and 2012, 1186 innovative collaborative projects have been funded by the Unique Interdepartmental Funds (« Fonds Unique Interministériel » in French) (dgcis, 2013). However, even if the effective paybacks are difficult to assess, it is noticeable that many projects never go beyond the development research phase for commercialization. Thus there is a need to develop a NPD process to conduct such collaborative projects. This research provides a real method to guide the definition of a specific recycling collaborative project that is the RSC collaborative design, taking into account the identified best practices (guidelines) to favor the success of such a project.

The proposed guidelines have been highlighted from the literature review and the observed industrial best practices. Because in the research state of the art these guidelines remain general features without implementation method, we proposed, through the conceptual phase of a specific NPD process, to implement an Eco-design strategy. We also applied specific guidelines concerning collaborative thinking and concurrent design as the identified best practices. *Table 10* points out where the identified guidelines can be found in the RSCDP.

| Guidelines for a recycling collaborative project construction | Place in the RSCDP |
|---|---|
| 1. A supply chain approach from the RRM extraction to the Disposal of End-of-life products (with the particular consciousness of a complex logistics) | ✓ [2.1] "Preliminary RSC scenarios study"<br>✓ [A.2.1.a1-5] "Identification of the RSC functional transition phases". (Particularly with [A.2.1.a3] regarding the complex logistics issues) |
| 2. The importance of the early design phase, where many product features are positioned. | ✓ [1] "Strategic study" and [2] "Project opportunity study" (are the two stages part of the early design phase) |
| 3. A collaborative project for sharing industrial skills and technologies | ✓ [1.1] "Collaborative project opportunity study". (This step in the first part of the "strategic study" [1], highlights the importance of the collaborative approach for such eco-design strategy.) |
| 4. A recycled product oriented approach for the design of a RSC, which corresponds to an innovative recycling activity (market pull and technology push approach) | ✓ The "product opportunity study" [1.2] (is also a part of the strategic study, and enforces that a RSC cannot be designed without any initial product definition) |
| 5. Consideration of the environmental regulations and more specifically the toxicity of the RRM | ✓ [A.1.2.e] "regulation study" in the first stage [1] |

| | |
|---|---|
| | ✓ [A.2.1.a1] "Raw material extraction study" (that introduces the issues of the material composition and toxicity)<br>✓ [A.2.1.a4] "use phase study", (considering that the user will be in contact with the product, there is a need to guaranty his health). |
| 6. Emphasis on the importance of the project partner selection | ✓ [A.2.1.b] "identification and allocation of key players" and [A.2.1.c1] "analysis of the collaboration feasibility", |
| 7. Opportunity to seek for financial helps from governmental funding systems, which support environmental challenges | ✓ [A.2.1.c2] "seek for funding organism"<br>✓ [A.2.2.a] "collaborative funding system documents elaboration" |

*Table 10: Implementation of the guidelines in the RSCDP*

Thus, the identified guidelines are well taken into account in the proposed RSCDP.

An originality of the proposed method is that the focus is on both the RSC and the new recycled product, designed with RRM coming from end-of-life products. This initiative enables to pull by the market the design of the RSC, however the RRM could be used in the future for the composition of other recycled products of the same type. This consciousness allows the company not only to be positioned on a new recycled product solution for a market, but also to think its activity differently with a circular economy concept that creates value and opportunities. In this sense, we are positioned in a quite new vector of considering the supply chain globally such as recommended by Linton et al. (2007). Indeed, the RSCDP enables to define a recycled product from end-of-life product, giving a possibility to create new resources (RRM) and new businesses in the recycling industry.

Halada et al. (2002) point out the innovativeness of such a recycling process, considering the relationship between the ecomaterials selection (that could be EoL products [A.1.2.a]: "Recyclable resource study"), and the new recycled products designed by a DfE oriented approach. In the RSCDP method, we consider this key concept by the simultaneous study of the three technical activities in step [1.2] ("product opportunity study"). We also introduced a guideline that is the recycled product design oriented approach (*guideline n°4*). An originality of our work is to focus on a specific eco-design strategy (introduction of RRM coming from end-of-life products, in new recycled products), which enables to propose an early phase eco-design process and a recycling collaborative project definition.

The two first stages of the RSCDP focus on the early design phase. An originality of the method is to implement the guidelines, which includes environmental aspects, at the very beginning of the project definition. Moreover the eco-design strategy, with the aim to develop an activity in the new recycling industry, integrates environmental consciousness by the mindset of the project itself. The early design phase of a NPD process, by its correspondence to a recycling collaborative project definition, enables to implement eco-design in the company that follow the RSCDP.

The proposed design process model is suitable for project managers who can easily adopt it. As showed in the introduction and literature review of this article, the integration of eco-design remains a challenge for companies and a research gap (Brezet, 2001; Le Pochat et al., 2007; Lindahl, 2006; Pigosso et al., 2013). The RSCDP fills this gap by giving one application of eco-design implementation, what we called

an operational model compared to conceptual models found in the literature (Le Pochat et al., 2007). Indeed, the RSCDP helps to include environmental consciousness as early as possible in the project definition in order to prevent from environmental impacts (Kengpol and Boonkanit, 2011; Mascle and Zhao, 2008). It organizes the different activities to conduct in order to achieve environmental benefits specifically on a recycling stand point. The RSCDP provides companies with an alternative solution regarding eco-design and EoL waste management, considering the regulation and more specifically the potential toxicity of the RRM. It is a possible answer to an identified lack of eco-design management tool within the literature review concerning recycling and creates a position for end-of-life product recycling.

The design process also includes dynamic aspects and, mastered by project managers, it should respond and still be effective even though industrial environments change. Because the study is based on industrial practices, each project provides specificities that have to be managed. However, this development study, based on three specific recycling collaborative projects and two years of gathering industrial feedbacks, is at this stage the best practice identified, with a good industrial coverage. Moreover, in today's industrial environment, the project presented in section 4, is considered as innovative (innovation award 2014 - Expoprotection Paris) and takes into account environmental concerns.

## *4. Conclusion*

As an overall, this research presents a specific concept concerning the concurrent design of a recycled product and a recycling supply chain, while considering the environmental aspect. Using guidelines from the literature and the industrial environment, we proposed a method in form of an operational process to apply this concept and implement an eco-design strategy. The contribution focuses on the conceptual design phase of a NPD process, in form of a recycling collaborative project definition. From an industrial stand point, the RSCDP gives the opportunity to companies to develop new businesses in the recycling industry, to develop new green supply chains, which contribute to better environmental practices. The development of recycling studies could inhibit the landfill of end-of-life products and gives a place for EoL products in the design of new recycled products.

We highlighted a limit of our exploratory study which is the assessment of the success of the RSCDP. In fact we encounter the same difficulty as other methodological research studies (Pigosso et al., 2013; Seuring 2013), which is the lack of industrial validation with several applications. However, the project described in the case study enters in an industrialization phase which emphasizes the relevance of the RSCDP. In this respect, the possibility to transpose the RSCDP to other RSC projects could be further investigated in extended engineering studies, but our industrial investigations and this application comfort us in its consistency.

A critical activity in the RSCDP (identification and allocation of key players) concerns partner selection. This aspect that is highlighted in *guideline n°6* regarding the importance of the partner selection, could be further investigated. In the literature, we observed the development of Multi-Criteria Decision Making techniques for supplier selection and rarely for partner selection. These models could be transposed to this original issue concerning partner selection in a recycling collaborative project, with the elaboration of a specific MCDM-based methodology.

Another issue concerns the study of the recycling industrial competitive environment. To answer this question and reinforce the strategic study of the RSCDP, a perspective is to study the emerging industry of recycling. Using value chain analysis concepts, we could propose a specific method to study such environment that would enhance business opportunities and risks linked to the eco-design strategy followed in this research.

This research is essentially based on the observation on a European industrial environment, and we focused on the European environmental regulations. In further work, a comparison between different territories could be of interest. Especially regarding emerging countries (such as China) , which have growing environmental consciousness that are observed by the development of national programs under strengthened regulations (Bai et al., 2014).

# CHAPTER 4: A METHOD FOR RECYCLING R&D PARTNERS SELECTION WITH A SUPPLY CHAIN DESIGN APPROACH

Regulations on product recycling rates, but also growing consumers' consciousness on the importance of environmental issues, enforce industrials to seek for solutions that consist in recycling their products at their end of life. A way to design and implement recycling industrial activities, with materials coming from end of life products, is to gather different industrial partners, in the scope of a collaborative project (CHAPTER 3:.

More and more collaborative inter-firms R&D projects are conducted, as a particular way to drive innovation, and especially over environmental topics. The concept of collaboration has been developed in the 1980s (Chen, 1997; Chesnais, 1988; Hagedoorn, 1990), as a way to share risks and benefits between involved companies. However, even today, it remains a large dynamic research topic, and a way for companies to gain competitive advantages. Different forms of collaborative systems have been introduced, such as vertical and horizontal collaboration (Arranz et al., 2008). A specific focus has been put on the partners selection for such collaborative engineering work (Li and Shen, 2009).

## 4.1 A problem of R&D partner selection for new RSC design

The focus of this chapter concerns projects for the development of innovative recycling industrial activities and the question is: "how to ensure successful collaboration between companies in such R&D projects?" In this respect, we are studying Green Supply Chain Management (GSCM) field, because collaborative R&D projects, in this case, aim at creating this recycling pattern (McDonough and Braungar, 2002). What is the best partner selection for such a "recycling R&D project"? In the literature review, different models have been developed for partner selection. *Figure 33* and *Table 11* describe related work and point out the lack of research investigations for this specific issue.

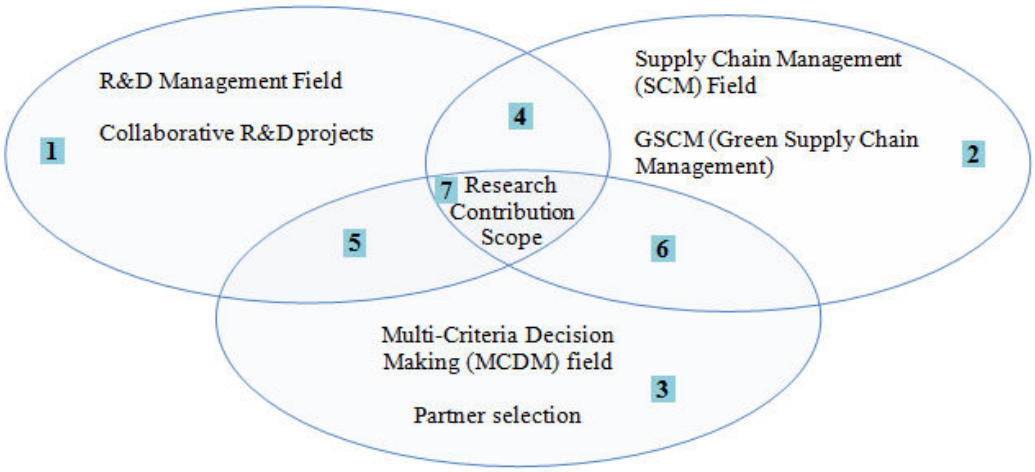



*Figure 33: Investigated Research Fields*

The description of each investigation field is defined as follows:

- 1: Collaborative R&D projects in the field of R&D management
- 2: GSCM in the field of SCM
- 3: Partner selection in the field of Multi-Criteria Decision Making (MCDM)
- 4: Collaborative R&D projects vertically integrated on the SC
- 5: Partner selection in the scope of collaborative R&D projects
- 6: Partner selection in the scope of GSCM
- 7: Partner selection in collaborative R&D projects for defining Recycling Supply Chain

The analysis of the research field investigation is synthesized in *Table 11*.

| **Research Scope** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **Total** |
|---|---|---|---|---|---|---|---|---|
| **Number of paper** | **8** | **14** | **3** | **0** | **3** | **18** | **0** | **46** |
| **Percent** | 17,4% | 30,4% | 6,5% | 0,0% | 6,5% | 39,1% | 0,0% | 100,0% |

*Table 11: Bibliometric chart of the literature review (see Annex 5)*

This table emphasizes the lack of bibliographic investigations in the fields 4, 5 and 7 but also shows that today the link between collaborative R&D project and GSCM is not treated.

In this respect, the question addressed in this chapter is declined within two contributions. On the one hand, in an early project definition phase concerning a new Recycling Supply Chain, we are focusing on the criteria definitions, that would be used in order to select potential project partners. On the other hand, we propose a MCDM method in order to give a decision support for the partner selection problem in the scope of recycling collaborative projects definition.

Our hypothesis is that a model for partner selection should help a R&D project manager to define an inter-firm collaboration. It also provides the adequate partnership at the early project definition phase, which favors the effectiveness of a collaborative project. Thus, integrating both GSCM criteria and collaborative criteria increases the chance of defining the best partnership.

The criteria and their definitions become invariants in the elaboration of similar projects at the partner selection stage. In order to identify the adequate criteria, the specific context has been investigated and the positioning of the chapter has been clearly highlighted ( *Figure 33*), also with the literature review (§1.2.5). The project context is based on a research project, dealing with a "recycling collaborative project", vertically integrated on the supply chain. Therefore, after extracting a first criteria list from the relevant literature, a validation process has been conducted with a various panel of experts (industrials and academics). This step enables to refine the initial list with the context needs. Then, the definitions have been reviewed and submitted once again for validation to a panel of experts through a questionnaire (

*Figure 34*).

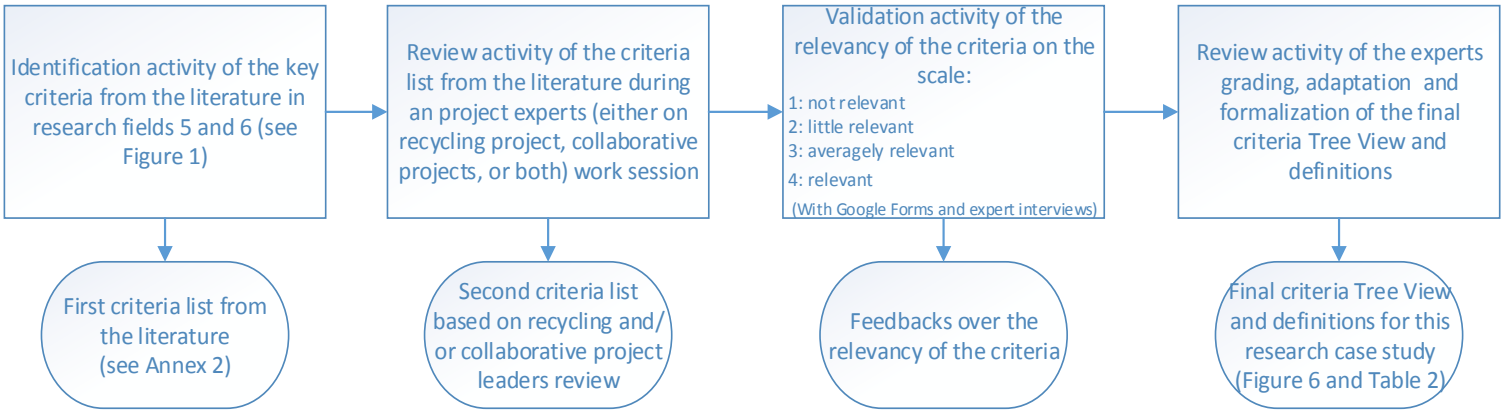



*Figure 34: Criteria Tree View and definitions elaboration*

Thus, this research presents the final Tree View and definitions of the criteria used in the case study.

From this criteria list we investigate decision making techniques to support the construction of a partner selection model. A combination of these techniques is proposed and a demonstration of its applicability is conducted in the case study.

## 4.2 Proposal of a method

This section relays on the literature and industrial reviews concerning R&D collaboration concepts, SCM and GSMC fields (see

*Figure 34*), and present the partner selection techniques for the use of the method construction.

The focus on partner selection techniques corresponds to an investigation on MCDM techniques, to identify the adapted method regarding this context study and available data.

### 4.2.1 Multi-Criteria Decision Making (MCDM) Techniques

The techniques of selection belong to a methodological frame aiming at supplying a recommendation to the decisions makers among a set of alternatives (so known as actions, objects, solutions candidates). These alternatives are estimated by several points of view, which are described by different criteria (so known as attributes, characteristics or objectives). Chai et al. (2013) make a critical study of the literature on the techniques used. They identify the most used MCDM techniques that they classify in four categories:

- Multiattribute utility methods such as Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP).
- Outranking methods such as Elimination and Choice Expressing Reality (ELECTRE) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE);

- Compromise methods such as Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and Multicriteria Optimization and Compromise Solution (VIKOR),
- And other MCDM techniques such as Simple Multiattribute Rating Technique (SMART) and Decision-Making Trial and Evaluation Laboratory (DEMATEL).

The choice of the techniques adapted to the selection problem, depends on the available information and on the objective of the study. Fuzzy information management is an important issue for partner selection. Indeed, the stages of judgment and comparison are subjective. As a consequence, fuzzy logic allows obtaining a less sensitive result. In this sense, several authors have adapted this fuzzy approach for the same techniques quoted previously, within the framework of multicriteria methods. In this respect different techniques exist such as the Fuzzy AHP, Fuzzy ANP, Fuzzy TOPSIS, Fuzzy ELECTRE, Fuzzy PROMETHEE, Fuzzy Vikor and Fuzzy DEMATEL (Chai et al., 2013; Lee et al., 2009). The Fuzzy Logic is a theory which supplies a mechanism to represent linguistic constructions as "A lot", "in the bottom", "means", "often", "little" to a mathematical language and to be able to work more easily with vagueness (Zadeh, 1965). The fuzzy approach is often used to refine existing decision support tools, but for a new study and the first application of MCDM techniques, it is better to initially investigate the problem with traditional MCDM techniques. Since collaborative partner selection in the recycling scope is a new problem we choose to focus on the traditional techniques.

The AHP technique was first proposed by Saaty, in the 1980s (Saaty, 1980), it is one of the most used methods to solve multicriteria problems in different contexts (Ho et al., 2010; Saaty, 2004). With AHP, the opinions and the evaluation of the decision-makers are treated using graded evaluation scales. This technique is based on a criteria tree model.

DEMATEL is a methodology to estimate the relationships between the criteria in MCDM problems. Indeed, Chen and Chen (Chen and Chen, 2010) show that “in the real world, most criteria are not mutually independent”. This technique enables to analyze the relevance of the AHP allocated weights, especially when the notation is made by expert opinions. For the application of this methodology it is necessary to follow a list of recommended stages (Michnik, 2013; Sumrit and Anuntavoranich, 2013a; Tan et al., 2012).

The TOPSIS method requires a low time investment from the user and its process is easy to apprehend. It takes into account the weights allocated to the criteria from AHP (Behzadian et al., 2012). The idea of TOPSIS is that the best solution is the one which has the shortest distance to the ideal solution and the most distant to the anti ideal solution. The method TOPSIS is based on five stages of calculation such as observed in Ishizaka & Nemery (2013) and Chen & Chen (2010).

It is recommended to consider more than a single technique for a better decision support (Chai et al., 2013) as well as it is necessary to consider the relation between the criteria for the construction of the final methodology (Hsu and Hu, 2009). Another work indicates that the context of the selection determines the type (s) of technique (s) to choose for the application (Roy and Słowiński, 2013).

In this paper, we propose a combination of three techniques (AHP, DEMATEL and TOPSIS) to have a consistent approach that enables to weight the proposed criteria (AHP), to evaluate their mutual influences (DEMATEL), and finally, to provide a ranking of the potential partners (TOPSIS) to help project managers to select the best partner.

### 4.2.2 Proposal of a ranking method and a list of criteria

In this section, the combinational approach of the three techniques is briefly presented and a list of criteria with their definitions is provided in order to evaluate potential partners.

#### 4.2.2.1 A Ranking method: Multi-criteria techniques combination

Different techniques are useful for our objective concerning the creation of a method for R&D partner selection. We decided to apply the technique AHP which allows the decision maker to compare the criteria proposed between each other and to attribute the weights. A hypothesis of AHP is that all the criteria are independent. The initial company (the one that initiates the collaborative project) will perform this weighting with AHP. Indeed the selection process is done by this company because the aim is to adapt the partner's profiles to its strategy and thus to favor the potential success of the collaboration. In this respect the criteria are adapted to the initial company by the weighting. For each activity of the Supply Chain the weighting may be different, this is the reason why the AHP process may be applied to each activity of the Supply Chain. It is also possible that the collaborative project is initiated by two initial companies. In this case the weighting process may be achieved during a work session involving these initial partners. A consistency index is proposed to complete the AHP technique to verify the logic of the answers provided by the initial company.

A mattering aspect that we want to consider is the relation between the criteria that may affect the importance of a criterion. For this aspect, the technique DEMATEL enables to make an analysis of the influences. We propose that the decision-maker checks the relevance of the obtained criteria weights regarding the decision-making objective (for this work, partner selection in a RSC project definition), by mapping the criteria with two axes: importance (weights obtained with AHP) vs influences (evaluation obtained with DEMATEL) (

*Figure 43*).

With criteria weights, defined with AHP, TOPSIS provides evaluations of potential partners and computes their ranking. With this ranking we can determine the company that is the closest to the ideal partner profile.

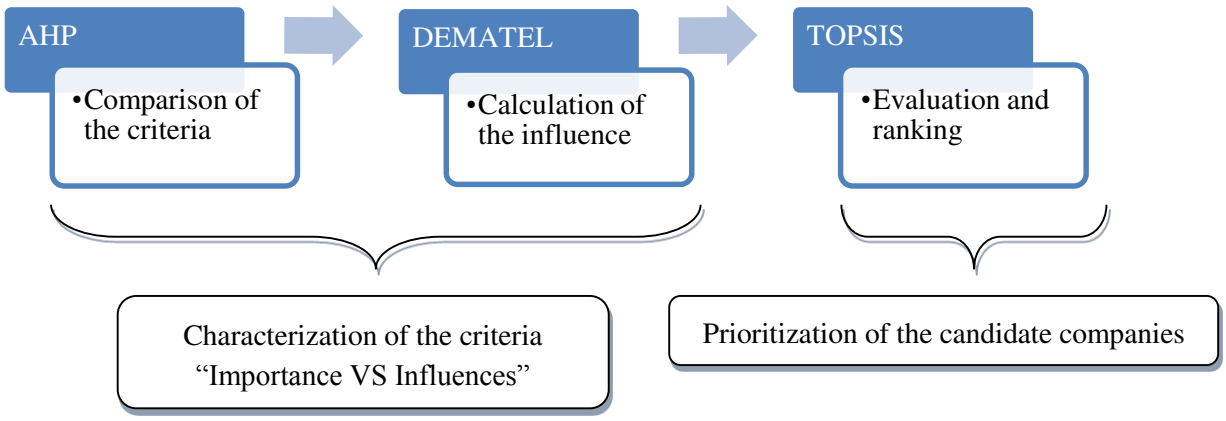



*Figure 35: Combination of the MCDM techniques*

The evaluation is preceded with quantitative scales that enable to measure the importance and the influence of each criterion relative to the business that initiates the collaborative approach. After defining the importance of each criterion for each activity of the project on its SC, the decision maker from the initial company makes exploratory interviews with the identified potential partners (also called candidate companies).

#### *4.2.2.2 Proposal of the final selection criteria list*

A focus of this research is the identification of criteria that should be taken into account when engaging a collaborative project for the specific application of RSC development. The scope regarding the project type is important for the criteria identification. Indeed, this aspect is confirmed by our industrial observations: there are so many different situations for a collaborative project definition, with original consortium that a generalization of the partner selection criteria is quite difficult. This is the reason why this research is integrated in specific collaborative projects, within the recycling industry. The criteria identification is based on the analysis of partner selection problems in both collaborative R&D projects and GSCM fields (see *Figure 33*).

The literature review enables to bring out the existing considered criteria for each of these topics (see *Annex 4: First criteria lists from the literature study*). Then the expert interviews concerning the relevance of these criteria enable to validate the final criteria list. The experts are project managers, working on recycling collaborative projects as ValVer, for end of life glass valorization (Farel et al., 2013).

Among the criteria identification and definition, the way the hierarchy is built, is an important matter for the model. The objective is to obtain a comparison between Candidate Companies (CC), depending on how they fulfill each criterion for a specific activity of the RSC. This classification is realized with a unique mark for each activity and this mark is an aggregation of different criteria categories. The literature review helps in defining 4 upscale dimensions which are: Strategic Value, Business excellence Value, Project Skill Value and Environmental Value *(Inspired from Morel & Boly 2006; Büyüközkan & Berkol 2011)*.

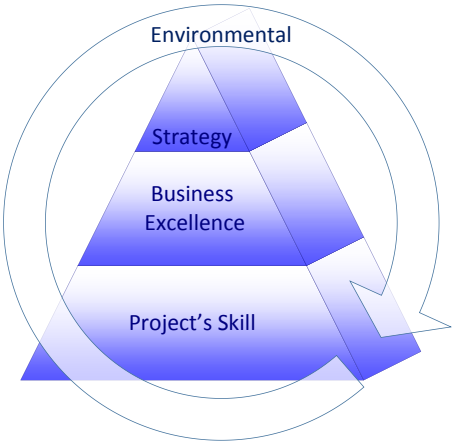



*Figure 36: The four upscale dimensions*

We choose the term Value, regarding the objective of this study as these dimensions are considered as values to reach. Indeed, the aim is to ensure that each partner is likely to add high value within the RSC. The criteria are sub-divided to help the evaluator to give an appreciation. Although the sub-criteria do not measure quantitative data, they are precise enough for the evaluator to make his analysis on 3 scales, a scale of importance (with AHP), a scale of influence (with DEMATEL) and a scale of evaluation (with TOPSIS).

The criteria tree divides each dimension into criteria and sub-criteria (*Figure 37*).

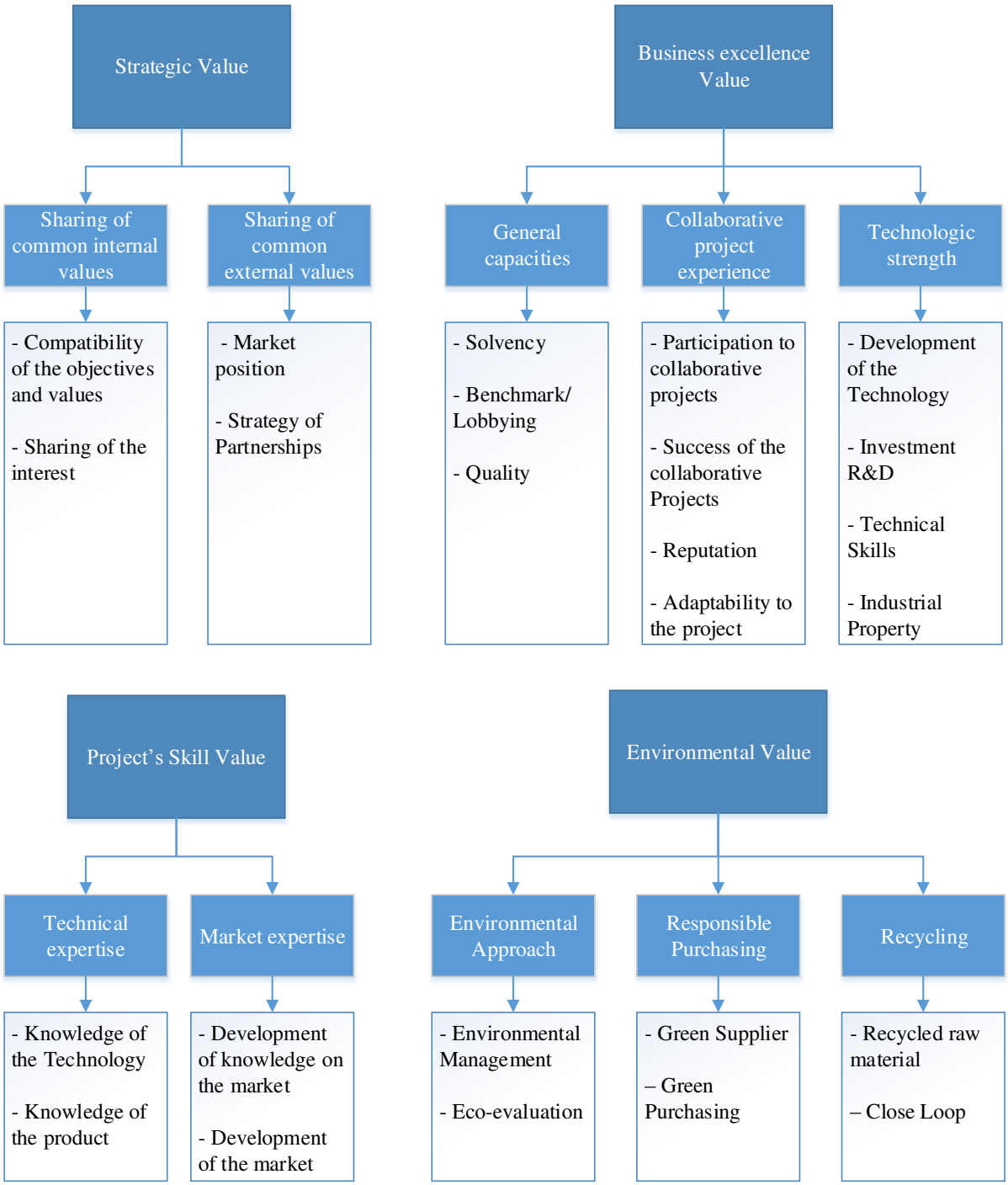



*Figure 37: Dimensions, criteria and sub-criteria*

This is built specifically in a context of recycling collaborative project definition. Thus, for the different dimensions, specificities are included, as observed in each sub-criterion definition. For instance, in the "Strategic Value" dimension, the sub-criterion "Strategy of partnership" takes into account the collaborative aspect.

*Table 12* gives the definitions of each sub-criterion used in this study.

| Dimension | Criteria | Sub-Criteria | Definitions |
|---|---|---|---|
| Strategic value | Sharing of common internal values | Compatibility of the objectives and values | The compatibility of the objectives and values with the companies that initiate the collaborative project definition is estimated. This sub-criterion enables to understand the potential partner's general position, regardless of the project proposal and to evaluate how the two companies share complementary views in a general stand point |
| | | Sharing of the interest | The partner is evaluated on its strategic interests regarding the project and how its interest is compatible with the project objective |
| | Sharing of common external values | Market position | The market position of the potential partner means that the importance of its influence on the market is measured. The recognition of the candidate company on its market is evaluated |
| | | Strategy of Partnerships | The strategy of partnership evaluation enables to measure the openness of the potential partner, which could be favorable to collaboration. Various co-development activities can be identified in order to make the evaluation |
| Business excellence value | General capacities | Solvency | Before committing in a relationship, the measure of the solvency is done. That reveals the potential partner's economical stability |
| | | Benchmark, lobbying | This sub-criterion enables the measurement of potential lobbying position of the candidate company |
| | | Quality | The quality certification of the candidate company is identified by this sub-criterion. It measures the adequacy with the project activity and with the collaborative relationship |
| | Collaborative project experience | Participation to collaborative projects | The participation of the potential partner to collaborative projects is evaluated based on the number of existing experiences |
| | | Success of the collaborative Projects | The success of past collaborative projects, conducted by the potential partner, is measured by the analysis of the industrial applications and the commercial success from these projects |
| | | Reputation | During collaborative projects, companies' reputation can be at stake depending on their general professionalism. So, this criterion takes into account this general feature observed in the company environment |
| | | Adaptability to the project | Innovative projects often demand changes in the initial orientation, so, the ability of the partner to follow the project trend must be evaluated. Thus this sub-criterion measures the potential flexibility and adaptability of the candidate company |
| | Technological strength | Development of the Technology | The sub-criterion "Development of the Technology" enables to measure how the potential partner contributes to the company, which initiates the project, learning about new technology |

| | | | |
|---|---|---|---|
| | | R&D Investment | The potential partner R&D investment measures its degree of development capacity. A high percentage of the capital for the R&D department shows a potential high implication in new products and projects |
| | | Technical Skills | For this sub-criterion, the degree of technical skills is evaluated. Strong technical skills demonstrate the interest of the potential partner regarding technical products allowing proposing new technical offers |
| | | Industrial Property | The industrial property is a feature, in the development of new offers, which secures the industrial application. The sub-criterion evaluates how the potential partner is aware and comfortable with the industrial property management |
| Project's Skills value | Technical expertise | Knowledge of the Technology | The sub-criterion "Knowledge of the Technology" enables to measure how the candidate company knows one or several specific technologies that could be used within the framework of the project |
| | | Knowledge of the product | The sub-criterion "Knowledge of the product enables to measure how much the organization knows about the technical aspects of the product to be developed within the framework of the project |
| | Market expertise | Development of the market knowledge | This sub-criterion measures how the candidate company contributes in growing the market knowledge on the project activity market segment |
| | | Development of the market | The sub-criterion "Development of the market" evaluates how the potential partner contributes in opening new export opportunities |
| Environmental value | Environmental Approach | Environmental Management | The sub-criterion "Environmental Management" enables to identify the environmental certifications of the candidate company. It measures the adequacy with the project activity and with the collaborative relationship |
| | | Eco-evaluation | The sub-criterion "Eco-evaluation", enables to measure the degree of utilization of the environmental evaluation tools by the candidate company (ACV, carbon assessment, balance sheet energy). This features show the implication of the potential partner regarding environmental consciousness and its environmental assessment habits |
| | Responsible Purchasing | Green Supplier | In the vision of a sustainable relationship, the sub-criterion "Green Supplier" enables to measure how the company runs a policy of green supplier selection |
| | | Green Purchasing | To understand the environmental consciousness in the potential partner organization, the sub-criterion "Green Purchasing" enables to measure the purchasing service implication in buying green materials (recycled, renewable resources…) |

| | | | |
|---|---|---|---|
| | Recycling | Recyclable raw material | The sub-criterion “Recyclable raw material” enables to identify the percentage of recycled material used by the candidate company compared with the total volume of material used. That evaluates the relevance of this rate |
| | | Close Loop | In order to understand the recycling implication of the potential partner, the sub-criterion “Close Loop”, enables to analyze if circular or closed recycling processes exist in the candidate company supply chain |

*Table 12 :Sub-criteria definitions*

## *4.3 Experimentation: A French R&D collaborative project definition for the recycling of textile materials*

In this section, a case study on a French collaborative R&D project concerning the definition of a recycling supply chain is presented.

### *4.3.1 Description of potential partners*

The proposed approach has been applied on a case study concerning a recycling collaborative project in the textile industry. We limit the application of the method to a specific activity of the RSC. This activity corresponds to the stage “Extraction of the raw materials” and in this specific project, it is called “Extraction of the textile raw materials Garment" (*Figure 38*)

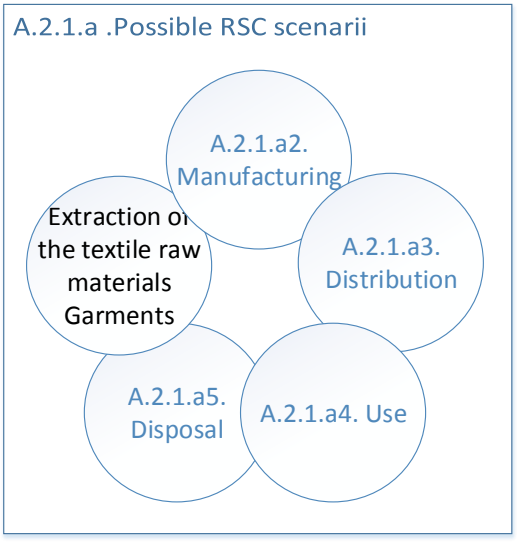



*Figure 38: Application of the multicriteria techniques to a specific activity of the RSC*

For this specific activity, we describe four candidate company's profiles (

*Table 13*).

| **Candidate company N°1** |
| --- |
| Company n°1 corresponds to a SME in the professional garment sector. The company possesses approximately 10 % of the French market. It delivers its products to great consumers, private or public, such as hospitals or airports. The potential evolution of the regulation toward greener practices is a motivation for this partner. But also more and more great user, in their call for tender, require an end of life management solution from their suppliers such as company 1.<br><br>Once launched on the market, company 1 does not keep the property of products; thus it possesses a good knowledge of the quantities introduced on the market, but possesses a weak vision of the materials which can potentially arrive at an end of life. The company makes a 55Million € turnover and counts an average of 250 employees. |
| **Candidate company N°2** |
| The activity of company n°2 is the renting and the cleaning of professional clothing. Contrary to the company n°1, this actor is an owner of a part of the clothes proposed to great consumers, and in this respect has to deal with the end of life of the products. This company relies on existing solutions and generally the wastes are landfilled. This actor recognizes being a leading actor on its market, investing in studies to develop a profitable activity, corresponding to its main motivation. Company n°2 deals with 3000T / year as a turnover of 1,3 Billion € and employs 12 000 persons. |
| **Candidate company N°3** |
| Company n°3 is a so called great consumer. User of the professional clothes for its professional activities, it deals with a relatively lower volume than companies 1 and 2 (150T a year). As a public enterprise, the image is a major importance and motivation. Nothing obliges today this actor to focus on the problems of recycling of the clothes of its agents, particularly because it is the agents who remain the owners of their professional clothes. The main figures of this company is a 30 Billion € turnover and 250 000 employees. |
| **Candidate company N°4** |
| Such as the company n°1, it is a seller of professional clothes, with a lower turnover (20Million of €). It is a direct competitor to company n°1. Company n°4 already has an experience of collaborative project of textile recycling. However there is no industrial accomplishment from this former project due to complex industrial study and high processing cost for the recycling activity. |

*Table 13: Description of the candidate companies*

### 4.3.2 Application of the methodology and results

Thus, the hierarchy of the criteria conducted and the data of companies gathered, the initial company of the project has to apply the proposed MCDM method (§4.2.2.1).

#### 4.3.2.1 Step 1: Application of AHP

Step 1 corresponds to the weighting of all the criteria (10 criteria) and then the sub-criteria allocated to each criterion. The model is applied to the specific activity of Extraction of raw material for the current project according to the theory of AHP on a scale of importance given in *Table 14*:

| | |
|---|---|
| 1 | Equal importance |
| 3 | Low importance |
| 5 | Medium importance |
| 7 | High importance |
| 9 | Absolute importance |

*Table 14: Definitions for the scale of importance*

The importance scale is presented in the questionnaire as follows:




*Figure 39: Illustration of the scale of importance*

For this example, criterion X is highly (selection of 7 on the scale of importance) more important than criterion Y.

The evaluation is done between criteria (with 45 questions) and then between sub-criteria of one criteria (with 22 questions).

In order to apply AHP, the project leader answers a questionnaire to obtain the comparison between the criteria. The AHP method has been applied using the software MakeItRational (directly at the address www.makeitrelational.com) (*Figure 40* and *Figure 41*).

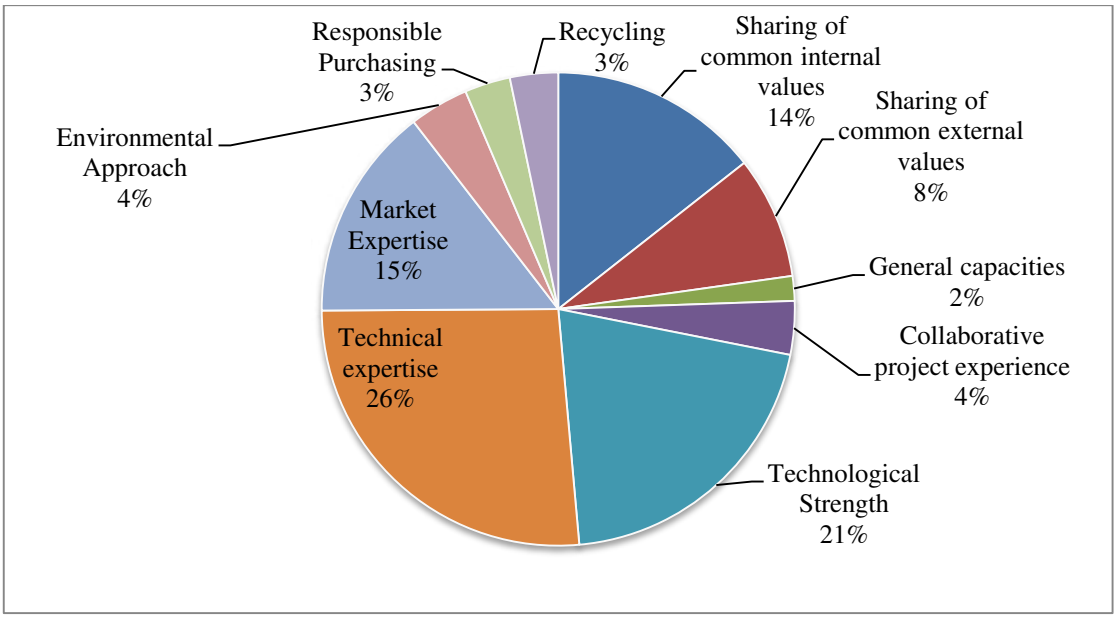



*Figure 40: Weight repartition of the Criteria*

We can observe that the criteria "Technical expertise" and "Technological Strength" are the best rated with respectively 26% and 21%. In this sense we can understand that for the initial company which makes this weighting, the technical side of the project is predominant, with learning and acquiring new Technological knowledge.

For the specific criterion Technological Strength (21%) we obtain the weights such as:

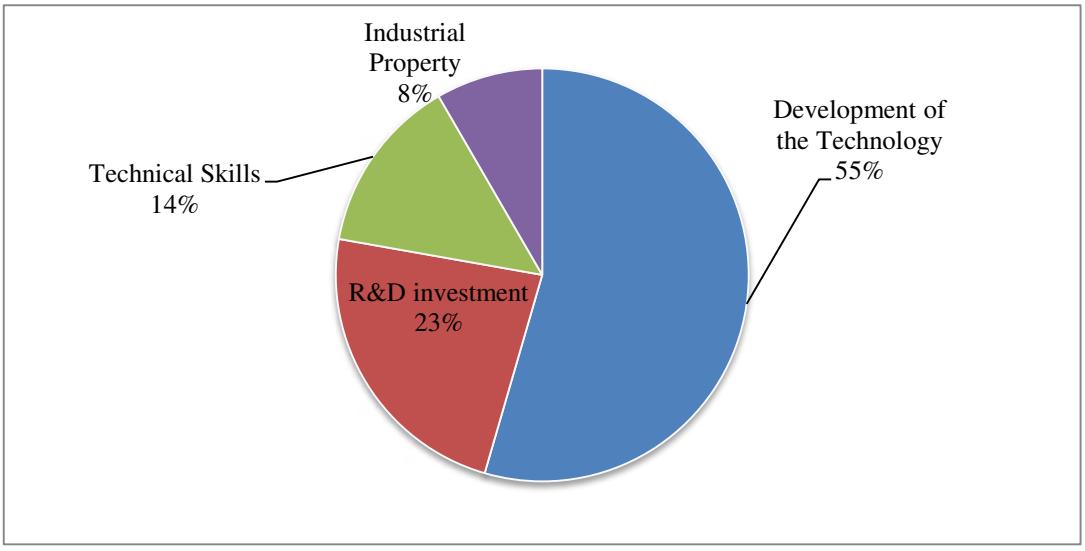



*Figure 41: Example of Weights repartition of the Criterion "Technological Strength"*

For this criterion, we can observe again that the Technological side of the project is of great interest for the initial company, which reflects with 55% of the weight.

Then, the combination of weights for criteria and sub-criteria provides the final sub-criteria weight as we can observe for the example concerning the criterion "Technological Strength":

| Criterion | Weight of the criterion | Sub-criterion | Weight of the sub-criterion | Weight of the combination Criterion*Sub-criterion |
|---|---|---|---|---|
| Technological strength | 21% | Development of the Technology | 55% | 11% |
| | | R&D investment | 23% | 5% |
| | | Technical Skills | 14% | 3% |
| | | Industrial Property | 8% | 2% |

*Table 15: Calculation of the weights and their combination for the criterion "Technological Strength"*

All the results from the AHP technique are in *Annex 8*.

To complete the AHP technique, Saaty (1980) introduced an Consistency Index (CI) in order to check that the judgments are neither random nor illogic. CI is based on the maximal eigenvalue ($\lambda_{max}$ = 11,07) and on the number of criteria (n = 10). In this case; $CI = \frac{\lambda_{max} - n}{n-1} = 11{,}88\ \%$. The consistency ratio (CR) is defined using the random consistency index (RI) as follows:

$$CR = \frac{CI}{RI}$$

With RI = 1,49 (a fixed value for n=10, computed by Saaty), we obtain $CR = 0{,}08 < 0{,}1$. So according to Saaty's criteria to check consistency, data provided by the expert are consistent.

#### *4.3.2.2 Step 2: Application of DEMATEL*

Step 2 corresponds to the analysis of the relationships between causes and effects among criteria. The initial company has to highlight the respective influences between each criterion according to the DEMATEL technique for the same activity. The scale of influence is presented in *Table 16*.

| | |
|---|---|
| 0 | Without influence |
| 1 | Low influence |
| 2 | Medium influence |
| 3 | High influence |
| 4 | Very high influence |

*Table 16: Definitions for the scale of influence*

The scale of influence is presented in the questionnaire as follows:

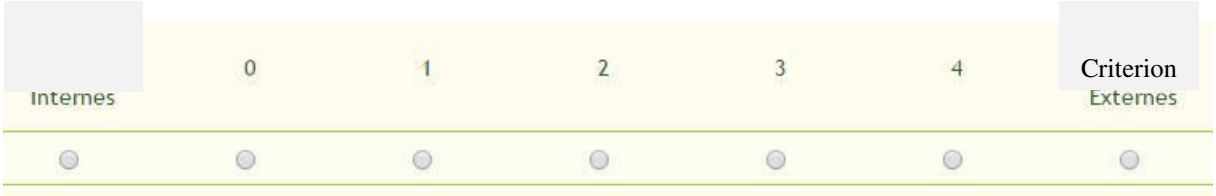



*Figure 42: Illustration of the scale of influence*

It enables to measure the influence of the criterion X on the criterion Y. There are 90 questions for the influences between the criteria.

Two values are important as a result from DEMATEL: *(R+C)* and *(R-C)*. The value of *(R*+C) represents the total effects both given and received by the criteria. In contrast, the value of (*R-C*) shows the net contribution of each criterion. The classification of (*R-C)* is divided between the positive and negative values. When (*R-C*) is positive, the criterion is a net cause. When (*R-C*) is negative, the criterion is a net receiver (Sumrit and Anuntavoranich, 2013b).

*Table 17* presents the synthesis of the criteria influences and their classification. The detailed results enable to understand the influence from one criterion to another, and show which criteria have/receive much influence to/from the others.

| Criteria | Abbr. | R | C | R+C | Classification R+C | R-C | Classification R-C |
|---|---|---|---|---|---|---|---|
| **Sharing of common internal values** | PVI | 0,270 | 0,657 | 0,927 | 10 | -0,387 | (4) |
| **Sharing of common external values** | PVE | 0,603 | 1,773 | 2,376 | 1 | -1,170 | (1) |
| **General capacities** | CG | 0,181 | 0,932 | 1,113 | 9 | -0,751 | (2) |
| **Collaborative project experience** | EPC | 0,656 | 1,107 | 1,763 | 5 | -0,451 | (3) |
| **Technological strength** | FT | 0,914 | 0,277 | 1,191 | 8 | 0,637 | 3 |
| **Technical expertise** | ET | 1,260 | 0,940 | 2,200 | 2 | 0,320 | 4 |
| **Market expertise** | EM | 0,733 | 0,999 | 1,732 | 6 | -0,266 | (5) |
| **Environmental Approach** | DE | 0,900 | 0,686 | 1,586 | 7 | 0,214 | 5 |
| **Responsible Purchasing** | AR | 1,404 | 0,560 | 1,964 | 4 | 0,844 | 2 |
| **Recycling** | R | 1,498 | 0,486 | 1,984 | 3 | 1,012 | 1 |

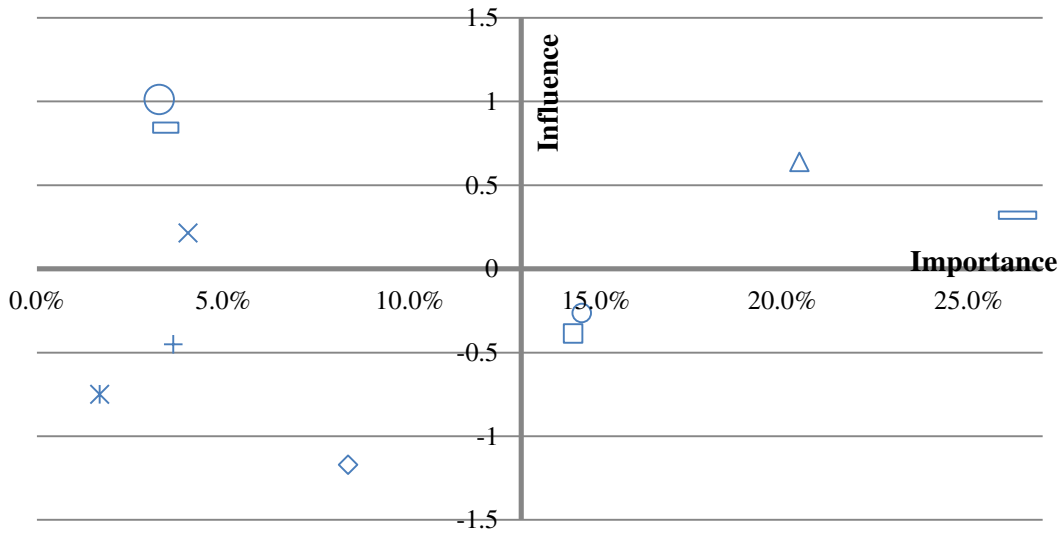
*Table 17: Criteria classification from DEMATEL*

We observe the classification of (*R+C)*. For instance criterion "Sharing of common external values" has the highest total influence effect (both given and received).

The criterion “Sharing of common external values” (highest negative value, classified as (1)), is the most influenced by the other criteria. This aggregated value is confirmed and detailed by the analysis of *Table 28* that highlights the important number of the relationships between criteria.
In addition, the criterion “Recyclability” (Highest positive value, classified as 1) has the greatest direct impact on the other criteria, particularly on the criteria concerning expertise (Technical expertise, market expertise) and the other two environmental criteria (Responsible Purchasing and Environmental Approach) as observed in *Table 28*.

The use of DEMATEL enables to complete the analysis with AHP that considers the criteria independently. Indeed DEMATEL calculates the synergy between the criteria that can highlight influences between them. We propose to compare criteria with the two dimensions: weights from AHP and influences from DEMATEL (

*Figure 43*).




Legend:

| | |
|---|---|
| □ | Sharing of common internal values |
| ◇ | Sharing of common external values |
| ✳ | General capacities |
| + | Collaborative project experience |
| △ | Technological strength |

*Figure 43: Importance VS Influence*

We divided the importance axis at a value of 13% (that is the median value of the obtained weights). We consider that the criteria above have a higher importance and the criteria below a lower importance than the other criteria. For the influence we consider a high influence above 0 and a low influence below 0. In this respect we can see that all the criteria of the Environmental Value have a low importance but a high influence.

The two criteria which have the less importance and influence are the "General capacities" and the "Collaborative project experience". In this particular case study and activity on the RSC, even if we aim at elaborating a collaborative project, the project leader from the initial company does not consider the relative criteria to be predominant. On the contrary the positioning of the criteria "Technological strength" and "Technical expertise" in the up right corner of

*Figure 43* reveals the particular interest of the initial company for these features.

"Technical expertise" (with the highest weight in AHP: 26%) has strong relations with the other criteria (rank 2 and 4 respectively for the *(R+C)* and *(R-C)* classification). However, the observation in matrix D (*Table 28*) shows that only two criteria are greatly influenced (criteria "Sharing of common external values" and "Collaborative project experience"). The project leader considers that the technical expertise of a company influences its experience relative to collaborative projects and the sharing of common external values (see definitions of the sub-criteria in

*Table 12*).

We observe that the criterion "Recycling" has a weak weight (3%) in AHP. However it is the criterion with the highest influence impact (rank 1 for *(R+C)* classification) in DEMATEL. This criterion influences the strongest criterion in AHP ("Technical expertise" (26%)), and other criteria. In spite of its weak weight in AHP, its rank in DEMATEL reveals its interest in the decision making. It is about the same conclusions for the criterion "Responsible Purchasing" also in the Environmental Value dimension.

#### *4.3.2.3 Step 3: Application of TOPSIS*

The final step consists in determining the ranking of the candidate companies. The objective of TOPSIS is to identify the closest alternative to the ideal solution and in the same way, the most distant from the anti ideal solution.

Using the weights resulting from AHP (Weight of the combination Criterion*Sub-criterion), we apply TOPSIS. We perform the evaluation for the 4 candidate companies, presented above, on a qualitative scale and on quantitative normalized data, for each sub-criterion as shown in *Figure 44*.




*Figure 44: Qualitative scale for TOPSIS*

For the criterion "Technological Strength" and sub-criterion "Development of the Technology" we obtain the marks (for example Mark Company 1 = 7) that enable the application of TOPSIS (

*Table 18*).

| Criterion | Sub-criterion | Company 1 | Company 2 | Company 3 | Company 4 | W(X) = Weight of the combination Criterion*Sub-criterion |
|---|---|---|---|---|---|---|
| Technological strength | Development of the Technology | 7 | 8 | 8 | 2 | 11% |

*Table 18: Illustration of the sub-criterion "Development of the Technology" final weight*

With TOPSIS we obtain the ranking of the companies (see *Annex 10: TOPSIS calculations*).

| Company X | TOPSIS Calculation | TOPSIS Classification |
|---|---|---|
| Company 1 | 55% | 1 |
| Company 2 | 40% | 3 |
| Company 3 | 50% | 2 |
| Company 4 | 9% | 4 |

*Table 19: Companies ranking with TOPSIS*

In this table, the TOPSIS calculation shows how each company favors the criteria. The result demonstrates how company 1 is in first place in the ranking. However the TOPSIS index for company 3 (50%) is close to the index for company 1 (55%).

## *4.4 Discussion and further work*

The project leader, who answered AHP and DEMATEL questionnaires, affected a low importance on the recycling criterion which could be surprising as the collaborative project aims at defining a new RSC. However the DEMATEL analysis points out that he considers the great influence of the Environmental value ("Recycling" and "Responsible Purchasing" ranked 1 and 2 for (R-C)), on many other criteria. With this analysis, we understand how the project leader takes into account influencing criteria for the partnership elaboration even if he does not consider environmental criteria with high weights.

Finally, the project leader has selected company 1 to be a partner of the collaborative project. Indeed, TOPSIS enables the project leader to have a ranking of the candidate companies, helping in the partner selection process. However with regard to the good results obtained by company 3, the project leader realized that it was an opportunity to involve this company also in the project. The complementarities of companies 1 and 3 are well suited to the RSC activity "Raw material Extraction".

In this paper, we have proposed an original criteria tree and a MCDM method for partner selection concerning the definition of recycling collaborative R&D projects.

This criteria tree construction is coming from a literature review (see *Annex 4*), the observations of existing recycling collaborative projects (Farel et al., 2013) and the definition of the hierarchy (see *Figure 4* and *Figure 37*). The tree structure and criteria definitions are original as it is the combination of criteria from two research fields (see *Figure 33*) adapted to partner selection for recycling collaborative projects. Because the construction also takes into account experts' reviews and especially industrial experts involved in recycling collaborative projects, it is adapted to our research topic and to a further industrial use of the model. Thus, the presented case study has illustrated the interest of this criteria tree and particularly the discussion about the environmental dimension.

In the research field of R&D collaboration, Arranz et al. (2008), emphasized variables that present positive influence for collaboration such as "the technological level" of a potential partner. However he does not propose any MCDM technique (or a combination of techniques such as AHP-DEMATEL-TOPSIS), to select partners, but only gives guidelines to the decision makers. As highlighted by (Geum et al., 2013), who addressed the question "how best to select collaboration partners?" (in research field 5 in *Table 11: Bibliometric chart of the literature review (see Annex 5)*), many researchers have worked on R&D partner selection using subjective expert judgments. This subjective aspect of MCDM techniques may be criticized. However, in this paper, we checked the consistency of expert judgments by computing a consistency index (as proposed by Saaty) and by proposing a mapping of importance vs influence (results from AHP – DEMATEL) that helps the project manager to better understand the consistency of the criteria weights. Indeed, the original mapping of Importance VS Influence (

*Figure 43*) has proved to be useful for the project manager to realize its implicit preferences and DEMATEL enables to validate the weights computed by AHP regarding his aim of specific decision making. In our case study the observation of high influencing environmental criteria with rather low

weights, proves that the project leader is aware of the environmental concerns, for this partner selection. This is consistent with his mission to define a recycling collaborative project.

Concerning the partner selection in GSCM, MCDM techniques have already largely been developed, and criteria for partner selection settled (see *Table 21: (Büyüközkan and Berkol, 2011)*; *Table 22: (Wu et al., 2009)*; *Table 23: (Kannan et al., 2009): Table 24: (Kannan et al., 2014)*). However to the best of our knowledge, the combination of the techniques AHP-DEMATEL-TOPSIS has not been proposed and its interest has not been discussed yet in the existing literature.

Moreover the originality of our work concerns the integration of two key research fields (partner selection either in GSCM or in the scope of collaborative R&D projects), regarding the increasing number of such industrial studies due to the regulation for end of life product management.

However, this case study is led on a specific RSC activity and by a specific group of experts which may be a limit of the validation of the proposed method. This conclusion would have to be confirmed by further investigations. The perspective to apply the combination techniques to other activities and other projects would comfort us in its relevance. However it presents a demonstration of the method application and supports good bases for further investigations.

Concerning the use of MCDM techniques that take into account influences among criteria (for instance, Analytic Network Process, Choquet integral), this perspective is envisaged even if this kind of approaches may be more fastidious to be computed than the proposed approach in this paper: longer questionnaire, more complex algorithms. The comparison should be useful.

# CONCLUSION

In the scope of this thesis, we investigated the new object of the industrial recycling process and recycling supply chain, in a new industry. Our thesis allows us to proposing methods for the elaboration, development and optimization of these innovative recycling processes. At different scales, the industry; the supply chain; the project, our problems focus on giving methods, to drive eco-innovation. These methods can be considered as guidelines by industrials to run proactive actions toward the issue of differentiation, using eco-design approaches and collaborative project conduction. In fine, the combination of the proposed three methods favors the overall environmental proactive approach of a business and the development of RSC.

## ➢ *Contributions*

First of all, we consider that the eco-system of this new object requires a structural analysis method. Thus we proposed the associated research question.

- ✓ **How can we study the structure of an emerging recycling industry?** (*CHAPTER 2*:).

We have noted in the literature state of the art that existing analysis methods enable to conduct structural industrial analysis (Porter, 1985). However the specificities of the recycling industry have not been treated, thus our positioning is original. Firstly, the identification of the market segment gives the scope of the analysis but also defines the material types that are considered. In this respect we highlighted the need to identify and characterize by market types ("individual"; "owner structure"; "rental structure") the activities that manufacture and deliver new products on the market. The volumes of these new products represent a potential supply of EoL goods. Their average life time (use phase period) permits to understand when this supply will potentially enter in the waste management circuits. Moreover, considering the regulation based on the growing "polluter pays" principle and the different waste management systems, the characterization of the activities by market types highlights in which of these waste management circuits the waste is taken care and where it is located. This study is conducted to understand the overall "EoL Material Availability", considering the *material type*, the potential *volumes*, *when* the supply will be available and its *location*. It gives indications on the dimensions required for the recycling activity and assures the availability of an EoL material supply for further investigation in the potential recycling process when designing a RSC for instance.

The second step of the method, when looking at the recycling stream, focuses on the technology required to transform the EoL material into a RRM. We also highlighted how this stream is in competition with others considering the ISO 14062 and how it is submitted to importation and exportation. The need to understand the volume of EoL material destined in this stream is important to dimension the activity on the territory. The preparation activity and its processes are identified based on existing technologies or/and implies specific equipment design with for instance the help of specific equipment suppliers. But also, we enhanced the fact that this study is driven by the specifications coming from the final product design. Once the technology of the RRM preparation is established, we obtain a new potential volume of RRM usable in the new product manufacturing.

The manufacturing activity study enables to integrate the RRM as a component of a new product for an identified market. This step requires product design activities in order to meet the functional established requirements in compromise with the technical capability and limits of the RRM preparation. We have pointed out that this step could be conducted regarding two different approaches, pulled by the market and pushed by the technology. It also enables to identify different range of technologies that can use the RRM, and different application fields. When identified, they represent potential applications or competitive streams.

For each step the exploitation conditions are studied. For the first step we emphasized that the logistic can be an important economic barrier depending on the territorial repartition of the resource, the location feature of the EoL material availability. In the synthesis study we highlighted the different possible situations between the functional value of the product and its final price. If the economic balance is not reached when the project of a RSC is conducted, we observe in the industrial environment that the green image of a product will generally not be enough for a market penetration (see §1.1.2). However we observe particular cases when activist markets are targeted, but it remains marginal and craft applications.

In the application of the method, the case study presents the structure of the FTRI (models represented by *Figure 20*, *Figure 23* and *Figure 24*). The possibility to conduct the structural analysis and to obtain the presented result, comfort us in the applicability of the method. The application of the method also reveals the fuzziness and emerging character of this industry. Indeed, the data gathered only give a general insight of the FTRI structure. The competitive environment for recycled textile and the evolution of the regulation make the analysis tedious considering industrials with uncertain and secret behaviors. However, our case study presents the state of the art of the industrial textile recycling environment.

In fine, the answer of our first research question is an original method to conduct structural industrial analysis in the recycling industries that can be used by business for decision making. One of these decisions can be the strategy of R&D collaboration to share development risk for the design of an RSC. This consideration leads us to our second research question.

- ✓ **Considering that collaborative projects favor the opportunity to conduct R&D studies, for the specific objective to develop a new RSC, how should these projects be organized?** *(CHAPTER 3:).*

Our hypothesis, based on existing research work, is that R&D collaboration favors the development of new activities, especially in an emerging industry (Arranz et al., 2008). However, in our literature review, we emphasize the lack of existing methods to guide industrials for the application of eco-design practices (Brezet, 2001; Lindahl, 2006). Within our research scope and hypothesis we propose an original method for a "recycling R&D collaborative project" definition. Because our problem is specific to the RSC, we present specific guidelines considered in the elaboration of the method. These guidelines are:

1/ A supply chain approach from the RRM extraction to the Disposal of End of Life products (with the particular consciousness of a complex logistics)

2/ The importance of the early design phase

3/ A collaborative project for sharing industrial skills and technologies

4/ A recycled product oriented approach for the design of a RSC, which corresponds to an innovative recycling activity (market pull and technology push approach)

5/ Consideration of the environmental regulations and more specifically the toxicity of the RRM

6/ Emphasis on the importance of the project partner selection

7/ Opportunity to seek for financial helps from governmental funding systems, which support environmental challenges

The simultaneous approach of the supply chain and product design enables to construct the project with an integrated RSC activities vision such as presented in the second chapter with the three steps method. This is also the reason why, the understanding of the recycling industry structure favors the conduction of the RSCDP and the information from the second chapter can be implemented in this method.

The application of the RSCDP to a specific recycling collaborative project enables to demonstrate its applicability. Moreover, because the method was elaborated in contact with industrials it is all the more relevant for the organization of such projects.

Our contribution is original, demonstrated its applicability and emphasized a critical aspect that is the selection of partners to favor the success of the project. This observation leads us to the conclusion regarding the third research question.

- ✓ **How to help the industrial to decide which partner is best suited for a R&D recycling collaborative project?** *(CHAPTER 4:).*

In the literature state of the art we identified two specific research fields (see *Figure 33*) that are:

- 5: Partner selection in the scope of collaborative R&D projects
- 6: Partner selection in the scope of GSCM

This observation, also based on a bibliometric analysis (see *Table 11*) reveals the importance of the issue and leads toward this last research question.

However, when conducting our bibliographic study, we found that our research scope (4: Collaborative R&D projects vertically integrated on the SC; see *Figure 33*) is not (or poorly), investigated. In this respect, the existing partner selection models and criteria cannot be used within our context and we propose an original criteria tree model to counter this issue. We developed this model using the existing criteria from the literature in the two research fields (5) and (6) presented above. But we also used expert feedbacks in order to give a consistent definition of each 25 criteria (see

*Figure 34*).

Completing this contribution, we defined a MCDM method with a combination of three existing techniques (AHP-DEMATEL-TOPSIS). Considering the issues in MCDM research field, such as the recommendation to consider more than a single technique for a better decision support, or to consider

the relation between the criteria (Chai et al., 2013; Lee et al., 2009), we proposed an original ranking method.

The ranking method positions the environmental value as an upscale dimension. In this respect, it favors environmental practices. The application of the method and our discussion in *(CHAPTER 4:)* highlight the influence of this dimension in regards of the specific project context.

In the end, the application of the RSC partner selection model at an early project definition phase enables the project manager to have an overview of its potential partners, helping in the selection decision process.

To put in a nutshell, the combination of the three presented methods highlights how we can act on the elaboration, development and optimization of a recycling activity. Conducting this process favors a proactive approach regarding business opportunities and strategy making in a recycling environment, and contributes to filling a research gap considering the development of an eco-innovation management practice.

### ➢ *Limits*

This paragraph raises the questions of relevance and transposition of our contributions to other case studies. Indeed, our positioning and immersion in a specific industrial environment (engendered by the CIFRE) is both the strength and the weakness of our research work. Our observations and conclusions may be driven by a restrained industrial environment for which we propose an adapted method, but subjective to this particular group. Even if we intended to broader our research scope by investigating a larger environment (see *Figure 4*) our contribution may be considered as only a specific answer to a research problem driven by industrial questionings.

We focused on the elaboration of practical methods, and we considered the main best practices that we integrated. However, the particular analysis of the recycling industrial structure is long and tedious to conduct. We have seen that depending on the maturity of the businesses, they are more or less concerned with these environmental questions and in this sense less mature companies might have difficulties in driving eco-innovation and particularly the proposed model. Indeed it requires time, considered as a luxury by many businesses. We did not study to which company types these methods are adapted but we are conscious that it depends on the maturity level.

Our contribution presents interests for the particular scope of recycling. However, our focus on the FRTI and a French collaborative project for textile recycling, which are the objects of our case studies in *CHAPTER 2*: and *CHAPTER 3*: also oriented our observations, industrial feedbacks and best practices identification. Because we applied the method on a single case study, the validation of the contributions may be discussed, especially considering the possibility to apply the models to other recycling emerging industries (plastics recycling, biopolymer recycling and others).

In the second chapter we emphasized the fuzzy and secret feature of the studied environment. In this respect, the synthesis work of the case study (§2.3.4) presents how to understand the textile RSC

development conditions (Value Function; Exploitation conditions; Market price) but is limited in giving examples of existing applications. Indeed these data and knowledge are new and represent a competitive advantage for businesses which investigated these recycling fields and are submitted to none disclosure agreements.

Moreover, regarding the collaborative project, investigated as our case study in *CHAPTER 3*:, the conclusion regarding the success of the project cannot be presented as it is still running by the time we are writing this conclusion. Although, the project is at its final stage, the project leaders are working with the clients to launch the commercialization of the products in order to start developing the associated RSC. The economic equation is defined, the technical limits of the recycling process and design work possibilities enhanced, the project also received an innovation award (innovation award 2014 - Expoprotection Paris), but only the commercialization will reveal the true success of the eco-innovation process. In fact we encounter the same difficulty as other methodological research studies (Pigosso et al., 2013; Seuring 2013), which is the lack of industrial validation.

The fourth chapter presents a practical method to be integrated in the RSCDP as a decision making tool. The case study is led on a specific RSC activity ("extraction of RRM"), a specific collaborative project, and by a specific group of experts which may be a limit of the validation of the proposed method. Moreover the technique combination is proposed based on the literature best practices, but is not confronted to another ranking method.

### ➢ *Perspectives*

Our analysis of the FTRI would require a dynamic observatory to witness its evolution. Indeed we presented a photography of existing data but due to the newness of the regulation, the industrial feedbacks over ongoing projects, a continuous observation should reinforce our initial model. An observatory could help to better understand this emerging industry and to identify business opportunities. However it would require finding financers, interested in such analysis results and on a sharing base.

The possibility to transpose the RSCDP to other RSC projects could be further investigated by the application of multiple case studies. Indeed, we have noticed that a single application is a limit of the methods validation. A way to do so could be to use existing organisms such as competitive poles, which aim at gathering industrials around common problems which may become collaborative projects. When the object of the study corresponds to new RSC design, these organisms could apply the model to reinforce its validation.

The development and establishment of a feedback index could emphasize the relevance of the method over time but also potentially highlight the need to integrate new general features not observed in this present research work. In this sense, the observations of concluded recycling collaborative projects should be analyzed and give feedbacks to the method.

We could also further investigate to which company's profiles this eco-innovation process is best suited. Indeed we have noted that its applicability may depend on the business maturity level, and we based our work on the fact that a company is investigating, on a particular project, how to adopt a more proactive approach. However, in the end, we do not know the requirements for the implementation of the models

that may be best suited for organisms such as competitive poles, rather than companies with a lower innovation capacity index.

Our fourth chapter corresponds to a critical aspect of collaborative projects, and we conducted an initial study in a new research context. We have seen the limits of the method regarding the application on one single project activity; we could run the process all along the project for each activity. Moreover, feedbacks over the initial selection should be measured in order to define the effectiveness of the selection process. Regarding the choice of the MCDM techniques, we chose to not focus on the fuzzy aspects even if it is the dominant trend in this research field. Indeed, because it is a new investigation context combining two research fields, we wanted to validate a combination of well known methods before going further and integrate fuzzy methods in future work.

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# *ANNEXES*

*Annex 1: Description of the French law transposition from the Waste Framework Directive*

In France, the Waste Framework Directive was transposed by the decree n° 2011-828 of the 11th July 2011("Décret n° 2011-828 du 11 juillet 2011 portant diverses dispositions relatives à la prévention et à la gestion des déchets," 2011). However, it is only by the decree n° 2012-602 of the 30th april 2012 ("Décret n° 2012-602 du 30 avril 2012 relatif à la procédure de sortie du statut de déchet," 2012) which complets the preceding one, that France formalized the procedure for a waste to become a product again (Cerfa n°14831*01 accessible on service-public.fr)**.** Indeed, this procedure is particular to each state member. In France it takes into account the environmental code and the EWC ("COMMISSION DECISION of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Co," 2000) which permits to find the relative EWC Code for the considered waste. In this catalogue a waste description is established by Commission Decision 2000/532/EC, reviewed and incremented with the evolution of the wastes. Regarding the project context, specific definitions of wastes are identified for the textile industry such as "waste from composite materials" or "wastes from processed textile fibers".

*Annex 2: Regulation Reach and action for EoL issues*

REACH (Registration, Evaluation, Authorization and Restriction of Chemical substances) is supported by the European Community Regulation on chemicals and their safe use (EC 1907/2006) ("Waste management," n.d.). The 1st June 2007, the law entered into force. REACH aims at improving the protection of human health and of the environment (*REACH, 30 réponses pour être conforme à la réglementation européenne*, 2008). In order to do so an earlier identification is done on chemical substances. More and more substances are included gradually into REACH. It is the ECHA (European Chemicals Agency) that is responsible of REACH central database, and the evaluation of suspicious chemicals.

In this regulatory context, how the conformity to the environment can be assured with EoL wastes which have been submitted to different uses and eventually polluted? How the project, dealing with heterogeneous RRM, will be able to demonstrate the conformity to REACH? Indeed, for instance an EoLV is brought into the destruction center after an average of 20 years, the textile and foams from one car to another can be more or less polluted by the environment. If only it was a matter of pollution, but 20 years ago, a vehicle was not design for REACH which only is applied since 2007. It is another difficulty that is being taken into account for the recycling of the materials. Moreover, as the vehicles are not commercialized any more, it is not possible to find security data sheets from the OEM, there is quasi no traceability of the material used into former cars. This traceability could have helped to understand the big changes in textile and foam trends used in the cars.

With these features, the period of the pre-registering phase of REACH, as a new, mandatory tool for substance tracing, created a turbulent environment in the recycling industry. Indeed, from their standpoint, the recycling stakeholders have not been consulted by the ECHA organism for the implementation of the regulation and at the release point they did not understand their position. Because REACH impacts the producers, who need to declare the substance used, based on existing lists reviewed twice a year, the RRM producers did not know how to be situated, and parts of them actually pre-registered on a preventing behavior, because of this fuzziness (from collection of testimonies). Of course, for most of it, the RRM reverted to be steal, and the recycling loop of such material is considered boundless with well know alloys used, even with 15 year time lag, the average lifetime of a vehicle. In this sense, and clarity made with ECHA in a second time, the industry was not to be worried, and considered the original virgin material as the only one to be declared. In this way, REACH and the European regulation that stand the waste management scale (Reuse – Recycling – Incineration – Land-field) remains coherent, and don't limit recycling.

However, we understand that when the scope is larger than Steal or non-complex Plastics, the question of REACH in RRMs should be questioned further. The main reason comes from the OE client's requirement, which must control hazardous material in its vehicle composition. Regarding steal or PP RRMs, the knowledge of the material and by extension the knowledge of associated hazardous substances, comforts the transformer and producer on the quality of the manufactured recycled product. But how to deal with complex materials existing in car components? Such as textile, for which the origin is unknown when the vehicle comes into its EoL, as no detailed database regarding material composition are available from original constructors, and by extension, no analysis process for its utilization would exist at a present time. In this case, in a recycling matter, how to guaranty the conformity to the regulation and make sure that textile products, introduced 15 years ago in a vehicle composition, remains conform to the standard of the client? PVC plastic components, or specific dies used in the textile

industry, are illustrations of the issue. By the time they were used the impact on health was not demonstrated, but today they are specified in the REACH restricted substance list, and henceforth, producers are using alternative solutions. Because of the upgrading restrictions, it is neither likely nor acceptable to recycle these materials, which have been, in a second time and since REACH, considered has dangerous for health. In this sense, when the OE is not confident in the origin of the RRM, they would rather not take the risk to potentially introduce restricted substances, even if the RRM come from its own EoL vehicle. It is the case and situation for EoL vehicles textiles today.

Those facts highlight a primordial issue for the acceptation of a recycled product by the client, and for the successful introduction of an innovative textile product. The requirement of a REACH declaration is general to all materials, and recycled products are submitted to the same rules. We saw that the risk was more easily taken by clients considering well known materials such as steal or PP, but for heterogeneous materials, coming from more complex supply chains, questions about the material quality are raised as in the current state of the art no database enables to verify the conformity of the RRM. However the product must respond to the client need, and in this respect it is necessary to drive a study on the potential hazardous substances present in the heterogeneous selected textile RRM.

The lack of information brought us to take the problem empirically and make a testing procedure (see *Annex 3*) of the considered material following a specific control plan. This plan will have to take into account the punctual material assessment on a specified distribution, but also the dynamic evolution of the substances entering into REACH. It is a task run by the project, worked with a specialized laboratory in substances detection.

*Annex 3: REACH Study work – Engineering work*

| | |
|---|---|
| Projet | ValTex |
| Titre de l'étude | PDCM (Plan de contrôle matière) |
| Equipe projet | Fabien Roland (ITECH)<br>Elisa Bonald (FEDERAL-MOGUL) |
| Date | 09/2014 |
| Sujet | Certification REACH des matières fin de vie automobile (cas Ceintures sécurités et Airbags) |

# 1 CONSIDERATIONS POUR L'ETUDE

## 1.1 Contexte de l'étude:

Dans le cadre du projet ValTex il est question d'extraire des sites de déconstruction automobiles, des gisements textiles recyclables, qu'on pourra utiliser pour la fabrication d'un nouveau produit non-tissé à partir des fibres courtes obtenues après traitement. Le projet à permis de prouver la faisabilité technique de ces mélanges, à partir d'airbags, de ceinture de sécurité, de housse de siège, d'absorbants acoustiques, fournis par le réseau INDRA. L'introduction sur le marché de ce produit innovant à partir de matières premières recyclées rencontre toutefois des barrières à l'entrée. Il s'agit pour le client final (constructeur automobile dans le cadre de ValTex) de la prise en compte du risque de la diffusion de substances chimiques interdites dans des véhicules neufs. Dans ce sens, la réglementation Reach impose au constructeur de déclarer les matières utilisées dans les véhicules, qui eux-mêmes imposent une déclaration obligatoire à leurs fournisseurs. Dans ce contexte d'assurance de la conformité règlementaire et pour permettre l'acceptation du produit innovant composé de matière première issue de véhicule hors d'usage (VHU), cette étude a été initiée par le fournisseur du produit issu de recyclage FEDERAL-MOGUL et le laboratoire d'ingénierie de l'ITECH.

## 1.2 Problématique :

Les VHU arrivent sur les sites de démontage fin de vie (entre autre du réseau INDRA qui couvre 1/3 du territoire), et y sont traités (dépollution, extraction des matières pour le marché d'occasion…). Ces « assemblage » automobile ont été conçus, 10,15, 20 ans en arrière, et les bases de données (type IMDS aujourd'hui), n'existaient pas. Aucune traçabilité des matières employées pour la fabrication des airbags ou des ceintures de sécurités n'a pu être accessible dans le cadre du projet, bien que plusieurs hypothèses d'experts aient pu être définies, aucune preuve n'a pu être fournie. Ce constat nous a amené à prendre une orientation empirique de l'évaluation des matières fin de vie des VHU ; comment assurer la conformité réglementaire tout en optimisant les coûts de contrôle des matières premières recyclables ? Notre réponse à cette problématique constitue notre étude « Plan de Contrôle Matière » (PDCM).

## 1.3 Objectif :

Assurer la conformité règlementaire lors de l'utilisation de matière fin de vie issue des véhicules hors d'usage (VHU), en minimisant les coûts du processus d'évaluation et de contrôle.

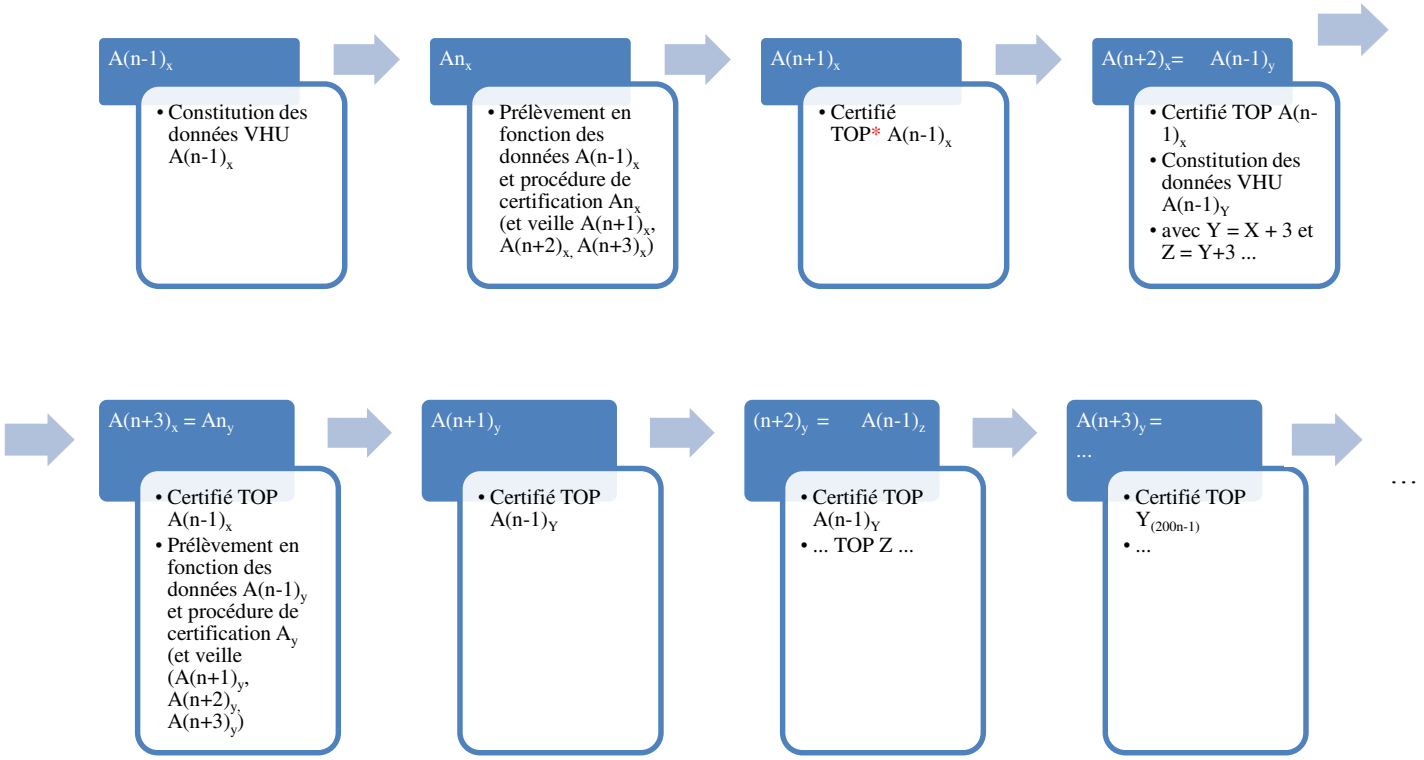
## 1.4 Architecture de l'étude :

Cette étude permet :

I/ De définir le modèle d'échantillonnage à mettre en place pour répondre à l'objectif de conformité réglementaire en minimisant le nombre de tests à réaliser. Apporter les justifications scientifiques associées.

II/ De définir la procédure d'échantillonnage à réaliser pour répondre à l'objectif de conformité règlementaire tout en respectant l'objectif de minimisation des coûts de cette procédure. Apporter les justifications scientifiques associées.

## 1.5 Résultats principaux :




*Chronologie de l'application du PDCM*

*Annex 4: First criteria lists from the literature study*

***IN RESEARCH FIELD 5:***

| **Characteristics** | **Criteria** | **Sub-criteria** |
|---|---|---|
| The basic characteristics of candidates | Technology strength | Technology share |
| | | Technology leadership |
| | | Technological impact |
| | R&D openness | Openness of organization |
| | | Openness of technology field |
| | | Openness of technology |
| The relational characteristics of candidates | R&D linkage | Joint ownership |
| | | Joint development |
| | | Joint operation |
| | Collaboration effect | Knowledge inflow |
| | | Knowledge criticality |
| | | Knowledge similarity |

*Table 20:* (Geum et al., 2013)

***IN RESEARCH FIELD 6:***

| **Dimension** | **Criteria** |
|---|---|
| Strategic dimension | Similar values-goals |
| | Similar size |
| | Financial stability |
| | Comparable culture |
| | Successful track record |
| | Sustainable relationship |
| Business excellence dimension | Technical expertise |
| | Performance |
| | Market knowledge |
| | Managerial experience |

*Table 21:* (Büyüközkan and Berkol, 2011)

| Criteria | Sub-criteria |
|---|---|
| Strategic dimension | Unique competencies |
| | Compatible management styles |
| | Compatible strategic objectives |
| | Higher or equal level of technical capabilities |
| Degree of Fitness | Compatible organization cultures |
| | Willingness to share expertise |
| | Equivalent of control |
| | Willingness to be flexible |
| Intangible Assets | Trademarks, patents, licenses, or other proprietary knowledge |
| | Reputation |
| | Previous alliance experiences |
| | Technically skilled employees |
| Marketing Know- ledge Capability | Increase market share |
| | Better export opportunities |
| | Knowledge of local business practices |
| Complimentary Capabilities | Managerial capabilities |
| | Wider market coverage |
| | Diverse customer |
| | The quality of distribution system |

*Table 22:* (Wu et al., 2009)

| Criteria | Explanation |
|---|---|
| 1. Quality | It covers product performance, accuracy, etc. and also 3PRLP's quality awareness, inspection methods, etc |
| 2. Delivery | It refers to 3PRLP's ability to meet delivery schedules. It covers flexibility and reliability of delivery, lead time, etc |
| 3. Reverse logistics cost | It includes inspection cost, inventory cost, transportation cost, packaging cost, material handling cost, warehousing cost, etc |
| 4. Rejection rate | It refers to inability of the returned product to meet the quality specifications consistently for the recycling process |
| 5. Technical/Engineering Capability | It refers to the availability of technical manpower, state-of-art reprocessing technology, R&D facilities, capability to perform reverse logistics function, etc |
| 6. Inability to meet future requirement | It refers to the inability to meet the expected demand, i.e. return ramp-up co-ordination |

| | |
|---|---|
| 7. Willingness and Attitude | It refers to the attitude of the 3PRLP towards the buyer and its willingness to do reverse logistics business with the buyer. |

*Table 23:* (Kannan et al., 2009)*:*

| **Main criteria** | **Sub-Criteria** | | **Definition** |
|---|---|---|---|
| C1: Quality | C11: | Quality Systems | Ensure high quality control on the products and provide the quality related certificates like ISO9000, QS9000 etc. |
| | C12: | Quality Assurance | Third party quality certificate is produced by supplier to ensure the green product |
| | C13: | Reject Rate | At what percentage the supplied materials are rejected by the quality control |
| | C14: | Warranties and Claim Policies | Existence of warranties and claim polices are provided by the supplier or agreements between the customer and the supplier for the faulty products |
| | C15: | Capability of handling abnormal quality | Capability to fulfill the abnormal quality specification of the customer without compromising the existing product price |
| C2: Price | C21: | Purchasing price | Lower product price without compromising the quality which includes warranty cost, processing cost, cost of greening etc. |
| | C22: | Price performance value | High quality performance for the product value |
| | C23: | Transportation cost | Fixed transportation cost for the supply of the products |
| C3: Capability of Supplier/ Delivery | C31: | Supplying capability | Ability to meet delivery schedules or promises and the ability to react quickly to the customer orders |
| | C32: | Level of Technique | Using innovative tools for scheduling and delivery |
| | C33: | Capability of Product Development | Capability of developing new designs and speed of development |
| | C34: | Order fulfill rate | Compliance with the predetermined order of quantities |
| | C35: | Lead time | Flexibility in time between the placement and the arrival of an order without compromising quality and cost. |
| | C36: | Capability of R & D | Having infrastructure for research and development work |
| | C37: | Technology Level | Technology development of the supplier to meet the current and the future demand of the firm |
| | C38: | Flexibility of the Supplier | The ability of scheduling and changing orders |
| | C39: | Supplier Stock Management | Compliance of supplier's stock management system with the production line |
| C4: Service | C41: | Rate of processing order form | Level of processing the customer order |
| | C42: | Rate of delivery in time | Level of delivery on time as per agreement with the customer |

| | | | |
|---|---|---|---|
| | C43: | Degree of information modernized | Tracking system of current orders, share expertise and resolve conflicts |
| | C44: | Service quality | Provide the service dimension by reliability, responsiveness, assurance and satisfaction |
| C5: Environment protection/Environment Management | C51: | Environment Protection System Certification | Whether the supplier has environment-related certificates, such as ISO 14000 |
| | C52: | Environment Efficiency | Production of material ecologically efficient |
| | C53: | EUP | Eco-design requirements for energy using products |
| | C54: | RoHS | Level of restriction of hazardous substance in the production process |
| | C55: | Environmental Protection policies/plans | Compliance with the local regulation and policies |
| C6: Corporate social responsibility (CSR) | C61: | The interests and rights of employee | Labor relations, human rights and interests of employee |
| | C62: | The rights of stakeholder | The interests and the right of shareholders, consumers, communities and related stakeholder |
| | C63: | Information disclosure | Expose non-financial information |
| | C64: | Respect for the policy | Comply with local regulations and policies |
| C7: Pollution control | C71: | Air Emissions | The quantity control and treatment of hazardous emission, such as SO2, NH3, CO and HC1 |
| | C72: | Waste water | The quantity control and the treatment of waste water |
| | C73: | Pollution control Initiatives | Pollution minimization initiatives related to Air emissions, Waste water disposal, Solid wastes, Energy consumption, Use of harmful materials, Hazardous wastes etc. |
| | C74: | Pollution Reduction Capability | Level of systems used to reduce the pollution |
| C8: Green Product | C81: | Recycle | Ability to treat the used products or their accessories, to reprocess the materials, and to replace the required new materials when producing new products. |
| | C82: | Green Packaging | The level of green materials used in packaging |
| | C83: | Cost of Component Disposal | The processing cost at the end of life of the products (The cost is reduced as recycling increases) |
| | C84: | Green Certifications | Provides green related certificates for products |
| | C85: | Green Production | Level of clean or environmental friendly production system maintained |
| | C86: | Reuse | Ability to obtain the used products and their related accessories. |

| | | | |
|---|---|---|---|
| | C87: | Re-Manufacture | Detach certain accessories from waste products for the future usage. |
| | C88: | Disposal | Capability of incinerating or burying the disposed material in the green way. |
| C9: Green Image | C91: | Materials used in the supplied components that reduce the impact on natural resources | The use of materials in the components that has a lower impact on the natural resources |
| | C92: | Ability to alter process and product for reducing the impact on natural resources | The ability of the supplier to alter the process and product design in order to reduce the impact on the natural resources |
| | C93: | Ratio of green customers to total customers | The ratio of customers that demand green products to the total customers of the supplier |
| | C94: | Green customers' market share | Retention of customers with green purchasing habits |
| | C95: | Stakeholder's relationship | Relationship with the supplier in the environmental activities and initiatives. |
| | C96: | Green materials coding and recording | Suppliers utilize materials coding and recording to separate RoHS and non-RoHS materials in storage which aims to avoid material mixing. |
| C10: Green Innovation | C101: | Green Technology Capabilities | Level of implementation of clean technologies |
| | C102: | Green Design | Capability of new product design of the supplier to meet the current and the future demand of the firm |
| | C103: | Green Process/Production Planning | The level of green process planning of the supplier |
| | C104: | Recycling Product Design | Supplier products are designed for recycling with the goal of achieving more efficient and complete recycling |
| | C105: | Renewable Product Design | Product manufactured by using lowest energy from the natural resources |
| | C106: | Green R & D Project | Green R&D projects on green product and process planning |
| | C107: | Redesign of Product | Capabilities to redesign the product to the environmental standards |
| C11: Hazardous Substance Management | C111: | Management for Hazardous Substances | Management of hazardous substances in the production procedure, the company should carry out preventive management approaches for the restricted chemicals. |
| | C112: | Prevention of mixed material | Level of production procedure standards should be established for green and non-green materials. |

| | | | |
|---|---|---|---|
| | C113: | Process Auditing | Auditing system for checking process conditions, parameter-setup document (document SOP and records) management, product change management, disqualified product management and tracking, improvement approaches, and quality management system for production environment. |
| | C114: | Warehouse Management | Level of warehouse management could prevent material-mixing and maintain the product quality |
| | C115: | Inventory of Hazardous Substances | Compliance with regulations of hazardous substances to prevent the products from containing exceed in restricted substances |

*Table 24:* (Kannan et al., 2014)

*Annex 5 :* References for the Bibliometric study

| Field (1;2;3;5;6) | Authors | Number |
|---|---|---|
| 1 | (Arranz et al., 2008) | 1 |
| | (Chen, 1997) | 2 |
| | (Link et al., 2002) | 3 |
| | (Calamel et al., 2012) | 4 |
| | (Adeoti and Adeoti, 2005) | 5 |
| | (Sarasini, 2014) | 6 |
| | (Ben Letaifa and Rabeau, 2013) | 7 |
| | (Narula, 2004) | 8 |
| | | |
| 2 | (Sharfman et al., 2009) | 9 |
| | (Zhang and Wang, 2014) | 10 |
| | (Vachon and Klassen, 2006) | 11 |
| | (Zhu et al., 2011) | 12 |
| | (Rizzi et al., 2013) | 13 |
| | (Mentzer et al., 2000) | 14 |
| | (Youn et al., 2011) | 15 |
| | (Govindan et al., 2014) | 16 |
| | (Appolloni et al., 2014) | 17 |
| | (Andiç et al., 2012) | 18 |
| | (Diabat and Kannan, 2011) | 19 |
| | (Walker et al., 2008) | 20 |
| | (Niknejad and Petrovic, 2014) | 21 |
| | (Simchi-Levi et al., 2003) | 22 |
| | | |
| 3 | (Roy and Słowiński, 2013) | 23 |
| | (Saaty, 2004) | 24 |
| | (Sumrit and Anuntavoranich, 2013b) | 25 |
| | | |
| 5 | (Kumaraswamy and Anvuur, 2008) | 26 |
| | (Verdecho et al., 2012) | 27 |
| | (Geum et al., 2013) | 28 |
| | | |
| 6 | (Büyüközkan and Berkol, 2011) | 29 |
| | (Theißen and Spinler, 2014) | 30 |
| | (Ding et al., 2013) | 31 |

| | | |
|---|---|---|
| | (de Boer et al., 2001) | 32 |
| | (Chai et al., 2013) | 33 |
| | (Ho et al., 2010) | 34 |
| | (Hsu and Hu, 2009) | 35 |
| | (Igarashi et al., 2013) | 36 |
| | (Kannan et al., 2013) | 37 |
| | (Kannan et al., 2014) | 38 |
| | (Kannan et al., 2009) | 39 |
| | (Lee et al., 2009) | 40 |
| | (Lu et al., 2013) | 41 |
| | (Wu et al., 2009) | 42 |
| | (Kubat and Yuce, 2010) | 43 |
| | (Ayağ and Samanlioglu, 2014) | 44 |
| | (Sharma and Balan, 2012) | 45 |
| | (Büyüközkan et al., 2008) | 46 |

*Table 25: References classification in the research field*

*Annex 6 : The technology of textile fiber preparation: Tiring or Opening process*

Effilochage :

L'effilochage est réalisé sur une CADETTE à 3 ou 5 cylindres. En annexe 3 : détail des organes de la machine.

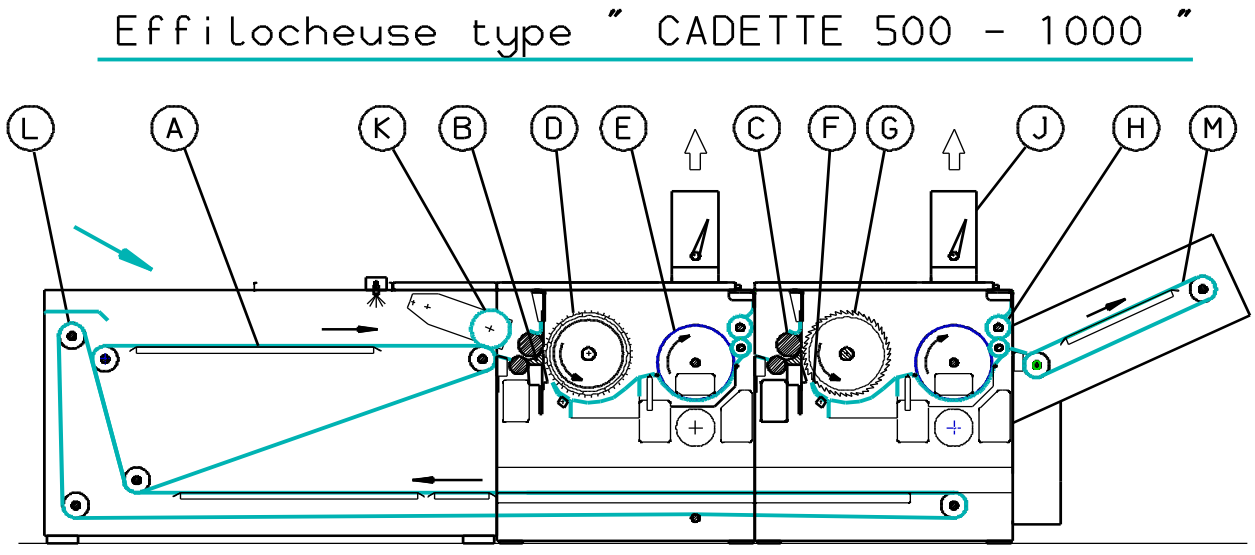


*Figure 45 Principe de l'effilocheuse*

La matière est entrainée par un tapis d'alimentation (1), puis en étant maintenu et compressé (2) elle est présentée au premier cylindre (3). Ce cylindre est garni de pointes inclinées qui vont permettre un premier défibrage de la matière. Les fibres sont ensuite aspirées grâce à un rouleau perforé (4) où une dépression est formée par un ventilateur, ainsi il se forme une nappe de matière défibrée. Cette nappe est délivrée par les rouleaux cannelés pour l'alimentation du cylindre suivant.



**Cylindre à pointes inclinées (3)**



**Résultat après le passage du premier cylindre**

Les deux cylindres suivants sont garnis de pointes radiales, ils vont affiner le défibrage de la matière par le même procédé.





**2éme cylindre, pointes radiales**

**Résultat après passage du second cylindre**

A chacune de ces étapes, un dispositif de triage ajustable au niveau des cylindres (5) permet de récupérer les morceaux non défibrés, qui vont être reconduits au début de l'effilocheuse afin d'être complètement défibrés.



**Déchets récupérés lors du premier passage.**

Results for Airbags:





The coating of some airbags is not problematic for the opening process. Good results, well opened fibers, good length, good tensile strength. Harder material to treat. Plan at least 6 rolls. Limited production.

Results for seatbelts:







Very good results obtained with well opened fibers, good length and good tenacity. It requires 4 or 5 rolls for an industrial process. Care the cutting step, determining the results, because it's a monofilament product.

*Annex 7 : Nonwoven technologies*

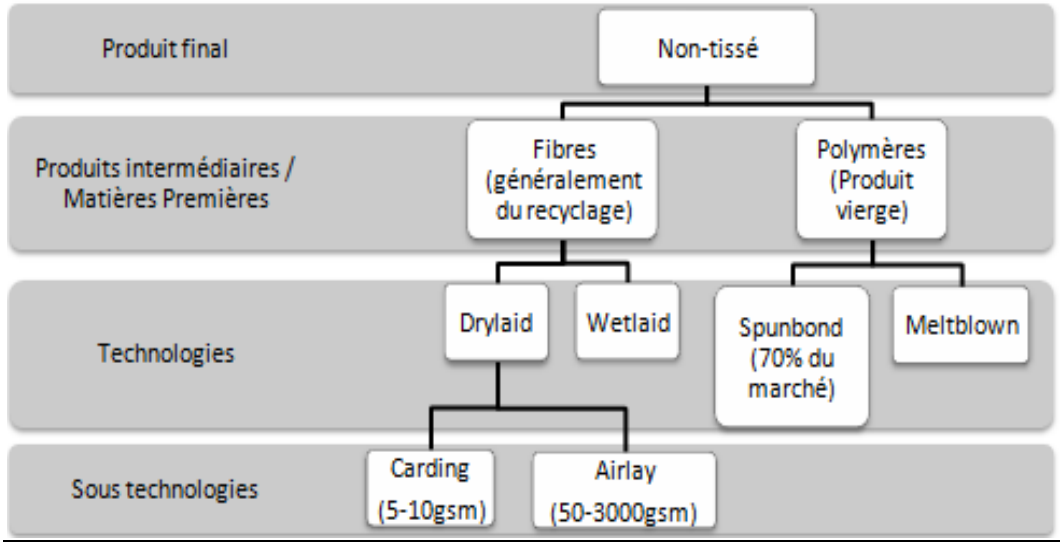



*Figure 46 : Technologies et Matières Premières, une interdépendance (Bonaldi, 2013)*

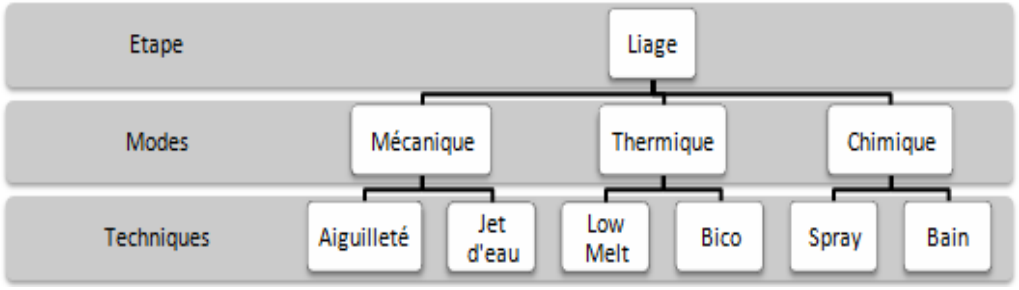



*Figure 47: Les techniques de liage de la toile*

*Annex 8 : Weighting by AHP*

| Dimension | Criteria | Weight | Sub criteria | Allocated Weights | Weights of the sub-criteria |
|---|---|---|---|---|---|
| Strategic Value | Sharing of common internal values | 14.4% | Compatibility of the objectives and values | 8% | 1,2% |
| | | | Sharing of the interest | 92% | 13,2% |
| | Sharing of common external values | 8,4% | Market position | 84% | 7,0% |
| | | | Strategy of Partnerships | 16% | 1,3% |
| Business excellence Value | General capacities | 1,7% | Solvency | 10% | 0,2% |
| | | | Benchmark | 64% | 1,1% |
| | | | Quality | 26% | 0,4% |
| | Collaborative project experience | 3,7% | Participation to collaborative projects | 52% | 1,9% |
| | | | Success of the collaborative Projects | 8% | 0,3% |
| | | | Reputation | 20% | 0,7% |
| | | | Adaptability to the project | 20% | 0,7% |
| | Technological strength | 20,5% | Development of the Technology | 54% | 11,2% |
| | | | R&D investment | 23% | 4,8% |
| | | | Technical Skills | 14% | 2,8% |
| | | | Industrial Property | 8% | 1,7% |
| Project's Skill Value | Technical expertise | 26,3% | Knowledge of the Technology | 92% | 24,2% |
| | | | Knowledge of the product | 8% | 2,2% |
| | Market expertise | 14,6% | Development of knowledge on the market | 16% | 2,4% |
| | | | Development of the market | 84% | 12,3% |
| Environmen - tal Value | Environmental Approach | 4,1% | Environmental Management | 16% | 0,7% |
| | | | Eco-evaluation | 84% | 3,4% |
| | Responsible Purchasing | 3,1% | Green Supplier | 84% | 2,6% |
| | | | Green Purchasing | 16% | 0,5% |
| | Recycling | 3,1% | Recyclable raw material | 92% | 3,0% |
| | | | Close Loop | 8% | 0,3% |

*Table 26: Weights results from AHP*

*Annex 9 : DEMATEL calculations*

| Criteria Influences | | Strategic Value | | Business Excellence Value | | | Project's Skills Value | | Ecologic Value | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sharing of common internal values | Sharing of common external values | General capacities | Collaborative project experience | Technologic strength | Technical expertise | Market expertise | Environmental Approach | Responsible Purchasing | Recycling | Σ |
| Strategic Value | Sharing of common internal values | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | Sharing of common external values | 0 | 0 | 3 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 7 |
| Business Excellence Value | General capacities | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Collaborative project experience | 1 | 3 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 7 |
| | Technologic strength | 0 | 2 | 1 | 1 | 0 | 3 | 1 | 1 | 0 | 0 | 9 |
| Project's Skills Value | Technical expertise | 1 | 3 | 1 | 3 | 1 | 0 | 1 | 1 | 1 | 1 | 13 |
| | Market expertise | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 7 |
| Ecologic Value | Environmental Approach | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 9 |
| | Responsible Purchasing | 2 | 2 | 1 | 0 | 1 | 1 | 2 | 3 | 0 | 2 | 14 |
| | Recycling | 2 | 1 | 0 | 0 | 1 | 2 | 2 | 3 | 3 | 0 | 14 |
| | Σ | 7 | 18 | 8 | 10 | 3 | 10 | 10 | 8 | 6 | 5 | |

*Table 27: Result of the Matrix Z obtained with the scale of Influence for DEMATEL study*

Results of the Matrix D are obtained by the normalization with the formula:

$$D = \lambda * Z \text{ with } \lambda = \text{Min}\left[\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}|zij|}; \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n}|zij|}\right]$$

Elements in lines have an influence on elements in columns

| **Matrix D** **Influence ➔** | PVI | PVE | CG | EPC | FT | ET | EM | DE | AR | R |
|---|---|---|---|---|---|---|---|---|---|---|
| PVI | 0,000 | 0,111 | 0,000 | 0,056 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| PVE | 0,000 | 0,000 | 0,167 | 0,111 | 0,000 | 0,056 | 0,056 | 0,000 | 0,000 | 0,000 |
| CG | 0,000 | 0,056 | 0,000 | 0,056 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 | 0,000 |
| EPC | 0,056 | 0,167 | 0,000 | 0,000 | 0,000 | 0,056 | 0,111 | 0,000 | 0,000 | 0,000 |
| FT | 0,000 | 0,111 | 0,056 | 0,056 | 0,000 | 0,167 | 0,056 | 0,056 | 0,000 | 0,000 |
| ET | 0,056 | 0,167 | 0,056 | 0,167 | 0,056 | 0,000 | 0,056 | 0,056 | 0,056 | 0,056 |
| EM | 0,000 | 0,111 | 0,056 | 0,056 | 0,000 | 0,056 | 0,000 | 0,000 | 0,056 | 0,056 |
| DE | 0,056 | 0,111 | 0,056 | 0,056 | 0,000 | 0,056 | 0,056 | 0,000 | 0,056 | 0,056 |
| AR | 0,111 | 0,111 | 0,056 | 0,000 | 0,056 | 0,056 | 0,111 | 0,167 | 0,000 | 0,111 |
| R | 0,111 | 0,056 | 0,000 | 0,000 | 0,056 | 0,111 | 0,111 | 0,167 | 0,167 | 0,000 |

*Table 28: The D Matrix from DEMATEL*

Matrix I (identity matrix) enables to obtain matrix I-D that is inversed with $I = \begin{matrix}1 & 0\\ 0 & 1\end{matrix}$. The matrix product $D*(I-D)^{-1}$ is then obtained in *Table 29*.

| $D*(I-D)^{-1}$ | PVI | PVE | CG | EPC | FT | ET | EM | DE | AR | R |
|---|---|---|---|---|---|---|---|---|---|---|
| PVI | 0,005 | 0,130 | 0,024 | 0,075 | 0,001 | 0,013 | 0,017 | 0,001 | 0,002 | 0,002 |
| PVE | 0,015 | 0,061 | 0,187 | 0,147 | 0,005 | 0,075 | 0,083 | 0,008 | 0,011 | 0,010 |
| CG | 0,005 | 0,071 | 0,013 | 0,067 | 0,001 | 0,009 | 0,012 | 0,001 | 0,001 | 0,001 |
| EPC | 0,067 | 0,219 | 0,050 | 0,053 | 0,006 | 0,082 | 0,138 | 0,010 | 0,015 | 0,014 |
| FT | 0,028 | 0,201 | 0,112 | 0,130 | 0,014 | 0,201 | 0,103 | 0,076 | 0,025 | 0,024 |
| ET | 0,096 | 0,281 | 0,127 | 0,237 | 0,068 | 0,066 | 0,128 | 0,091 | 0,085 | 0,081 |
| EM | 0,029 | 0,174 | 0,099 | 0,102 | 0,013 | 0,090 | 0,045 | 0,031 | 0,077 | 0,073 |
| DE | 0,087 | 0,191 | 0,106 | 0,112 | 0,014 | 0,095 | 0,104 | 0,033 | 0,081 | 0,077 |
| AR | 0,157 | 0,237 | 0,131 | 0,089 | 0,074 | 0,127 | 0,179 | 0,211 | 0,053 | 0,146 |
| R | 0,169 | 0,207 | 0,084 | 0,095 | 0,080 | 0,182 | 0,190 | 0,226 | 0,209 | 0,056 |

*Table 29: Results of the Matrix T*

R is then obtained by the sum of the lines and C the sum of the columns of the T matrix for each criterion. (R+C) and (R-C) are presented in (

*Table 19*) for interpretations.

*Annex 10: TOPSIS calculations*

| Dimension | Criteria | Weights | Sub criteria | **CC 1** | **CC 2** | **CC 3** | **CC 4** |
|---|---|---|---|---|---|---|---|
| Strategic Value | Sharing of common internal values | 14.4% | Compatibility of the objectives and values | 8 | 6 | 9 | 7 |
| | | | Sharing of the interest | 9 | 8 | 10 | 6 |
| | Sharing of common external values | 8,4% | Market position | 10 | 10 | 10 | 8 |
| | | | Strategy of Partnerships | 0 | 1 | 1 | 1 |
| Business excellence Value | General capacities | 1,7% | Solvency | 9 | 5 | 9 | 10 |
| | | | Benchmark | 4 | 9 | 10 | 2 |
| | | | Quality | 7 | 9 | 10 | 5 |
| | Collaborative project experience | 3,7% | Participation to collaborative projects | 0 | 1 | 1 | 2 |
| | | | Success of the collaborative Projects | 0 | 0 | 0 | 1 |
| | | | Reputation | 7 | 4 | 4 | 9 |
| | | | Adaptability to the project | 6 | 5 | 2 | 3 |
| | Technological strength | 20,5% | Development of the Technology | 7 | 8 | 8 | 2 |
| | | | R&D investment | 3% | 2% | 4% | 1% |
| | | | Technical Skills | 8 | 5 | 10 | 5 |
| | | | Industrial Property | 0 | 8 | 25 | 0 |
| Project's Skill Value | Technical expertise | 26,3% | Knowledge of the Technology | 3 | 2 | 1 | 1 |
| | | | Knowledge of the product | 2 | 2 | 2 | 1 |
| | Market expertise | 14,6% | Development of knowledge on the market | 1 | 1 | 4 | 1 |
| | | | Development of the market | 1 | 1 | 8 | 1 |
| Environmen - tal Value | Environmental Approach | 4,1% | Environmental Management | 9 | 6 | 10 | 6 |
| | | | Eco-evaluation | 7 | 6 | 7 | 4 |
| | Responsible Purchasing | 3,1% | Green Supplier | 5 | 5 | 1 | 1 |
| | | | Green Purchasing | 2 | 0 | 0 | 0 |
| | Recycling | 3,1% | Recyclable raw material | 2 | 1 | 0 | 0 |
| | | | Close Loop | 2 | 1 | 2 | 1 |

*Table 30: The obtained results for the 4 companies*

For the criterion we make a normalization using the formula:

$$N(X) = Mark\ Company\ X / \sqrt{(\sum_{x=1}^{x=4} Mark\ Company\ X)^2}$$

We make the weighting:

$$W(X) = N(X) * W(X)$$

Using the maxima and minima, respectively $W_{max}(X)$ and the $W_{min}(X)$, we calculate the $(W_{max}(X) - W(X))^2$ and $(W(X) - W_{min}(X))^2$:

| Company X | normalization | weighting | Max X = $(W_{max}(X) - W(X))^2$ | Min X = $(W(X) - W_{min}(X))^2$ |
|---|---|---|---|---|
| Company 1 | 0,52 | 0,058 | 7E-05 | 0,0017 |
| Company 2 | 0,59 | 0,066 = $W_{man}(X)$ | 0 | 0,0025 |
| Company 3 | 0,59 | 0,066 = $W_{man}(X)$ | 0 | 0,0025 |
| Company 4 | 0,15 | 0,017 = $W_{min}(X)$ | 0,0025 | 0 |

*Table 31: Calculation in TOPSIS of the $W_{max}(X)$ and the $W_{min}(X)$*

Than we calculate the $D^+(X)$ that corresponds to the square root of the sum of all Max X of the sub-criteria (25 in our case) of each Company X (X={1:4} in our case):

$$D^+(X) = \sqrt{\sum_{Sub-criteria\ 1}^{Sub-criteria\ 25} \text{Max X}}$$

The same way we calculate D-(X):

$$D\text{-}(X) = \sqrt{\sum_{Sub-criteria\ 1}^{Sub-criteria\ 25} \text{Min X}}$$

And finally the rating between the 4 Companies:

$Ca = D^{-}(X)/(D^{-}(X)+ D^{+}(X))$

| Company X | $D^{+}(X)$ | $D^{-}(X)$ | Classification TOPSIS |
|---|---|---|---|
| Company 1 | 0,11 | 0,14 | 55% |
| Company 2 | 0,13 | 0,08 | 40% |
| Company 3 | 0,13 | 0,13 | 50% |
| Company 4 | 0,18 | 0,02 | 9% |

*Table 32: Candidate companies' ranking*

*Annex 11:Engineering activities that I conducted during the collaborative project ValTex*

ValTex, a collaborative project, supported by ADEME, was composed of 8 complementary competencies, represented by 8 partners:




### 1. *Raw material identification and database elaboration*

This activity required a collaborative approach. Indeed, in order to define which materials were useful for the design of the new product, complementary expertises were needed. With the dismantler, who can define the time required to remove the part; with the designer, who can define which material could potentially be used; with the opening process expert, who assesses the possibility to transform the EoL textile parts into fibers.

- From EoL vehicles

Classification (quantitative and qualitative study) of the materials in order to develop the specifications:

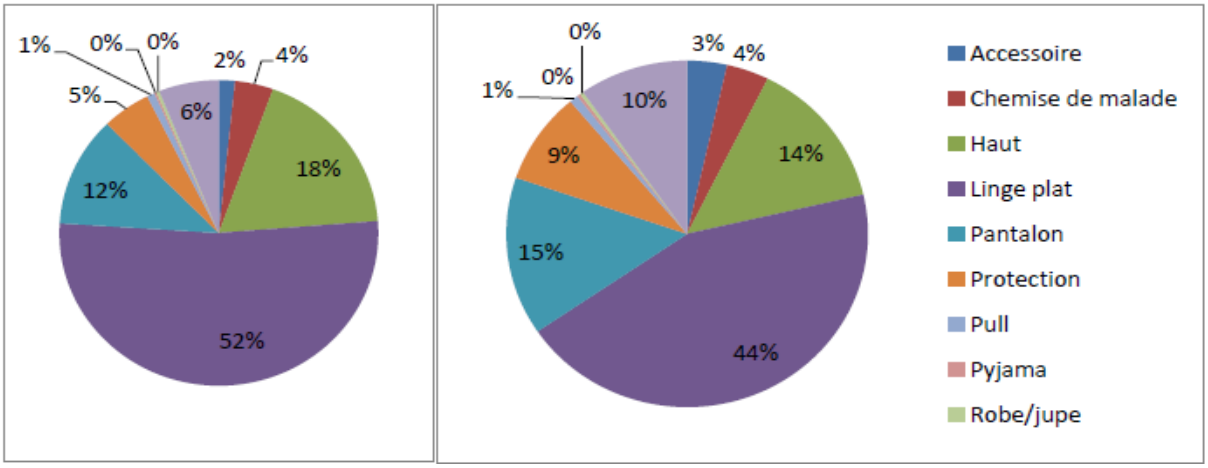


*Classification Table obtained with this analysis (confidential)*

These materials have been described by an identification number. A data sheet, for the operator, has been elaborated. Also, tools, to dismantle efficiently the parts from the car, have been tested. This enables to optimize the dismantling time and to give standards to the dismantling activity. The conditioning features have been investigated as well as logistic issues.

- From EoL garments

The materials have also been analyzed quantitatively and qualitatively:

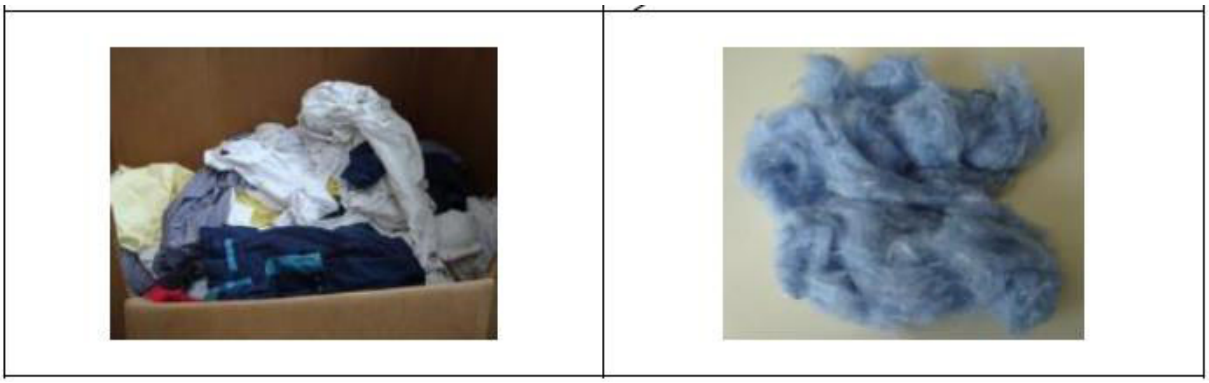



*Analysis of the garment materials*

The repartition on the territory, for the accessibility issue of the material, has been investigated as well.

### 2. *Recycling process analysis*

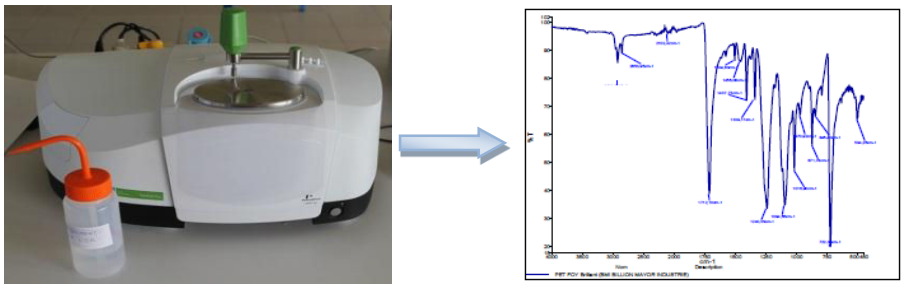
Based on the material specification from the product design step, the recycling processes must be adapted to provide the quality of the fiber required (process speed, material mix, machines' and parameters' modifications).



*Fibers obtained based on product specifications*

### 3. *Fibers analysis*

This study has been done with ITECH, to identify the fiber material composition using characterization process such as infrared analysis.



*Infrared analysis*

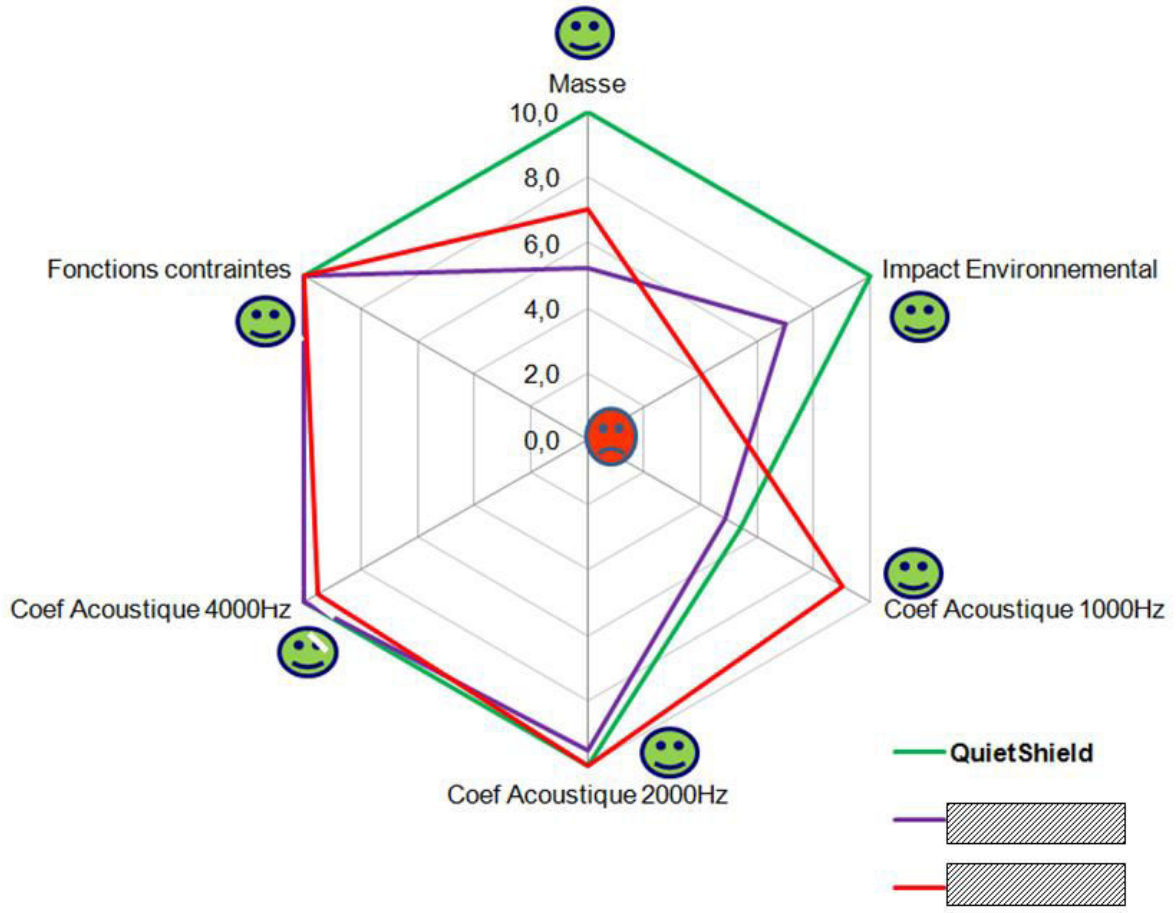
Also, the fiber structure is important, and the fibers' lengths have been measured, based on a specific method.



*Measurement of the fiber's lengths*

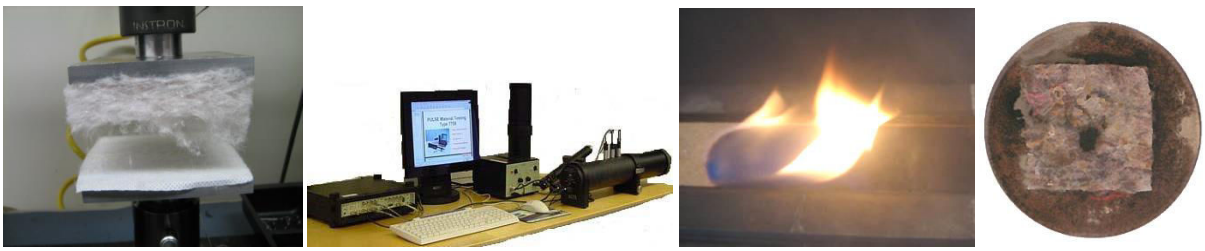
### *4. Product design and characterization*

Different trials have been planned based on various designs of experiments, in order to study the influence of different parameters.
First, the acoustic material is produced on a Laroche nonwoven line. Then, the materials go to Federal-Mogul to apply the finishing and start the characterization process based on Renault's standards.
This process enabled to obtain the final recycled raw material mix, for the product composition, and to present the functional properties to the client. Compared with competitive products, the features of this new product have been emphasized (lower weight, improved performance and better environment impact):




*Results summary presented at Renault's*

Different tests have been conducted, which are part of the client validation plan:



*Acoustic, flame, moisture and strength tests*

At the end of this stage, the results have been presented to the client (for a range of six products), and applications on a new vehicle have been assigned.

### *5. Intellectual Property work*

Federal-Mogul submitted an invention disclosure form to protect the design work and knowledge obtained through the project. This form entered the patentability process, managed globally, and is being followed by the R&D department.

### *6. Ongoing relationships between Federal-Mogul / Renault*

The first presentation of ValTex and of the first test results occurred in July 2013. The objective of the meeting was to give a direction to the project, to understand which applications could be targeted in regards of the first products' performances. It was also an awareness-raising action of Renault's team. From this date, we worked on the product design with two main targets (acoustic performance and lower weight).
We could use Renault's internal tools to measure the product acoustic performances, which created a trustworthy relationship and facilitated the development work. In October 2014, we could present the final product range. However, it took time from this stage to be assigned to an application. First drawings were supplied for the design of the final part, and the economic study conducted, but it is only in July 2015 that the official request for information from Renault was sent to Federal-Mogul. This document means an interest for the product performance and first economic data, and also a growing awareness and support from Renault's collaborators for the ValTex project. This status could also be explained by the different press actions proposed all along the project (see also §7).

### *7. Marketing Study*

The importance of the passenger comfort is a strong argument to reduce engine and exterior noise. During our search we could observe a positive growth of the sound absorbers market in the automotive industry. Different technologies and resources are used today. We defined the different market segments using these inputs and evaluated the risk to go after each segment. Once the scope was defined, we identified the main actors; competitors, raw material suppliers, focusing on the European market. This analysis contributed to better define the strategy to pursue, but also to identify the market share required to be competitive for Federal-Mogul.

This study also helped Federal-Mogul to understand the "green" environmental industrial behavior in the automotive market, and how it could potentially become a commercial argument. The main conclusion on this aspect is that a recycled material is considered as a lower quality material, thus, cost of a recycled product must be lower than products composed of virgin materials. This observation drove the actions to prove the high product quality, by strong technical reports and a substance study based on REACH database and requirements. Also, because the automotive industry focuses on weight reduction, this aspect was completely included in the product design requirements.

### *8. REACH study work*

See annex n°3

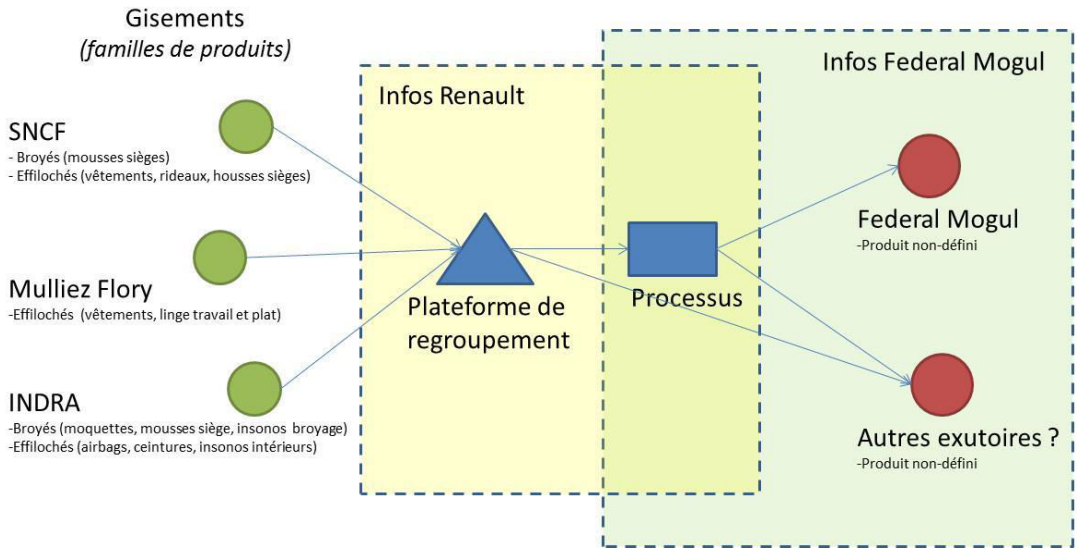
### *9. Collaborative Web*

A collaborative Web has been designed for the project partners (during the first year of the project). The aim of this work is to favor collaboration and to respect confidentiality. In this respect, we defined the requirements by the elaboration of the specifications.
Also, to give a visibility to the project, a description of the project has been published and supported by an association on *prorecyclage.com.* However, during the project, this association has merged with the

association Orée (http://www.oree.org/). In this association, a professional club gathers companies to discuss the common topic of textiles valorization.

### *10. Logistic study*

Based on the different raw materials' databases (vehicle and garment), and the partners' positioning, we developed the following supply chain representation:




*Representation proposed by ISEL*

Using this representation and the associated data (volumes; localization; processes) the adapted logistic model could be proposed to optimize the cost and the $CO_2$ impact.

### *11. Economic final study*

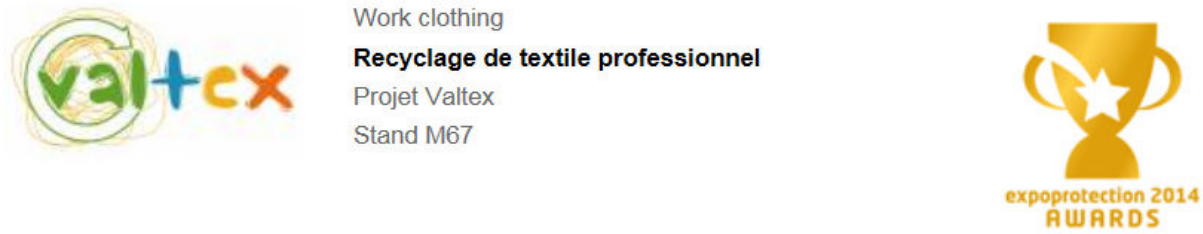
Renault and Federal-Mogul worked together on the supply chain cost structure, considering each transformation costs, logistics processes and other required activities. This study also helped in defining the partners' roles, the business model, to achieve the presentation of different industrial scenarios. These costs, today, are based on different volumes provided by Renault, and the business model being built considering strategic concerns of the actors.
A final offer must be presented by Federal-Mogul at the end of September 2015, which will give further directions for the industrialization stage.

### *12. Certification: Eco-Label*

The partner, Ecocert, is in charge to establish the eco-label. The definition of the requirements has been developed collaboratively taking into account the possibility for each partner to achieve the certification. Targets, such as: "a minimum of 75% of EoL recycled materials must enter in the composition of the product", have been approved by the consortium. The aim of the certification is to reinforce the EoL recycled material image, to guarantee the material quality to the customer and to provide a differentiated solution, compared to other recycled products.

### *13. Contributions to press articles and awards*

In order to gain supports, essential for the achievement of the project, various communication actions have been driven collaboratively. Indeed, for instance, Mulliez-Flory won the innovation award at the exhibition Expoprotection, supported by Renault, Federal-Mogul and the partners:




We also participated, twice, in a row (2012 and 2013), at the Pollutec TV show:




A brochure, containing samples from the first design of experiments, has been published to support different shows that we attended:




*Brochure, front and back page*

Press articles have been published following interviews or exhibitions:



**PROJETS COLLABORATIFS //** Pressé par les directives européennes, le secteur organise des filières logistiques complexes de récupération. Les mousses, le textile et le verre sont les plus délicats à traiter.

# L'automobile recycle sur les chapeaux de roue






L'argus

Deuxième projet, « ValTex » pour Valorisation Textile. Piloté par Renault, ce projet, auquel participent aussi la SNCF et un spécialiste de l'habillement professionnel, est destiné à donner une seconde vie aux tissus et mousses : « *Nous en sommes à mi-parcours* » fait savoir Toni Gallone, responsable industriel de Renault environnement et porteur du projet Valtex, « *nous*

ValTex was also presented at the "Prix Entreprises & Environnement 2015" in the category "circular economy" on the 8th of July 2015:




These actions are essential to gain internal and external support, and they proved the innovativeness of the project.