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Performance assessment and decision-making tools for the development of eco-industrial and tertiary parks: Applications in the French and Quebecois context

Mathilde Le Tellier

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THÈSE

Pour obtenir le grade de

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(UQTR)**
dans **l'École Doctorale SISEO et ED-UQTR**

Modèle d'évaluation de la performance et d'aide à la décision pour le développe- ment des écoparcs d'activité

Application aux contextes français et québécois

Thèse soutenue publiquement le **16 Décembre 2020**,
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Résumé

Les parcs industriels, communément définis comme des espaces physiques aménagés pour l'usage simultané de plusieurs entreprises et gérés par un gestionnaire, font aujourd'hui face à des enjeux relatifs à leur aménagement et à leur fonctionnement. La prise en compte du concept de développement durable, vu comme la conjugaison équilibrée de ses trois piliers, respectivement environnemental, économique et social, apparaît comme une réponse à ces enjeux. Ce travail concerne le développement d'un modèle accompagnant les gestionnaires de parcs industriels dans une démarche de développement durable. L'approche présentée est systémique et globale, elle vise l'amélioration continue sur de longs horizons temporels. Le modèle proposé repose sur une modélisation systémique du parc industriel durable appelé écoparc, d'une méthode d'aide à la décision pour l'établissement d'un plan d'action et d'un sous-modèle d'expression de la performance. Ce modèle a été validé auprès de parcs industriels français et québécois offrant un panel diversifié par leur taille, leur maturité et leur engagement dans la démarche de développement durable. Cette diversité a nourri la réflexion et a renforcé la genericité du modèle développé.

Mots-clés : Ecoparc, Parc industriel, Développement durable, Expression de la performance, Aide à la décision multicritère

Abstract

Industrial parks, commonly defined as physical spaces developed for the use of several firms simultaneously and managed by a designated manager, currently face challenge pertaining to their development and operation. Sustainable development, regarded as the conjunction of its three pillars, respectively environmental, economic and social, appears to be the answer to those challenges. This thesis is concerned with the development of a model supporting industrial park managers with their commitment to sustainable development. The presented approach is systemic and global, it seeks continuous improvement on long time horizons. The proposed model consist of a systemic modelling of the sustainable industrial park called mixed-use ecopark, a decision marking method for the establishment of an action plan and a performance expression sub-model. This model was validated with industrial parks from France and Quebec that offers a diverse panel of size, degree of maturity and commitment to sustainable development. This diversity enriched the reflection and strengthened the genericity of the developed model.

Keywords : Mixed-Use Ecopark, Industrial park, Sustainable development, Performance expression, Multi-criteria decision analysis

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Avant-propos

Le travail de recherche présenté dans cette thèse est le fruit d'une cotutelle entre l'Université Savoie Mont Blanc en France et l'Université du Québec à Trois-Rivières au Canada. Cette thèse a été supervisée par mes quatre directeurs de recherche : Lamia Berrah et Benoit Stutz (Université Savoie Mont Blanc) ainsi que Jean-François Audy et Simon Barnabé (Université du Québec à Trois-Rivières).

Cette thèse est rédigée sur le principe d'une thèse avec insertion d'articles. La contribution principale de cette thèse inclut trois articles dont je suis l'auteure principale. Pour ces trois articles, j'ai agi en tant que chercheuse principale et les coauteurs ont passé en revue les ébauches successives aboutissant au manuscrit publié ou soumis à publication. La contribution et la responsabilité des co-auteurs sont décrites dans la suite de cette section.

Article 1 : "Towards sustainable business parks : A literature review and a systemic model", co-signé par Benoit Stutz, Lamia Berrah, Simon Barnabé et Jean-François Audy. Cet article a été publié par le Journal of Cleaner Production le 10 avril 2019. La version insérée est identique à celle publiée.

Cet article inclut une revue de la littérature sur les éco-parcs ainsi qu'un cadre conceptuel de l'éco-parc sous forme de modélisation systémique. J'ai réalisé la revue de la littérature et proposé la modélisation systémique de l'éco-parc suite à plusieurs discussions avec Lamia Berrah, Benoit Stutz et Jean-François Audy. J'ai rédigé cet article qui a été relu et corrigé par l'ensemble des coauteurs.

Les actes de conférence suivants, pour lesquels j'ai agi en tant que chercheuse principale, ont respectivement servi à poser la base et fournir une extension à cet article :

- Le Tellier, M., Berrah, L., Stutz, B., Barnabé, S., & Audy, J.-F. (2017). From SCM to Eco-Industrial Park management : Modelling Eco-Industrial Park's Symbiosis with the SCOR model. IFIP Advances in Information and Communication Technology, Volume 514. IFIP WG 5.7 International Conference, APMS 2017, Septembre 3-7, Hamburg, Germany.
- Tellier, M. Le, Berrah, L., Stutz, B., Audy, J.-F., & Barnabé, S. (2018). A Review of Actions Towards Circular Economy for Business Park's Governance. Going Green CARE INNOVATION 2018, Novembre 26-29, Vienne, Autriche.

Article 2 : "Using MACBETH for the Performance Expression of a Mixed-Use Ecopark", co-signé par Lamia Berrah, Vincent Clivillé (Université Savoie Mont Blanc), Jean-François Audy, Benoit Stutz et Simon Barnabé. Cet article a été accepté par le Journal of Multi-Criteria Decision Analysis le 10 Juillet 2020. La version insérée est identique à celle acceptée.

Cet article présente un modèle d'évaluation de la performance temporelle d'un plan d'action pour le pilotage de l'éco-parc. J'ai développé ce modèle et réalisé son application sur un cas d'étude. Lamia Berrah a offert une orientation générale au travail de définition de la problématique de

pilotage de l'écoparc. Vincent Clivillé, maître de conférence à l'Université Savoie Mont Blanc m'a assisté dans le développement du modèle et l'utilisation de la méthode d'aide à la décision multicritère MACBETH. Jean-François Audy m'a assisté lors de l'application du modèle au cas d'étude. J'ai rédigé cet article qui a été relu et corrigé par l'ensemble des co-auteurs.

Cet article est basé en partie sur les actes de conférences suivants, pour lesquels j'ai agi en tant que chercheuse principale :

- Le Tellier, M., Berrah, L., Clivillé, V., Stutz, B., Audy, J.-F., & Barnabé, S. (2019). Definition of the ecopark's multi-criteria decision-making problems and their challenges. EURO Working Group on Multicriteria Decision Aiding. Avril 11-13, Trento, Italy. (*Soumission d'un résumé servant de base à la discussion seulement, présentation réalisée par Vincent Clivillé*)
- Le Tellier, M., Berrah, L., Audy, J.-F., Stutz, B., & Barnabé, S. (2019). Vers un modèle d'expression de la performance pour le pilotage d'un écoparc d'activités. 13ème conférence internationale CIGI QUALITA. Juin 25-28, Montréal, Canada.

Article 3 : "An overall sustainability assessment model for industrial parks : a Choquet integral aggregation approach", co-signé par Lamia Berrah, Jean-François Audy, Benoit Stutz et Simon Barnabé. Cet article a été soumis au Journal of Ecological Indicators le 10 Juillet 2020. La version insérée est identique à celle soumise.

Cet article présente un modèle d'agrégation pour l'évaluation de la performance durable de l'écoparc. J'ai développé ce modèle et réalisé son application sur un cas d'étude. Lamia Berrah a offert une orientation générale au travail de définition de la problématique d'agrégation pour l'évaluation de la performance durable. Vincent Clivillé et Gilles Mauris, maître de conférence à l'Université Savoie Mont Blanc, m'ont assisté dans l'utilisation de l'intégrale de Choquet comme opérateur d'agrégation. Jean-François Audy m'a assisté lors de l'application du modèle au cas d'étude. J'ai rédigé cet article qui a été relu et corrigé par l'ensemble des co-auteurs.

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Introduction générale

Objet de la recherche

Les activités artisanales et industrielles ont toujours eu tendance à être géographiquement regroupées. Les motivations de ce regroupement trouvent leurs origines dans le fait de spécificités communes d'une part (matière première, clientèle, logistique, etc.) et de complémentarités d'autre part. Historiquement, le principal lieu de regroupement de telles activités a été la ville où se mélangaient alors respectivement activités de production, artisanales ou industrielles et autres fonctions urbaines (résidentielles, culturelles, sociales, commerciales, etc.). Cette proximité des activités en tout genre trouva très vite ses limites, du fait de désagréments, de contraintes d'espace, et autres aspects pouvant nuire à la qualité de vie urbaine. C'est dans ce contexte que la notion de parc industriel est apparu, fruit d'un urbanisme fonctionnaliste, qui, par définition, sépare géographiquement ce qui se rattache à l'industrie, au sens large du terme, de la vie urbaine. Cette notion émergea tout d'abord en Europe et en Amérique du Nord, dans les années 1950 pour s'étendre assez rapidement au reste du monde.

La séparation géographique des activités industrielles et urbaines dont le but était de réduire les conséquences néfastes de l'activité industrielle sur les villes, se traduit ainsi par une planification de l'aménagement et la mise en place de réglementations de zonage relatives à l'implantation des entreprises porteuses des activités économiques considérées. Au-delà de cet avantage de réduction des nuisances, depuis sa création, le parc industriel viendra faciliter la promotion du développement économique du territoire dans lequel il est implanté, en offrant des infrastructures dédiées, des services communs, ainsi que des dispositions fiscales avantageuses (Nunnally and Pollina, 1973) aussi bien dans les pays dits "développés" (Peddle, 1993; United Nations Industrial Development Organization, 1997) que dans ceux dits "en voie de développement" (Leducq and Liefvooghe, 2007; Renard-Grandmontagne, 2007). En l'occurrence, ce modèle d'organisation a su s'adapter aux orientations de l'économie post-industrielle, à savoir les hautes technologies, la Recherche et Développement (R&D) ainsi que les activités de service, inspirant de ce fait la création de parcs technologiques : les technopoles. En résumé, depuis son apparition, le parc industriel est devenu une organisation incontournable dans le paysage industriel contemporain.

La notion de parc industriel s'est vue communément définie comme étant "*une étendue de terre développée pour l'usage simultané de plusieurs entreprises, qui se distingue par ses infrastructures partageables et la proximité des entreprises*" (United Nations Industrial Development Organization, 1997). Dans ce sens, à quelques nuances près, selon les pays et leurs réglementations respectives, un parc industriel est reconnu pour être (Nunnally and Pollina, 1973; Bale, 1974; Peddle, 1993; United Nations Industrial Development Organization, 1997; Cerema, 2014) :

- Un espace physique défini et aménagé pour l'usage d'entreprises ;
- Le regroupement d'un certain nombre d'entreprises qui partagent des infrastructures et des

services ;

Et aussi :

- Une entité gérée par une autorité (publique ou privée) appelée gestionnaire, ayant une compétence définie à l'égard des entreprises résidentes.

En tant qu'espace physique aménagé, le parc industriel fait face à de nouveaux défis en matière d'aménagement. En effet, de nos jours, l'urbanisme fonctionnaliste est remis en cause au profit de la recherche de son opposé appelée mixité fonctionnelle, soit une répartition équilibrée des différentes fonctions urbaines à l'intérieur de la ville. En l'occurrence, par l'ampleur de leurs emprises au sol et le surdimensionnement des infrastructures routières qui les desservent, les parcs industriels contribuent nettement à l'étalement urbain, à la raréfaction du foncier et à l'artificialisation des sols (Lejoux and Charieau, 2019). Les concentrations d'entreprises qui les caractérisent engendrent pour leur part des mobilités urbaines, liées au transport de marchandises et au travail, avec les contraintes qui en découlent, comme des pénuries de stationnement, de la congestion routière et ultimement, de la pollution. De plus, les bâtiments constitutifs des parcs industriels peuvent être confrontés à leur obsolescence, qui se traduit, notamment, par une mauvaise desserte, la présence de friches industrielles et/ou de bâtiments vacants dont l'éventuelle remise sur le marché est rendue difficile, la vétusté des locaux, la dégradation de l'environnement ou encore le manque de sécurité. En France par exemple, les parcs industriels construits dans les décennies 1980/1990 sont les premiers concernés par la requalification et l'obsolescence, mais ceux aménagés dans les décennies 2000/2010 feront bientôt place aux mêmes défis (Cerema, 2014). Coûteuse et complexe, cette requalification est l'occasion d'intégrer de nouvelles préoccupations environnementales et sociales. Dans ce sens, le parc industriel devient un objet urbain du passé qu'il convient de transformer. Ainsi, ces observations nous permettent-elles de formuler un premier postulat :

- **Pour répondre à ses enjeux d'aménagement, la conception et la construction de nouveaux parcs industriels doit être repensée et les parcs industriels existants doivent être transformés dans une logique d'aménagement durable.**

Cette notion d'aménagement durable a inspiré la conception d'un objet urbain d'une autre nature : l'écoquartier. Apparu dans les années 1960, l'écoquartier se définit comme : "*Un espace bâti nouveau ou reconverti d'une ville, dans ou à proximité d'un centre urbain dense, de l'échelle d'un quartier, ayant pour vocation d'appliquer, de préserver et de développer sur le temps long l'ensemble des principes environnementaux, sociaux et économiques de développement durable qui ont gouvernés à sa conception*" (Boutaud, 2009). Les parcs industriels pourraient donc s'inspirer du concept et des expériences d'écoquartiers sur des problématiques communes telles que la densification, la gestion des eaux pluviales, la gestion des espaces verts, l'efficacité énergétique des bâtiments, la mobilité, etc. On retiendra néanmoins que les problématiques d'aménagement des quartiers résidentiels pouvant différer de celles des parcs industriels, l'aménagement durable de ces parcs industriels devra s'adapter à leurs contraintes et leurs besoins.

Au delà de cet aspect d'objet urbain à aménager de manière durable, le parc industriel fait également face au défi de fonctionner de manière durable. Ainsi, les entreprises constitutives des parcs industriels pourront-elles bénéficier des opportunités offertes par ce fonctionnement durable, tout en devant satisfaire aux contraintes qui en sont induites, et ce, au-delà de leurs contraintes propres. En l'occurrence, le parc industriel peut offrir des réponses à des enjeux tels que ceux liés à l'optimisation des ressources, à l'attractivité de la main-d'oeuvre ou encore à la mutualisation des moyens. Une manière de procéder dans ce sens est de parvenir à mettre en place des mécanismes de collaboration inter-entreprises qui permettent ce fonctionnement et de les piloter. Notons que ces mécanismes de collaboration peuvent aussi s'effectuer avec des acteurs de la communauté locale, extérieurs au parc industriel. Un exemple serait la mise en place d'échanges énergétiques entre le parc industriel et les espaces d'habitation à proximité, permettant une exploitation optimale de l'énergie en lissant sa consommation. Ainsi, ces observations nous permettent-elles de formuler le second postulat de ces travaux :

- **Pour répondre à ses enjeux de fonctionnement durable, le parc industriel doit créer un cadre favorisant toute collaboration entre les entreprises qui le constituent et la communauté locale.**

Naturellement, les mécanismes de collaboration inter-entreprises dans un parc industriel varieront selon la nature des entreprises constituant ce parc. Un modèle remarquable dans ce sens est celui du parc éco-industriel apparu dans les années 1990, dont le principe est un fonctionnement basé sur la notion de symbiose industrielle. Chertow définit la symbiose industrielle comme "*engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity*" (Chertow, 2008). Dans ce sens, le parc éco-industriel est un parc industriel où les entreprises collaborent les unes avec les autres et avec la communauté locale pour partager des ressources (U.S President's Council on Sustainable Development, 1997), ces échanges sont appelés synergies. Ainsi, de nombreuses initiatives de développement de parcs éco-industriels, *ex-nihilo* ou à partir de parcs industriels existants, ont vu le jour dans le monde. Un exemple couronné de succès est celui de Kalundborg au Danemark où une vingtaine de synergies éco-industrielles ont été développées entre les entreprises du parc au cours des cinquante dernières années. Si bon nombre d'initiatives ont réussi à incarner ce modèle de fonctionnement durable, d'autres n'ont pas pu le faire, et ce, pour des raisons liées au contexte socio-économique ou encore à une simple question de faisabilité. En particulier, la difficulté voire l'impossibilité à faire coïncider les intrants (matières premières, énergie, eau, ressources humaines etc.) et les extrants (produits et déchets) d'industries localisées dans un même parc industriel est considérée comme un frein majeur à la mise en place de parcs éco-industriels. Le modèle de parc éco-industriel concerne des regroupements d'entreprises aux échanges de ressources possibles et spécifiques. Il exclut par-cela même les entreprises aux activités tertiaires.

Problématique et Méthode

L'engagement des parcs industriels dans une démarche de développement durable est aujourd'hui un enjeu majeur unanimement reconnu. Souscrivant à cette vision, notre problématique de recherche générale s'exprime sous la forme suivante : ***Comment accompagner un parc industriel à s'inscrire dans une démarche de développement durable ?***

Prise au sens le plus générique, cette problématique englobera tout parc, quelles que soient ses spécificités et sa maturité en matière de développement durable, soit de durabilité. Pour sa part, l'accompagnement sera similaire aux principes de pilotage pratiqués dans les entreprises, à savoir la conduite du système considéré à l'atteinte de ces objectifs, et ce à partir de la formulation de ces derniers.

Accompagner un parc industriel dans une démarche de développement durable sous-entend selon nous plusieurs questionnements successifs. En premier, il est important d'identifier précisément les contours d'un parc industriel durable. D'où la première étape de nos investigations :

- Q1 : *Qu'est ce qu'un parc industriel durable ?*

Une fois ce référent connu, il s'agira alors de réfléchir aux actions à mener pour que le parc industriel considéré puisse s'y conformer. Cela ouvre la voie aux réflexions résumées en la question ci-dessous :

- Q2 : *Quelles sont les actions qu'un parc industriel doit mener pour s'inscrire dans une démarche de développement durable ?*

Et de manière corollaire en complément avec la question précédente, il s'agira d'exprimer la performance au vu des résultats atteints. La performance est synonyme dans ce contexte de durabilité. Il deviendra nécessaire alors de disposer d'un modèle qui en permette la mesure :

— Q3 : *Comment exprimer la durabilité d'un parc industriel ?*

Les travaux menés dans cette thèse s'inspirent fortement des approches d'amélioration de la performance pratiquées dans les entreprises. Si la notion d'entreprise et celle de parc industriel sont différentes à bien des égards, une certaine similarité peut s'observer de par la complexité d'une part, et l'existence d'un pilote (gestionnaire) d'autre part, en charge de l'atteinte des objectifs à atteindre. Afin de donner des éléments de réponse aux trois questions structurantes de nos travaux, nous effectuerons une succession d'allers-retours entre la théorie - analyse de la littérature et développement de modèles - et la pratique, soit l'observation de quatre cas particuliers de parcs industriels, partenaires de cette recherche.

Sur la base d'une analyse de l'état de l'art, une définition de la notion de parc industriel durable sera ainsi proposée dans un premier temps, sur la base d'un enrichissement des concepts voisins tels que celui de l'écoquartier ou celui du parc éco-industriel. Une modélisation systémique de ce parc que nous qualifierons d'écoparc permettra d'en préciser la finalité, les objectifs, la structure et le fonctionnement. En second lieu, nous nous baserons sur les méthodes d'analyse multicritère et d'agrégation de la performance pour aider le gestionnaire, d'une part, à choisir les actions les plus adaptés à son contexte et, d'autre part, à exprimer la performance atteinte, aussi bien à des niveaux élémentaires qu'à un niveau global.

Contenu de la thèse

Cette thèse, sur articles, se présente sous la forme de 5 chapitres dont 3 sont des articles. Le chapitre 1 est une présentation des parcs industriels ayant servi de cas d'étude pour ces travaux. Les chapitres 2, 3 et 4 sont des articles offrant une réponse aux questions posées plus haut. Après la conclusion et le résumé des perspectives de ces travaux de recherche, trois articles de conférences sont présentés en annexe. Ces articles annexes, écrits en parallèle des articles principaux, présentent des réflexions complémentaires qui ont permis de préciser notre approche. Car ils présentent des pistes de recherches additionnelles, ces articles sont une exploration de certaines perspectives présentées en conclusion. La Figure 1 illustre la structure de cette thèse. Dans cette section nous détaillons les contributions et l'articulation des chapitres 2, 3 et 4.

Objectifs et contributions du chapitre 2

Le chapitre 2 présente un état de l'art sur le sujet du parc éco-industriel d'une part et dans le domaine de l'aménagement urbain durable sur le sujet de l'écoquartier d'autre part. Cette revue de la littérature permettra de définir un modèle de parc industriel durable appelé écoparc d'activités¹. Une fois l'écoparc défini, nous pourrons le positionner par rapport aux autres concepts similaires existants. Une fois l'écoparc défini, pour amorcer la réponse à notre deuxième question, la seconde partie du chapitre proposera une modélisation systémique de l'écoparc. La modélisation systémique offrira une représentation générique de l'écoparc qui pourra servir de base aux réflexions sur l'expression et l'amélioration de sa performance.

1. Par soucis de concision, on utilisera le terme "écoparc"

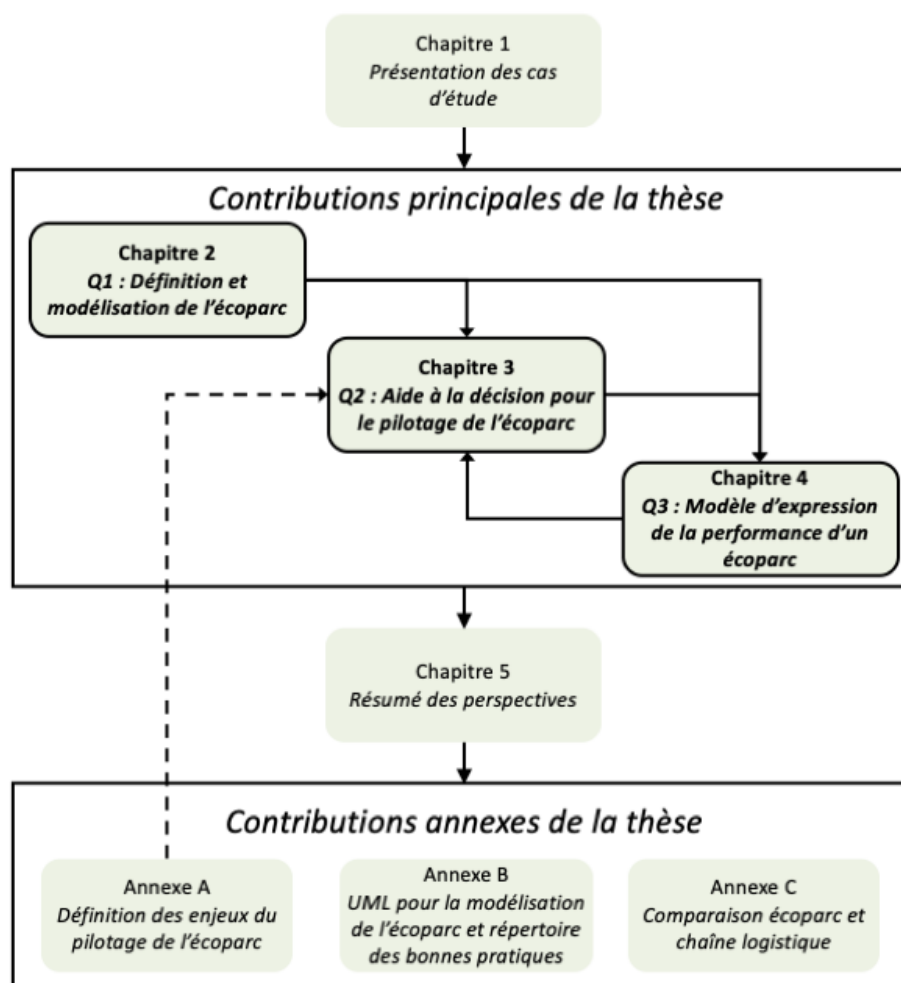


Figure 1 – Structure de la thèse

Objectifs et contributions du chapitre 3

Dans la continuité du chapitre 2, le chapitre 3 porte sur le pilotage de l'écoparc et de ses plans d'action. L'article de ce chapitre est basé sur un article de conférence portant sur le pilotage de l'écoparc fourni en Annexe A. Nous y voyons le pilotage de l'écoparc comme s'inscrivant dans le cadre général proposé par la roue de Deming (Plan-Do-Check-Act) et sa philosophie d'amélioration continue. Piloter un écoparc devient de fait un processus fondé sur l'itération permanente d'un processus de déclaration d'objectifs, de définition et d'enclenchement de plans d'action, d'évaluation des résultats obtenus et de réaction au vu des résultats obtenus (Deming, 1982). Le pilotage s'appuie ainsi sur une expression de la performance qui alimente le processus de décision d'enclenchement de plans d'actions. Dans la première partie du chapitre, en repartant de la modélisation systémique de l'écoparc et en s'appuyant sur une revue de la littérature, une hiérarchie de critères pour l'expression de la performance d'un écoparc est proposée. Dans un deuxième temps, l'intérêt de recourir à une méthode d'aide à la décision multicritère pour le pilotage de l'écoparc sera argumenté puis démontré avec la méthode Measuring Attractiveness by a Categorical-Based Evaluation TecHnique (MACBETH) (Bana e Costa and Vansnick, 1997). En particulier, MACBETH

sera utilisée pour exprimer la performance d'un plan d'actions et donc aider à sa planification avant exécution. Cette utilisation originale de MACBETH sera expérimentée et validée auprès d'un parc partenaire de cette thèse.

Objectifs et contributions du chapitre 4

Le chapitre 4 se focalise sur l'expression de la durabilité de l'écoparc. La durabilité d'un écoparc se traduit comme un compromis de l'atteinte d'objectifs dans les trois piliers du développement durable (environnemental, économique et social). Dans un premier temps, la complexité d'une telle entreprise est présentée. Cette complexité repose à la fois sur la complexité intrinsèque de l'écoparc en tant que système mais aussi de la durabilité en tant que finalité de l'écoparc. De ce fait, conformément aux préceptes de la décomplexification systémique, nous voyons cette durabilité comme se déployant conformément à ses trois piliers et ce, sur autant de niveaux que le requiert le pilotage de l'écoparc. L'expression de performance qui lui sera associée sera par conséquent le résultat de l'agrégation des différentes expressions de performance associées aux objectifs issus du déploiement. Le recours à des opérateurs d'agrégation de la famille des compromis est alors argumenté et modélisé. Une application à un cas d'étude permettra une conclusion sur ces propositions.

1

Présentation des cas d'étude

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1.1 Généralités

Depuis son émergence dans les années 1950, la notion de parc industriel a connu une large diversification dans sa conception et sa mise en oeuvre. En effet, en référence à sa définition usuelle, cette diversification se traduit à plusieurs niveaux tels que la taille, les stratégies de développement, le statut juridique, le secteur des entreprises résidentes, le mécanisme de gouvernance, etc.

En conséquence de cette diversification, les dénominations pour le parc industriel sont nombreuses. En France par exemple, le parc industriel traditionnel désormais communément appelé Zone d'Activité Économique (ZAE) se décline en plusieurs types, selon le secteur des entreprises résidentes (artisanales ; commerciales ; industrielles ; logistiques ; de service ou tertiaires ; portuaires ou aéroportuaires ; technologiques). Au Québec en revanche, l'appellation la plus communément utilisée reste parc industriel. Cette appellation inclut les regroupements de tout type d'activités à l'exception des activités commerciales. De même, dans les pays anglophones, les termes varient en fonction des pays et de l'activité principalement développée dans le parc : *industrial park*, *industrial estate*, *industrial district*, *trading estate*, *business park* ou encore *office park*.

Dans un souci de généricité, en français, nous choisissons d'utiliser le terme historique "parc industriel", incluant de ce fait les parcs regroupant des entreprises aux activités industrielles, logistiques, artisanales et tertiaires.

1.2 Choix des cas d'étude

Le périmètre de notre travail couvre les contextes français et québécois autour de quatre cas particuliers proches des régions où a été réalisée la thèse, la Savoie et Haute-Savoie en France et la Mauricie et Centre-du-Québec au Québec. Les parcs industriels retenus sont :

- L'écoparc industriel Daniel Gaudreau à Victoriaville au Québec.
- Le technopole Savoie Technolac au Bourget-du-Lac en France.
- L'écoparc Savoie Hexapole à Méry en France.
- Les parcs industriels du Grand Annecy en France.

Des évaluations faites en 2007 estimeraient le nombre de parcs industriels en France à un nombre variant autour de 30 000, représentant approximativement 450 000 hectares répartis sur 12 000 communes (Cerema, 2014). Au Québec, le répertoire des parcs industriels du Canada recense précisément à ce jour 237 parcs industriels dans la province¹, soit une proportion par habitant similaire à celle de la France. Ainsi, avec ce seul critère de comparaison et toute proportion gardée, nous pourrions conclure à une certaine similarité dans la densité des tissus économiques français et québécois et potentiellement une certaine similarité des parcs industriels.

Les quatre cas choisis offrent un panel diversifié par leur maturité, leur taille, leur localisation et leur engagement dans la démarche de développement durable. Cette diversité a nourri notre réflexion et a renforcé la généricité des outils développés.

Afin de mieux appréhender les parcs industriels retenus et alimenter nos réflexions à partir de leurs spécificités, nous allons procéder dans ce chapitre à leur description conformément à un certain

1. <https://parcsindustrielscanada.com/quebec>

nombre de caractéristiques supportant la compréhension de leur fonctionnement, l'identification de leurs objectifs et de leurs préoccupations au sujet de la durabilité. En l'occurrence, nous retiendrons les éléments suivants : le contexte, le gestionnaire, la taille et le type d'entreprises résidentes, l'engagement dans une démarche de développement durable et, finalement, les enjeux. Nous reviendrons alors, pour chacun de ces cas, sur son positionnement au regard de notre problématique générale.

1.3 L'écoparc industriel Daniel Gaudreau

Contexte :

La ville de Victoriaville est située dans la région Centre-du-Québec, dans la province du Québec au Canada. C'est une ville de 46 000 habitants dont le territoire s'étend sur 86 km². En 2008, après avoir découvert qu'une partie du terrain de son parc industriel était un milieu humide, la ville de Victoriaville a décidé de transformer cette contrainte en opportunité en initiant la conception d'un parc industriel respectueux de cet écosystème. Ainsi, en 2013, Victoriaville inaugurerait ce parc industriel, baptisé "écoparc industriel Daniel Gaudreau" en 2018². Ce parc est le 7^{me} parc industriel de Victoriaville et sa région.

Gestionnaire :

L'écoparc industriel Daniel Gaudreau est géré par la Commission de Développement Économique de Victoriaville et de sa Région (CDEVVR) pour le compte de la municipalité de Victoriaville³. La CDEVVR est une organisation à but non lucratif dont la mission est de soutenir le développement économique et d'accroître le rayonnement international des industries de Victoriaville et sa région. Pour l'écoparc industriel Daniel Gaudreau, la majeure partie du rôle de la CDEVVR consiste en la réalisation d'un ensemble de missions de natures différentes. En premier lieu, vient la prospection d'entreprises en quête d'implantation éventuelle ainsi que la mise en application d'exigences relatives à ces implantations. Il s'agira également de veiller à l'accompagnement des entreprises résidentes. De manière plus globale, la CDEVVR a également pour mission la promotion, l'entretien et l'aménagement du parc.

Taille et entreprises :

L'écoparc industriel Daniel Gaudreau est un parc industriel de taille modeste. Il est divisé en 22 terrains sur une superficie totale de 11 hectares. Actuellement, en 2020, 3 entreprises y sont installées. L'écoparc est à même d'accueillir des entreprises du secteur du service et de celui de l'industrie légère⁴. A l'heure actuelle, il n'existe pas de collaborations inter-entreprises sur le parc car le nombre d'entreprises implantées est trop restreint.

Engagement dans une démarche développement durable :

L'écoparc industriel Daniel Gaudreau est d'ores et déjà conçu dans le respect des principes de l'aménagement durable. De plus, chaque entreprise qui s'installe dans ce parc doit se conformer à

2. <https://www.ecoparcindustriel.com/>

3. <https://www.regionvictoriaville.com/page/1189/corporation-de-developpement-economique-cdevvr.aspx>

4. Ce sont des entreprises manufacturières qui produisent des produits à haute valeur ajoutée à partir d'une quantité modérée de matière première transformée.

des exigences relatives à ses dites "pratiques d'affaires" ainsi qu'à la conception et à la construction de son bâtiment et de ses aménagements extérieurs. Les exigences relatives aux pratiques d'affaires sont contenues dans un label interne à Victoriaville et sa région appelé "Démarche D2", dont le but est d'accompagner une entreprise dans l'établissement, l'exécution et le suivi d'un plan d'action personnalisé en développement durable. Les exigences relatives à la conception et à la construction de bâtiments et des aménagements extérieurs sont détaillées dans un cahier des charges établi par le gestionnaire.

Enjeux :

A ce jour, le gestionnaire de l'écoparc industriel Daniel Gaudreau fait face à trois enjeux principaux :

- Attirer plus d'entreprises afin de poursuivre son développement car beaucoup de terrains du parc cherchent toujours acquéreurs.
- Faire de l'écoparc un laboratoire d'expérimentation sur les bonnes pratiques qui pourraient être transférées au reste des parcs industriels de la ville et de sa région
- Rayonner en matière d'aménagement et de gestion durable de parcs industriels au Québec⁵.

Ainsi, l'écoparc industriel Daniel Gaudreau est un parc encore peu développé mais qui, depuis l'origine, s'est déjà fortement engagé dans une démarche de développement durable. Il s'agira donc d'accompagner son gestionnaire à enrichir cette engagement en évaluant ses premiers résultats et en aidant à prendre des actions correctives si nécessaire.

1.4 Le technopole Savoie Technolac

Contexte :

Savoie Technolac est situé en France au Bourget-du-Lac en région Auvergne-Rhône-Alpes en France. Le Bourget-du-Lac est une commune de 4900 habitants situé dans l'aire urbaine de la ville de Chambéry qui totalise 224 800 habitants. Créé en 1987, Savoie Technolac a été construit sur l'ancienne base aérienne militaire du Bourget-du-Lac, à proximité de la rive sud-ouest du lac du Bourget.

Gestionnaire :

Savoie Technolac est aujourd'hui géré par Chambéry Grand Lac Economie (CGLE), un nouveau syndicat mixte en charge du développement économique de l'aire urbaine de Chambéry⁶. CGLE est né en 2017 de la fusion des deux communautés d'agglomération "Grand Chambéry" et "Grand Lac" suite à l'application de la loi NOTRe⁷, dont le but était de renforcer les compétences des régions et des établissements publics de coopération intercommunale. Ainsi, CGLE est chargé de la gestion de l'ensemble des 20 parcs industriels sur son territoire. Pour chacun de ces parcs industriels dont Savoie Technolac, le rôle de CGLE consiste en premier lieu en la prospection d'entreprises ainsi que la mise en application d'exigences relatives à ces implantations. Il s'agira

5. À sa création, l'écoparc industriel Daniel Gaudreau était le premier parc industriel à revendiquer une qualité d'écoparc au Québec. La CDEVRA avait donc pour vision d'en faire ainsi qu'un endroit de référence au Québec pour les pratiques d'affaires responsables.

6. <https://www.chambery-grandlac.fr/>

7. <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000030985460/>

également de veiller à l'accompagnement des entreprises résidentes et au soutien de leurs projets ainsi qu'à animer le réseau des entreprises résidentes. Comme la CDEV, de manière plus globale, CGLE a également pour mission la promotion, l'entretien et l'aménagement du parc.

Taille et entreprises :

En tout, lors d'un sondage réalisé en 2014, Savoie Technolac comptait 230 entreprises, 5000 étudiants et 4000 employés dont 1000 chercheurs. Savoie Technolac est un technopole, soit un parc industriel accueillant des entreprises de services et comprenant une forte proportion d'activités de R&D, pour une part en liaison avec les universités. La première filière développée à Savoie Technolac est celle de l'énergie. En effet, Savoie Technolac est un des plus importants groupements d'entreprises dans le domaine en France. Les deux autres filières développées sur le parc sont celles respectivement du numérique et du bâtiment. On trouve à Savoie Technolac le plus gros incubateur entrepreneurial de la région Auvergne-Rhône-Alpes ainsi que l'Université Savoie Mont Blanc. De nombreuses entreprises de services aux employés s'y sont également graduellement implantées.

Engagement dans une démarche développement durable :

Le gestionnaire de Savoie Technolac encourage et est régulièrement à l'origine de projets relevant de l'aménagement du parc et visant à réduire son empreinte énergétique. Par exemple, un tronçon test de 68m² de route solaire a été construit sur le parc en plus de 2 500 m² de panneaux photovoltaïques et d'une station hydrogène. Pour améliorer la qualité de vie au travail, CGLE a encouragé la mise en place de plusieurs services offerts aux employés du parc. Parmi ces services, on compte un club des entreprises, une crèche d'entreprises, de nombreuses offres de restauration, un bureau de poste, un pôle médical, des services de reprographie, une livraison de produits frais, etc.

Enjeux :

Actuellement, Savoie Technolac étant proche de sa pleine capacité, son enjeu principal est donc son extension. Le gestionnaire de Savoie Technolac prévoit d'agrandir son territoire lors de deux opérations d'aménagement. A terme, il est prévu que Savoie Technolac couvre une superficie de 150 hectares et double sa capacité d'accueil, soit une capacité de 18 000 personnes. Ainsi, un enjeu découlant de cette extension est celui du transport des personnes travaillant ou étudiant sur le parc, et de sa durabilité. Enfin, un dernier enjeu pour le gestionnaire de Savoie Technolac est l'intensification des liens et collaborations entre les entreprises résidentes.

En somme, on peut constater que Savoie Technolac est un parc au développement fructueux et qui s'est ponctuellement engagé dans une démarche de développement durable suite à des opportunités. Il s'agira donc d'accompagner son gestionnaire à enrichir cet engagement à l'occasion de l'agrandissement du parc, en l'aidant à redéfinir des objectifs dont la finalité est la durabilité.

1.5 L'écoparc Savoie Hexapole

Contexte :

Savoie Hexapole est situé en France à Méry, une commune voisine du Bourget-du-Lac, dans la région Auvergne-Rhône-Alpes en France. Le parc a été créé en 1999 à la suite du succès de Savoie Technolac.

Gestionnaire :

Savoie Hexapole était auparavant géré par le Syndicat Mixte Savoie Hexapole. Aujourd'hui, comme Savoie Technolac et suite à la loi NOTRe, Savoie Hexapole est géré par CGLE. Le rôle de CGLE vis-à-vis de Savoie Hexapole est le même que pour Savoie Technolac.

Taille et entreprises :

Actuellement, 160 entreprises, totalisant 1700 employés, sont installées sur ce parc de 150 ha. Une majeure partie de ces entreprises est spécialisée dans le domaine du sport extérieur et du bien-être.

Engagement dans une démarche développement durable :

Savoie Hexapole revendique sa qualité d'écoparc justifiée par la labellisation ISO 14001⁸ de son Système de Management Environnemental (SME) obtenue entre 2007 et 2017. Dans cette logique, de nombreuses actions visant à améliorer la qualité environnementale du site ont été menées par son gestionnaire :

- Les actions en lien avec l'aménagement durable sont réparties selon si elles concernent l'organisation du site et les aménagement extérieurs (*e.g.* densification, gestion des eaux pluviales, déplacement altermodaux, conservation des espaces naturels) ou si elles concernent la constructions (*e.g.* qualité environnementale des bâtiments) ;
- Les actions en lien avec le fonctionnement durable du parc sont réparties selon si elles concernent la gestion des ressources (*e.g.* optimisation de la consommation d'électricité, mise en place de système énergie renouvelable, optimisation de la consommation d'eau, l'entretien des espaces verts) ou si elles concernent l'animation du parc (*e.g.* suivi des entreprises et leur sensibilisation aux enjeux environnementaux, communication sur les actions du parc et création d'un environnement propice à la collaboration inter-entreprises).

Enfin, on note que comme à Savoie Technolac, les entreprises de Savoie Hexapole ont accès à de nombreux services mutualisés : restauration, télécommunications, salle de réunion, salle de sport, crèche, etc.

Enjeux

L'enjeu actuel du gestionnaire de Savoie Hexapole est la pérennité du parc et son développement. En effet, le parc n'a pas encore atteint sa pleine capacité et il n'est donc pas prévu de l'agrandir.

Finalement, on constate que Savoie Hexapole est un parc qui s'est fortement engagé dans une démarche de développement durable à l'occasion de sa certification ISO14001. Il s'agira aujourd'hui d'accompagner son gestionnaire à perpétuer cet engagement hors de sa démarche de certification.

1.6 Les parcs industriels du Grand Annecy

Contexte :

Le Grand Annecy est la communauté d'agglomération du bassin Annécien, situé dans la région Auvergne-Rhône-Alpes en France. Elle est formée en 2017 par la fusion de la communauté de l'agglomération d'Annecy avec les communautés de communes du bassin Annécien. Ainsi, en

8. <https://www.iso.org/fr/iso-14001-environmental-management.html>

plus d'Annecy, 34 communes font partie du Grand Annecy qui totalise ainsi 207 000 habitants sur un territoire de 540 km². Le Grand Annecy est chargé de la gestion des 44 parcs d'activités existants sur son territoire.

Gestionnaire :

Le rôle du Grand Annecy vis-à-vis de ses parcs industriels consiste de manière globale en la prospection des entreprises, l'entretien et l'aménagement des parcs et la gestion du foncier.

Taille et entreprises :

Parmi les 44 parcs d'activités du Grand Annecy, deux accueillent plus de 100 entreprises : le parc d'activité économique des Glaisins à Annecy-le-Vieux, le parc Altaïs à Chavanod et Cran-Gevrier. À titre d'illustration, le parc Altaïs est un parc industriel de 60 hectares qui accueille environ 130 entreprises et 1600 employés, ce qui représente un taux d'occupation de 70%. Les autres parcs d'activités sont de tailles variables, 7 parcs accueillent entre 50 et 100 entreprises, 8 accueillent entre 20 et 50 entreprises et les 27 restants accueillent moins de 20 entreprises.

Engagement dans une démarche développement durable :

À l'heure actuelle, le parc industriel du Grand Annecy qui fait preuve du plus fort engagement dans une démarche de développement durable est le parc Altaïs. L'aménagement du parc Altaïs intègre des critères sociaux et environnementaux. En guise d'exemple, le parc a été conçu pour la valorisation des espaces boisés environnant et des points de vue sur les montagnes. La prise en compte des modes de déplacement écologique s'est traduit par l'aménagement d'une piste cyclable. Enfin, les entreprises candidates à l'implantation dans le parc doivent se conformer à un cahier de prescriptions urbanistiques, architecturales et paysagères qui définit les règles en matière de volumétrie, de positionnement des bâtiments et de matériaux à utiliser.

Enjeux :

Actuellement, un enjeu du Grand Annecy est la pénurie de foncier commercialisable. En effet, très attractif, le territoire arrive actuellement à saturation et les projets sont de plus en plus complexes en raison de la topographie et des contraintes agricoles. Dans les parcs industriels existants, peu de locaux vacants sont à la fois adaptés aux besoins actuels des entreprises et accessibles financièrement. Enfin, à l'inverse du parc Altaïs, certains parcs sont actuellement confrontés à leur obsolescence et nécessitent donc d'être requalifiés. Cette requalification sera donc l'occasion pour ces parcs de s'engager dans une démarche de développement durable. En résumé, il s'agira d'accompagner le Grand Annecy à s'engager dans une démarche de développement durable à l'échelle de tout ses parcs industriels.

1.7 Synthèse de la description des cas d'étude

Le Tableau 1.1 offre une synthèse des caractéristiques de nos 4 cas d'étude.

Tableau 1.1 – Synthèse description des cas d'étude

Cas d'étude	Maturité	Taille	Engagement développement durable	Enjeux
Ecoparc Industriel Daniel Gaudreau	Parc en début de développement	3 entreprises	Fort engagement en aménagement	Développement, Transfert de bonnes pratiques, Rayonnement
Savoie Technolac	Parc développé et en cours d'extension	230 entreprises	Engagement ponctuel en aménagement et fonctionnement	Extension du parc
Savoie Hexapole	Parc en fin de développement	160 entreprises	Fort engagement en aménagement et fonctionnement	Pérennité
Parcs du Grand Anecy	Diverse maturité des parcs du territoire	44 parcs industriels	Engagement ponctuel dans l'aménagement d'un parc industriel du territoire	Pénurie du foncier économique, Obsolescence et requalification de certains parcs industriels

2

Écoparc : revue de la littérature et définition du concept

Ce chapitre présente l'article intitulé "Towards sustainable business parks : A literature review and a systemic model", publié dans le Journal of Cleaner Production. Un résumé de l'article en français introduit le chapitre.

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2.1 Résumé

Dans les pays développés, les zones d'activité et zones industrielles rencontrent divers défis tels que la pollution atmosphérique locale, la gestion des déchets, la consommation de matières premières, le vieillissement des infrastructures ou la raréfaction de terrain constructible. Résultat de la création des notions de développement durable et d'écologie industrielle, l'idée de créer de parcs éco-industriels, fondés autour de l'échange de ressources, a été reconnue comme une stratégie prometteuse pour remédier à ces enjeux. La création d'un réseau d'échanges de matériaux et d'énergie par le couplage des procédés industriels, appelé symbiose industrielle, est réalisable au sein de zones rassemblant des industries majoritairement lourdes. Les zones d'activité constituées d'industries plus "légères" ou d'entreprises de services peuvent améliorer leur durabilité par des approches différentes. D'autres types de collaboration peuvent être envisagés telles que l'offre de services partagés pour les entreprises ou employés, la logistique collaborative ou la recherche et développement collective. De plus, une partie de la réflexion peut être orientée vers l'aménagement du parc et de ses infrastructures. Par ces observations, un nouveau type de parc éco-industriel est introduit : l'écoparc. L'écoparc est un archétype plus accessible, convenant mieux au cas des zones d'activités constituées d'industrie légères ou d'entreprises de service. En affirmant que l'écoparc est un système, un cadre conceptuel est proposé suivant les principes de la modélisation systémique de Le Moigne. La modélisation systémique décrit l'écoparc à travers ses objectifs, son environnement et sa structure. Elle offre un cadre aussi bien robuste que flexible pour le développement futur d'un modèle d'évaluation de la performance durable de l'écoparc.

2.2 Introduction

Growing concerns on several issues such as air and water pollution, resource depletion and the economic and financial crisis have motivated initiatives worldwide to establish sustainability in various fields and contexts. Sustainable development gained worldwide acceptance after the ([World Commission On Environment and Development, 1987](#)) in Rio de Janeiro, Brazil. It is defined as "*a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". In other words, sustainability's goal is to meet human needs without undermining the integrity and stability of natural systems. Sustainability can be broken down into three pillars, also called "triple bottom-line", namely social, economic and environmental aspects. Since then, with the local applications of Agenda 21, the will to move towards sustainable development has become particularly strong at the regional and local levels ([United Nations, 1992](#)).

One of the major challenges for communities is the development of respectful and productive business parks. According to the United Nations Industrial Development Organization, a business park is : "*A tract of land developed and subdivided into plots according to a comprehensive plan with provision for roads, transport, and public utilities for the use of a group of industrialists*" ([United Nations Industrial Development Organization, 1997](#)). In this article, for the sake of clarity, a business park with mostly heavy industrial activities is called an "industrial park" and a business park with lighter industries or that is solely service-based is called a "mixed industrial park" as proposed by [Lambert and Boons \(2002\)](#).

The creation of industrial and mixed industrial parks resulted from the generalization of the urban planning concept called "zoning" which is the process of dividing land between different areas specific to their use in order to set planning guidelines for urban development. This concept was developed by planners and architects who wanted to clear up the frictions between industrial deve-

lopment and the quality of urban life. Lambert and Boons (2002) indicated that this concept is now the classical model for planning and developing cities in Europe since it was recommended by Le Corbusier in 1928. They indicate that the idea behind the distancing of heavy industrial activity from others is that industry requires specific infrastructures that are not compatible with the urban fabric and that its impacts need to be separated from residential areas, for comfort, health and safety reasons. They estimate that in the case of mixed industrial parks, the intention is to provide large floor plates, located near main roads, at a cheaper cost (Lambert and Boons, 2002).

Nowadays, business parks need to transform themselves in order to manage with the economic, environmental and social shortcomings stemming from waste handling, resource consumption, infrastructure aging, land rarefaction, etc. (Lambert and Boons, 2002). For this reason, much is being done today to propose more sustainable business parks. Several disciplines and key concepts are related to this endeavor such as industrial ecology and sustainable urban planning.

The first contribution of this article is an analysis of the multidisciplinary literature positioning the concepts surrounding the sustainability of business parks that leads to the proposal of a new model of sustainable business park : the mixed-use ecopark (MUE). The second contribution of this article is the systemic modeling of the MUE. Indeed, a conceptual framework of the MUE is required in order to support its definition. Systemic modeling was chosen for this description because it can apprehend the MUE through the interactions of its components and logically define its behavior and objectives. The main objective of this article is to set the basis for the development of a sustainability performance measurement system (SPMS) for the MUE's management.

This article is structured as follows. Section 2.3 describes the method used for the literature review on the concept of sustainability in industrial parks and the selection of business parks studied. Section 2.4 presents the results from the literature review from the perspective of two different disciplines. Subsection 2.4.1 presents and positions concepts relating to the eco-industrial park (EIP) and Subsection 2.4.2 presents the principles of sustainable urban planning and development. Following this literature review, the observation of the case studies and the proposal of a new concept called MUE are presented in Section 2.5. Then, a conceptual framework of the MUE, using systemic modeling, is proposed in Section 2.6 and the potential for this approach to set the basis of a SPMS for the MUE is discussed. Section 2.7 concludes this article.

2.3 Materials and Methods

2.3.1 Literature review on the sustainability of business parks

The literature review is carried in a cascading approach starting with the definition of the EIP. This review is narrative and multidisciplinary, investigating the topic of business parks' sustainability in the fields of industrial ecology and urban planning. Peer-reviewed papers from indexed publications were selected along with grey literature sources. Moreover, when clearly identified for a given concept, the seminal paper is mentioned.

The keywords used are the following : "*sustainable industrial park*," "*sustainable business park*," "*eco-industrial park*," "*industrial ecology*," "*circular economy*," "*industrial symbiosis*," "*sustainable urban planning*," "*eco-city*" and "*eco-neighborhood*." The search was executed with one or two keywords on Google Scholar and in the Scopus database.

In total, 116 documents were consulted between September and March 2018. On those 113 document 92 dealt with topics related to the field of industrial ecology and 21 dealt with the topic of sustainable urban planning. On the 92 documents from the industrial ecology literature, 38 were

focused on the subject of Eco-Industrial Parks specifically.

2.3.2 Case Studies

Three business parks were investigated for this study : Savoie Technolac and Chambéry's district La Cassine in Savoie, France and Daniel Gaudreau ecopark in Quebec, Canada. This study is attached to the context of two regions : Savoie in France and Centre-du-Québec in Canada. Indeed, during the last three decades the city of Chambéry in Savoie went through a progressive de-industrialization. Despite the land pressure caused by the proximity of the mountains and the population growth, more than 50 hectare of brownfield close to the city center are abandoned. Those sites offer potential for urban development integrating business parks. The development of those business parks must take the geographical, economic, social, environmental and energy local context into account. It must be federating, robust, concerned with the quality of life and the environment and likely to create an endogenous and competitive territorial development. In the Centre-du-Québec region, the city of Victoriaville faces similar challenges with the development of an eco-industrial park. Victoriaville engaged in this development in a different context with the intention to attract and retain the labour they currently lack of. For those reasons, the case studies were volunteers to be part of a research project on the performance evaluation and design of decision-making support tools for the development of sustainable business parks. Moreover, the case studies were selected because they offers diversity in the following terms.

- Size : Savoie Technolac have 250 tenants when Daniel Gaudreau ecopark only have 2.
- Development stage : La Cassine is still at the design phase, Daniel Gaudreau have currently sold 10% of its lots and Savoie Technolac is a complete business park wishing to extend itself in the near future.
- Geography : Two case studies are located in France and one is located in Canada allowing for a comparison between both culture and policies. Moreover La Cassine is located in Chambéry's center whereas the two other case studies are built in the periphery of the city.
- Targeted companies : Savoie Technolac is specialized in the building, energy and electronic sector, La Cassine wants to attract service companies and local artisans and lastly, Daniel Gaudreau ecopark accepts light industries from all sectors.

2.4 Results from the literature review on sustainability in business parks

2.4.1 Sustainable development through industrial ecology : eco-industrial parks and other initiatives

The starting point of this literature review is industrial ecology (IE) and its application at the business park scale : the EIP. This section defines these concepts and other similar approaches and strategies addressing the sustainability of industrial and mixed industrial parks.

Industrial ecology

IE is the discipline promoting the concept of industrial ecosystems, which derives from a metaphor of biological ecosystems and proposes solutions aimed at improving the industry's environmental impact (Frosch and Gallopoulos, 1989; Erkman, 1997). An industrial ecosystem should develop an optimal web for the recycling and cascading of materials and energy, mimicking food webs in

the natural ecosystem (Korhonen, 2001). The essential idea, also called "roundput" by Korhonen (Korhonen, 2001; Korhonen and Snäkin, 2005; Korhonen, 2007), is that the effluents of a company become the input of another to minimize virgin input. The ideal industrial ecosystem would operate in a closed loop of recycling and reusing so that it does not produce any waste (Ayres and Ayres, 2002).

IE moves away from the preventive approaches that consist of reducing virgin materials or energy inputs and reducing waste (Lovins et al., 2007). Contrarily to cleaner production which focuses on companies (Hens et al., 2018), it is applicable at all levels from micro to macro. IE offers the basis for achieving sustainability through cooperation between waste-producing and waste-consuming processes. It considers society's metabolism as a whole rather than optimizing each of its components independently. The application of IE should provide a win-win-win outcome for the community, where the environmental impact of businesses is lessened, achieving economic and social benefits (Dunn and Steinemann, 1998).

Applications of IE concepts are mostly encountered at the local or regional scale through the form of eco-industrial development or industrial symbiosis (IS) (Gibbs et al., 2005; Deutz and Gibbs, 2008). As defined by Chertow (2000) : "*Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantages involving physical exchange of materials, energy, water, and/or by-products. The keys to IS are collaboration and the synergistic possibilities offered by geographical proximity.*"

IE and IS are often associated with the circular economy concept (Ellen MacArthur Foundation, 2013). A circular economy promotes the shift from the traditional, linear, open-ended economic system to a circular economic system, with "closing-the-loop" production patterns. A first theoretical framework for the circular economy was proposed by the environmental economists Pearce and Turner (1989). The second law of thermodynamics and Georgescu Roegen's theory on the irreversible exhaustion of natural resources through economic activity serve as the major arguments for the need to shift to a circular system (Georgescu-Roegen, 1971). IE was introduced at the same time as the circular economy concept with Frosch and Gallopoulos publishing their seminal article the same year that Pearce and Turner published theirs. Nevertheless, some authors considered that the circular economy concept takes its roots in IE and that it builds on IE's concepts for the industrial system, scaling them up for the whole economic system (Ghisellini et al., 2016; Saavedra et al., 2018). It seems that circular economy's focus is wider than IE and the analysis of flows in industrial systems.

Eco-industrial park

At the local scale, a business park implementing a long-term IE strategy is called an EIP (Lowe and Evans, 1995; Cohen-Rosenthal et al., 1996; Desrochers, 2001). A famous definition of the EIP was proposed in 1997 by the (U.S President's Council on Sustainable Development, 1997). They defined an EIP as : "*A community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, energy, infrastructure and natural habitat), leading to economic gains, improvements in environmental quality and equitable enhancement of human resources for businesses and the local community.*"

Pellenbarg (2002) proposed the following characteristics to identify an EIP :

- joint use of facilities and collective facilities ;
- closing material cycles through the use of waste materials ;
- relocating firms for a more efficient use of space ;
- clustering firms that are complementary in terms of economy and ecology.

Tudor et al. (2007) examined the different options of cooperation between those aiming at sustainable production processes (or streams) and those aiming at sustainable site arrangements (or parks). There seems to be a debate on the defining characteristics of an EIP, but the symbiosis, or "roundput," appears to be its ultimate goal (Deutz and Gibbs, 2008).

The most famous EIP is Kalundborg's EIP in Denmark. It has been abundantly documented in the IE literature as the best example of IS and serves as evidence of the benefits provided by the implementation of IE in a geographically restrained space (Lowe and Evans, 1995; Chertow, 2000; Gibbs et al., 2005). A network of energy and materials exchanges has organically grown in Kalundborg industrial park between the city, a power plant, a refinery, a pharmaceutical plant, a gypsum board manufacturer and a waste treatment plant. This has already helped to save on a consequential amount of resources and to decrease production of waste (Jacobsen, 2006).

Another model of industrial parks cooperating to gain various economic benefits is the concept of industrial clusters. Porter (1998) defines an industrial cluster as : "*a geographic concentration of interconnected companies, specialized suppliers, service providers, firms in related industries and associated institutions (e.g., universities, standard agencies, trade associations) in a particular field that compete but also cooperate.*" The EIP can also focus its strategy on one particular field, but the difference between the EIP and industrial clusters is that the objective of an industrial cluster is mainly, if not solely, economic and thus does not address all the objectives of sustainability.

It should be noted that all of the concepts and approaches described in this article are specifically orientated towards the particular case of geographically constrained collections of business. Other concepts and analogous approaches can be found in the literature. Particularly, in the supply chain management community, very similar approaches such as environmental management, design for the environment, product stewardship, green purchasing and reverse logistics are used to improve the sustainability of supply chains (Leigh and Li, 2015). Excluding geographical proximity, the similarities between supply chains and business parks could be used for the development of sustainable business parks drawing from supply chain management experience (Le Tellier et al., 2017).

Having defined the various concepts and disciplines surrounding the EIP paradigm, these concepts are positioned in Figure 2.1. sustainable development is at the root of most explorations in the circular economy concept and IE. Knowing that the focus of the circular economy concept is wider than the industrial system, it was placed above IE, even if they were both introduced the same year. It should also be noted that other concepts relating to the circular economy and IE were added to Figure 2.1 as an illustration of the variety of potential approaches of both fields.

Other initiatives of sustainable business parks documented in the literature

The Research Triangle Institute (1996) identified seven types of eco-park development that should not be considered equivalent to an EIP. These eco-parks are presented in Table 2.1. The Research Triangle Institute consider that : "*An EIP could include any of these features. But the critical element in defining an EIP should be the interactions among its member businesses and between them and their natural environment,*" or in other words, that only IS is the defining element of an EIP.

In Italy, the concept of ecologically equipped industrial area (EEIA) was introduced by a legislative decree in 1998. According to Taddeo (2016), the EEIA is a geographically delimited production area with high environmental quality standards. Taddeo argues that the EEIA displays a number of limits preventing it from becoming a generalizable model, specifically its initial investment with a long return time and its rigidity. However, it can play a role in the implementation of the EIP model in Italy by encouraging collaboration between co-located companies and helping to overcome the regulatory limits preventing waste exchange.

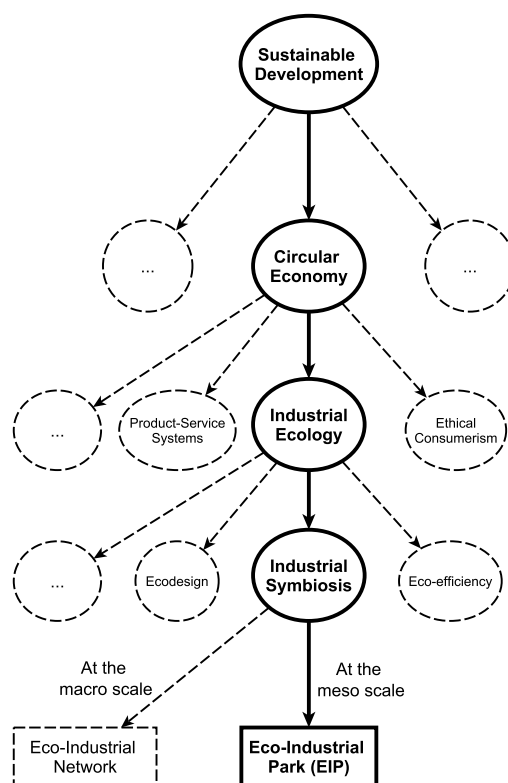


Figure 2.1 – Position of the EIP concepts

In Belgium, efforts have been made by the Walloon government to encourage more sustainable strategies for the development of business parks with the introduction of the "eco-zoning" concept. [Van der Kraaij et al. \(2011\)](#) give the following definition of eco-zoning : "*Economic activity area, pro-actively managed by the association of its company members, positively interacting with its environment, and where urban planning, environmental management and IE contribute to optimize the use of land, materials and energy, to support the performance and economic dynamic of the company members and the community and to lower the local environmental impacts.*" The main difference between an EIP and eco-zoning is that the latter goes beyond IE. Indeed, the eco-zoning concept addresses issues related to the planning and management of a business park while the EIP's main objective is to create a mature IS.

As can be seen, both the EEIA and eco-zoning were created in a local context to respond to local needs and realities.

[Lambert and Boons \(2002\)](#) proposed a typology of EIP initiatives differentiating the mixed industrial park from the heavy industrial complex. They define the mixed industrial park as "*industrial activities, mainly small- and medium-sized enterprises, which are concentrated in dedicated areas, of a very diverse nature with no or little coupling of production processes.*" Having identified this particular type of industrial park, the authors argue that their impact on the environment and country planning is non-negligible even if it is insufficiently examined. Indeed, they argue that once the lots are issued, the selection of companies and trivial collective managements such as traffic control, fire protection and signposting are absent. They then propose two types of mixed industrial park initiative developed under the banner of IE and EIPs :

1. greenfield development, which addresses ecological issues in the different stages of the development process ;
2. brownfield development, which is the revitalization of an existing area, taking the reduction

Tableau 2.1 – Sustainable industrial developments that are not an EIP

1	Single by-product exchange pattern or network of exchanges ;
2	Recycling business cluster (e.g. resource recovery recycling companies) ;
3	Collection of environmental technology companies ;
4	Collection of companies making "green" products ;
5	Industrial park designed around a single environmental theme (e.g., a solar energy-driven park) ;
6	Park with environmentally friendly infrastructure or construction ;
7	Mixed-use development (e.g., industrial, commercial and residential).

of the environmental impact into account.

2.4.2 Sustainable urban planning and development

Following the presentation of different concepts relating to IE in industrial parks, it is suggested that the sustainability of industrial park planning could also be improved. Industrial and mixed industrial parks could benefit by integrating notions of sustainable planning into their design, development and performance evaluation. To support this proposal, the following section outlines and briefly introduces urban sustainability and its application at the city scale ("eco-cities") and the district scale ("ecodistrict" or "eco-neighborhood").

Emergence of sustainability in procedural planning theory

Urban planning is a scientific and professional field concerned with the design of the urban environment. More precisely, urban planners handle the development of buildings, the use of land, and the design of urban infrastructures such as transportation, communications, and distribution networks (Merlin, 2002). Urban planning is an independent professional discipline relating to different fields such as architecture, landscape architecture, civil engineering, and public administration.

Since its introduction in 1987, the concept of sustainability has been implemented in the urban planning field (for a historical review of trends and theoretical approaches leading to urban sustainability, see (Bayulken and Huisingh, 2015)). Nowadays, urban planners in most European cities focus on reaching a certain level of sustainability and researchers work to define what urban sustainability is and how to reach it. Aiming at the triple bottom-line, urban sustainability spans economic concerns - investment and operating costs - environmental concerns - mobility, waste handling, energy and water management and biodiversity preservation - and social concerns - political and social solidarity and equality, comfort, citizenship, governance. Campbell (1996) considers urban sustainability as the trade-off between the three conflicts resulting from the triple bottom-line : between economic growth and equity arises a conflict of property ; between equity and environment protection arises a conflict of development ; between economic growth and environment protection arises a conflict around resource consumption. At the center of this conflict triangle is the sustainable urban development that Campbell qualifies as "green, profitable and fair." Sustainability is often seen as an elusive goal, but more than a goal in itself, it is the opportunity to understand, to increase awareness and responsibility, and finally to rethink lifestyles and their physical impacts on cities and the environment.

Eco-city, ecodistrict and related concepts

The eco-city and similar concepts such as "sustainable city", "resilient city" and "low-carbon-city", are (more or less) the application of sustainability to the planning of a city. De Jong et al. (2015) interpret these concepts as initiatives aimed at upgrading urban infrastructure and services, in an effort to create better environmental, social and economic conditions and to enhance cities' attractiveness as well as their competitiveness.

At a smaller scale, sustainable urban planning projects adapted to a neighborhood are called eco-districts or eco-neighborhoods (Næss, 2001). Examples of famous ecodistricts are Vauban in Freiburg, Germany (Schroepfer and Hee, 2008), BedZed in London, UK (Chance, 2009) and BO01 in Malmö, Sweden (Austin, 2009). In France, and especially in Paris, many eco-neighborhood projects have been undertaken. The popularity of the concept can be explained by the support given by the French government through the addition of new regulations and especially the *Grenelle 2 law* (About-de Chastenet et al., 2016; Boutaud, 2009).

Other than scale, according to Joss (2011), eco-city endeavors can be differentiated by types of urban development (such as new developments of entire urban centers built from scratch, urban "infill" developments - new districts built on brownfield sites, or "retrofit" developments, regenerating and upgrading existing urban areas), phases of development (pilot/planning phase, under construction, or implemented) and key implementation mode (through technological innovation, integrated sustainability plan, or civic engagement). Joss (2015) also proposed dimensions, or areas of interest, for the eco-city based on the sustainability triple bottom-line applied to the urban context. These dimensions are sorted into five categories : environmental sustainability, economic sustainability, social sustainability, urban design and systems and urban governance. Each eco-city can address different criteria of these categories with specific related targets. These details are presented in Table 2.2. It should be noted that an initiative does not have to apply every element of sustainability ; decision-makers can choose a broad approach but can also focus on a limited set of key goals. Moreover, these dimensions will impact and require the involvement of several different stakeholders such as regional and local governments, public service providers and citizens. This framework is only one proposal among others since there are no international frameworks or standards defining the eco-city or ecodistrict.

Having defined the notion of urban sustainability, it is suggested that the concept of ecodistrict could be transposed to business parks even if they may be geographically remote from the city. Indeed, planning a business park can integrate some of the same sustainability elements as those proposed for an ecodistrict, for instance, smart technologies or sustainable storm water management. For a business park, strategies relating to sustainable urban development and IE are complementary even if undertaken at different time scales. Sustainable planning of the park will be an important target at the early stages of the project and the creation of a symbiosis should be a major concern during the selection of companies and the animation of the collaboration in the park.

Tableau 2.2 – *Eco-city dimensions (adapted from Joss 2015)*

Categories	Dimensions
Environmental sustainability	CO ₂ /GHG emission
	Buildings' energy consumption
	Water consumption
	Public transport integration
	Waste handling
	Biodiversity protection
Economic sustainability	Highly skilled, "green" jobs
	Competitiveness and resilience
	Smart technology/innovation
	Well-being
	Housing affordability
	Urban agriculture promotion
Social sustainability	Livability
	Equity
	Civic engagement
	Cultural diversity
Urban design and systems	Housing density
	Multi-scale integration
	Ecosystems management
Urban governance	Multilevel policy coordination
	Public-private partnerships
	Political accountability

2.5 Observation and proposal of a new concept of sustainable business park

In this section, the results from the observation of the case studies are presented. Following these observations and the literature review, a new concept of sustainable business park is proposed : the MUE.

2.5.1 Observation of initiatives towards sustainable business parks

Three initiatives of sustainable business parks were observed by the authors : Savoie Technolac in Le-Bourget-du-Lac, France ([Chambéry-Grand Lac Economie, 2018b](#)), La Cassine in Chambéry, France ([Chambéry-Grand Lac Economie, 2018a](#)) and Daniel Gaudreau's MUE in Victoriaville, Canada ([Corporation de Développement Economique de Victoriaville et de sa région, 2018](#)). The local stakeholders for each business park were questioned on the subject of their respective business parks, their structure and their objectives. Savoie Technolac's stakeholders provided their indicator scorecard and Victoriaville's stakeholders provided their development plan and the approval charter for candidate companies. The private planner in charge of the design of La Cassine

provided the results of their preliminary economic and environmental study with the recommendations they made to the decision-makers in charge of the project. Moreover, additional information were provided by the respective internet websites of those business parks.

Savoie Technolac is a French technopole focusing its strategy on the innovation, building and energy sector and, more particularly, the solar energy sector. Companies implanted in Savoie Technolac mostly produce services. They benefit from close proximity to the local university and the strong entrepreneurial dynamic created by the business incubator and growth accelerator. Savoie Technolac does not advertise itself as a sustainable business park, but it has implemented many collaborative sustainable actions over the years. For example, one of their most recent projects doubles their production of renewable energy to an 18,000-person capacity. Daniel Gaudreau's MUE is located in Victoriaville in the Quebec province of Canada. Built next to a wetland, this young MUE focuses its strategy on sustainable urban planning and architecture and requires its companies to be certified to a local standard on sustainable business practices called Démarche d².

Lastly, La Cassine is a district of Chambéry, a 60,000-inhabitant city in the Savoy region in France. The local stakeholders' intention is to rehabilitate the Cassine district in a mixed industrial park for service companies and small craft enterprises to attract tourists traveling to the Alps or Italy. Their wish is to alleviate the impact of the district on both the environment and the city by adopting a sustainable urban development approach.

In summary, the business parks observed show diversity in their sizes, their companies' activities, their life cycle stages and their cultural and natural environments. Since their companies' production process are rarely compatible, none of these business parks wish to develop an industrial symbiosis based on material substitution synergies. However, all these business parks' stakeholders expressed and enforced an ambition to improve their sustainability through :

- sustainable urban planning and architecture ;
- shared services to the employees, such as shared restaurants, child day care, a car-sharing platform etc. ;
- collaboration between companies, such as joint logistics, joint research, offices renting, energy substitution synergies (residual heat from data center or private renewable energy production for example) etc.

As a result of this observation, a new concept of sustainable business parks is proposed.

2.5.2 Proposal for a new concept : the mixed-use ecopark

The IE strategy and the creation of an IS is complicated by the diversity of activities concentrated in some business parks. Companies in the tertiary sector cannot couple production processes and create material synergies. Of course, synergies can also be created for the sharing of energy. Indeed, even an exclusively service-based business park can create a beneficial exchange of energy between buildings. Moreover, the sharing of services such as restaurants and child care could improve the well-being of the business park's users at a lower cost.

Despite this potential, the creation of a symbiosis is rarely the first goal of most local governments. French and Quebec local governments working on the design and marketing of business parks reported they have close to no power over the already implanted businesses and their practices. Local government can only encourage collaboration by matching businesses. They cannot force implanted companies to cooperate and will not discourage new companies from establishing themselves in their business parks by enforcing coercive rules.

A literature review and observations of sustainable business parks' strategies concluded that the decision-makers' understanding of sustainability is mostly orientated towards the park planning. They endeavor to provide a high-quality business area with a lesser impact on the environment and

high social acceptance, providing more jobs and more economic recognition in the long run than its classic counterpart. Moreover, the popularity of the concept of ecodistrict could also explain the desire to plan attractive and sustainable business parks. High-quality business parks are one of the solutions towards attracting jobs, retaining employees, against building land rarefaction, and against competition with other industrial parks.

Arising from the previous analysis of concepts such as the EIP and the ecodistrict, a particular case of sustainable business park called mixed-use ecopark is proposed. The MUE is a variant of EIP with a stronger emphasis on the sustainability of its planning and development. The MUE shares similar endeavors with the ecodistrict but it is not necessarily a district and it is not designed for mainly residential purposes. Eventually, as can be seen in Figure 2.2, the MUE is a combination of an EIP and an ecodistrict. By adding this characteristic, a definition for the MUE, based on the one given by the US President's Council on Sustainable for the EIP (U.S President's Council on Sustainable Development, 1997) , is introduced. "An MUE is a community of businesses located on a business park planned and built in a sustainable approach, that cooperate with each other and with the local community to efficiently share information, materials, energy or infrastructure, leading to economic gains, improvements in environmental quality and equitable enhancement of human resources for businesses and the local community."

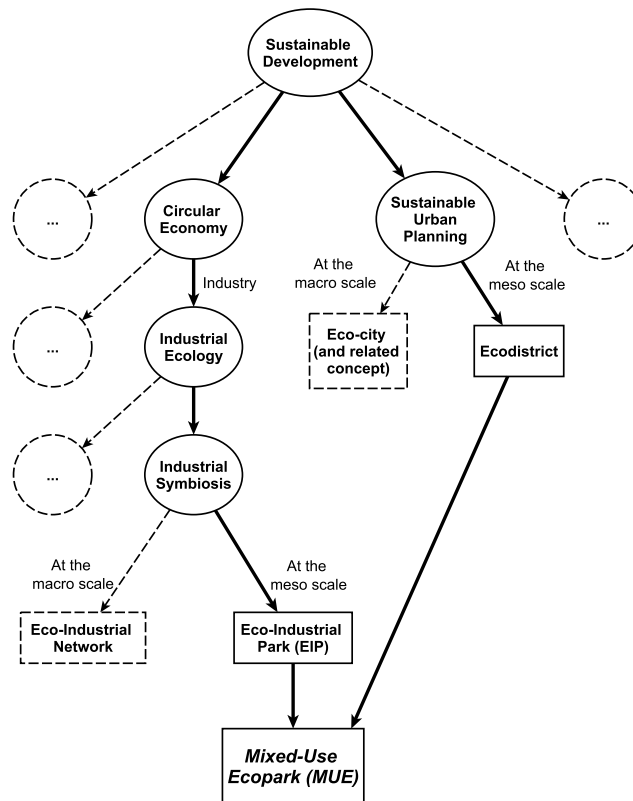


Figure 2.2 – Emergence of the MUE within its founding concepts

2.6 Systemic modeling of mixed-use ecopark

2.6.1 Systemic nature of the MUE

Similar to an EIP (Haskins, 2007; Felicio et al., 2016) and given the systemic nature of cities (Zhao et al., 2013; Masson et al., 2014; Chapman et al., 2016; Pandit et al., 2017), the MUE should be considered as a system. Indeed, the characteristics of natural or human activity systems are the following (Chapman et al., 2016) :

1. A system is an *integrated whole* that is more than the sum of its parts ;
2. A system is comprised of *nested systems* at a range of scales ;
3. A system is *self-organizing*, it can regulate itself in response to changing external conditions ;
4. A system's behavior is *complex*, non-linear and seldom stable ;
5. A system is *resilient*.

Since the MUE corresponds to all these characteristics, it is suggested describing it through systemic modeling. Indeed, understanding the systemic nature of the MUE will benefit the definition of its conceptual framework.

2.6.2 Method

The chosen systemic modeling approach is the one proposed by Le Moigne since his work revolves around artificial systems. His approach to describing an artificial system offers a coherent methodology to formulate a conceptual framework. Le Moigne (1994) defines a system as : "*The representation of an active phenomenon, perceived as identifiable by its projects, in an active environment, in which it operates and transforms itself teleologically.*" His approach consists of describing a system through several characteristics that are summarized in the following list. These characteristics will be further explained as this modeling approach is unfolded, and a summary will be given in Table 2.3.

1. *Finality* : the finality of the system at the highest level of abstraction. It reflects the observer's idea of the system's mission.
2. *Environment* : the components interacting with the system and these interactions.
3. *Structure* : the organization of the subsystems, entities and internal interactions that constitute the system.
4. *Objectives* : the objectives set to attain the finality, described for at least two levels : exogenous (the system and its environment) and endogenous (inside the system).
5. *Behavior* : the normal operation of the system and its transformation when its objectives cannot be reached.

2.6.3 Description of the systemic model of an MUE

Finality

The observer of the MUE is its *Governing_Body*. As its name indicates, the *Governing_Body* is the decision maker for the MUE's development according to a predefined, specific strategy. This body can be composed of several actors with different individual goals, shifting during the different stages of the MUE's development. It can be composed of public or private investors, planners, local governments, designated decision makers of the MUE, etc. Another role of the

Governing_Body is to be the animator of the MUE and the instigator of the collaboration between its members.

For example, in the case of Savoie Technolac, the *Governing_Body* is a union of the local urban agglomerations' governance and of the regional governance. This union delegated the planning of the park to a developer but was strongly implicated in the animation of a collaboration between members. In this union, an accreditation committee ruled on the companies' permit applications. Indeed, some companies cannot join Savoie Technolac as they have to comply to predetermined criteria, especially regarding their activity sector. Being an expert in the innovation and energy sector, Savoie Technolac favored companies working in this area.

To be in accordance with its definition, the finality of an MUE should be sustainability. Sustainability fits Le Moigne's idea of finality perfectly since it is a process of continuous improvement through decision making through interactive learning. To be sustainable, a MUE should seek to balance its performance in each of the three pillars of sustainability. This interpretation of sustainability, favoring consensus over the outstanding achievement of only one target, lies outside the weak vs strong sustainability paradigm. Weak sustainability assumes that natural and artificial capital can be substituted, whereas strong sustainability assumes they cannot (Daly and Cobb, 1994; Dietz and Neumayer, 2007; Chandrakumar and McLaren, 2018). Moreover, this interpretation of sustainability grants an equally important weight to each pillar and more notably to the social sustainability of the MUE (Dempsey et al., 2011).

Environment

As an MUE is a collection of companies, these companies necessarily interact with entities, such as suppliers and clients, implanted outside the MUE. This collection of external suppliers and clients is a part of the system's environment. Entities other than suppliers and clients can influence the behavior of the MUE's companies, but the goal of modeling here is not to give an exhaustive representation of the environment of a company. It should be noted that since the MUE can be exclusively service-based, some MUEs can be integrated into the city where it can unfold new synergies with the residents. In this case, those residents can become new elements of the MUE's environment in the form of clients or suppliers.

Naturally, being the observer of the MUE, the *Governing_Body* is a part of its environment.

Structure

As was established by its definition, in a macroscopic perspective, the MUE is composed of two subsystems. This structure and its relations with the environment is illustrated in Figure 2.3.

The first subsystem is called *Public_Space*, it represents all the public land and the public infrastructure on this land, such as public green areas, public parking, roads or networks. This *Public_Space* provides a service to the companies who pay for it as taxes and fees, directly or indirectly to the *Governing_Body*, which provides its design and maintenance. It should be noted that besides the companies, some clients, as visitors, can access the *Public_Space* of the MUE.

The second subsystem is called *Members*. It is composed of two types of entities : "*company*" and "*building*."

1. *company* : In this model, a *company* includes the part of a private company implanted on the MUE with its employees but not its premises. A *company* can be in the secondary or tertiary sector, of any type or size. For example, Savoie Technolac presently contains around 250 companies.
2. *building* : A *building* comprises a building and its land with any private infrastructure such as parking places. In some cases, a company only rents space and does not own the building

that it is implanted in. Moreover, several companies could be renting space in the same building. As an illustration, Savoie Technolac contains 55 buildings.

To be considered an MUE, the system should have a minimum of two companies and two buildings. The differentiation of *company* and *building* entities will allow defining specific objectives for both.

The *Members* subsystem logically interacts with other systems such as *Suppliers* and *Clients* outside of the MUE, but the main advantage of the MUE is that many mutually beneficial interactions occur inside the subsystem. Figure 2.4 gives an example of the complexity of these interactions, both with the environment (Figure 2.4a) and inside the MUE (Figure 2.4b).

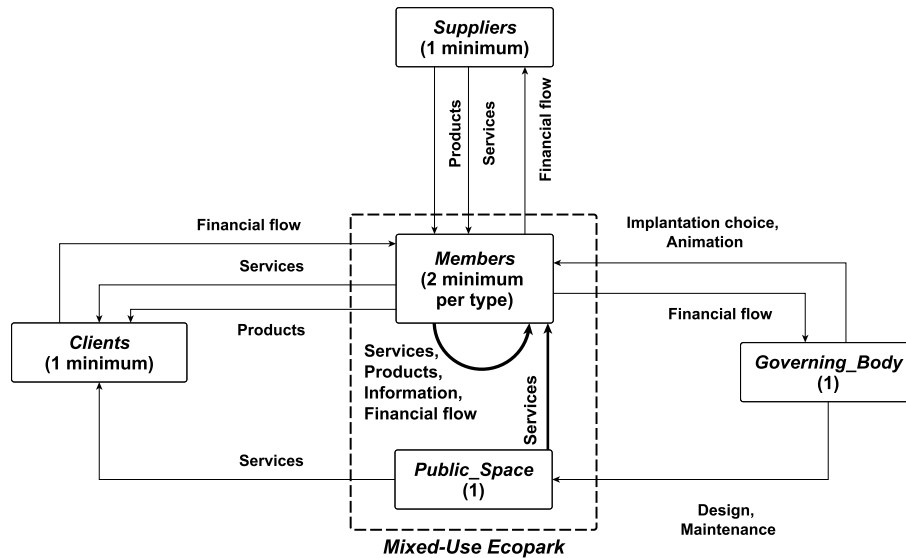


Figure 2.3 – Structure of the MUE

The interactions can occur between the entities, the subsystems and the environment. An interaction can be broken down into three elements : product, service and financial elements. The product element of an interaction concerns the exchange of energy or material, whether raw material, components, products, by-products, coproducts or waste. In the case of an exchange of products, the service element of the interaction is the transport. The service part of an interaction can be the main component of the interaction, for example renting a company its premises or subcontracting to another company of the MUE. Lastly, the financial element is when the interaction occurs with a financial compensation. In Figure 2.3 and 2.4, the interactions are represented by simple arrows pointing to the entity giving a financial compensation and/or receiving a service. For example, the waste handling facility receives waste from company A (product element), processes them (service element) and gets paid for it (financial compensation). In this case, the interaction arrow points to company A. Following this logic, a waste handling facility is a supplier, even if it receives material.

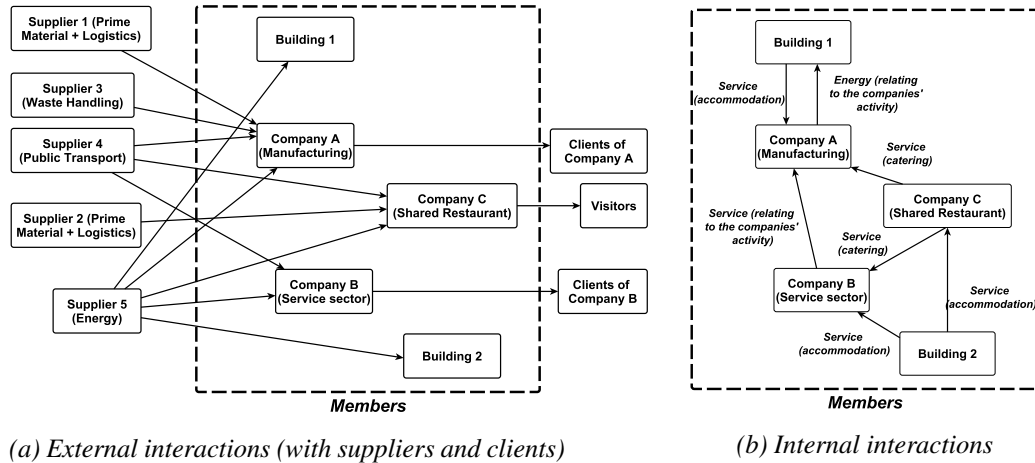


Figure 2.4 – Illustration of external and internal interactions.

Objectives

The objectives set to achieve the ultimate goal can be described for at least two scales. First, some exogenous objectives characterize the expected outputs of the systems from the environment. Secondly, some endogenous objectives characterize the organization of the system needed to achieve the exogenous objectives.

To achieve these exogenous objectives, the MUE fixes some endogenous objectives related to its different entities. These endogenous objectives are specific for each MUE while the exogenous objectives are generic to an MUE and therefore cannot be altered. The endogenous objectives will likely be consistent with the particular strategy and theme of the MUE.

Behavior

A system can adopt two different behaviors : operation and transformation. The system operates when it elaborates its outputs in accordance with its exogenous objectives. When it can no longer reach its exogenous objectives, it needs to transform itself by updating its structure. Two extreme cases of transformation are the initial creation and the final removal of a system.

The operation of the MUE is when the subsystems or entities operate by satisfying the exogenous objectives. The transformation is the updating of its structure by revising its endogenous objectives, such as the choice of a new strategy or the change of regulations.

As a system, the MUE consists of nested systems, and its entities' behavior is also either operation or transformation. Transformation of an entity such as the arrival or the departure of a company is part of the normal operation of a MUE. Indeed, welcoming new companies should not require transforming the whole structure of the system. In Savoie Technolac, new companies come and go every year and those modifications constitute the normal operation of the MUE.

Tableau 2.3 – Summary of the systemic modeling characteristics of the MUE

Characteristics		Modeling of the MUE
1. Finality		Sustainability
2. Environment		<i>Suppliers, Clients</i> and <i>Governing_Body</i>
3. Structure		<i>Public_Space</i> and <i>Members (company and building)</i>
4. Objectives	Exogenous	Economic sustainability
		Social sustainability
		Environmental sustainability
		Balance between the three pillars of sustainability
		Continuous Improvement
	Endogenous	Specific to each MUE
5. Behaviour	Operation	Operation of the entities satisfying its exogenous objectives
	Transformation	Evolution of the MUE's structure and its endogenous objectives

2.6.4 Discussion

The systemic modeling approach presented is an appropriate model for the representation of the MUE. It is generic, it can be expanded if necessary and allows examining the MUE at different levels of abstraction. In future work, this conceptual framework will enable the development of a SPMS for the MUE. The notion of SPMS emerged from the evolution of the performance measurement system concept (Neely et al., 1995; Searcy, 2012), which is "a multi-criteria instrument, made of a set of performance expressions [...] to be consistently organized with respect to the objectives of [a] company" (Clivillé et al., 2007). The existing literature on SPMSs is focused on corporate sustainability measurement (Vanleer et al., 2016), with its most famous example being the sustainable balanced scorecard (Hubbard, 2009). As a MUE is different system, with different objectives and stakeholders, it requires a bespoke SPMSs.

Existing performance measurement methods have been designed for the EIP. To the best of our knowledge, these methods focus primarily on specific aspects of the EIP's performance such as eco-efficiency (Fan et al., 2017), circular economy (Zhao et al., 2017), industrial symbiosis (Felicio et al., 2016; Valenzuela-Venegas et al., 2016), life cycle assessment (Boix et al., 2017) and environmental impact (Pilouk and Koottatep, 2017). In a similar manner, sustainability assessment of an urban planning project does not fully account for the wide scope of the MUE's performance because it does not focus on companies' collaboration and symbiosis (He et al., 2011).

Since the MUE is an integrated concept, its SPMS should address performance within a wide viewpoint. From this standpoint, systemic modeling provides a structure to design the MUE's SPMS. Indeed, systemic modeling gives a robust yet flexible framework to define the objectives and evaluate performance. Besides defining performance indicators for the whole system, indicators can be expressed for each type of entity - *building*, *company*, and the *Public_Space* - and for each type of interaction - *building* to *company*, *company* to *company*, *company* to *Public_Space*. This will make it possible to measure the MUE's performance within a global approach.

2.7 Concluding remarks

In this paper, an analysis of the EIP's founding concepts led to the proposal of a framework positioning the EIP, helping the navigation in the complicated field of IE. From this analysis and observations, it was argued that the EIP is not always the most adequate model when improving the sustainability of business parks. The coupling of production processes, the heart of IS, is not the only target for business parks, including office parks and commercial parks. Based on the belief that sustainable planning of the area is an important asset to provide high-quality, high-performance and green mixed industrial parks, a brief introduction of the field was unfolded by characterizing the eco-city and the ecodistrict. A new paradigm, called the MUE, was proposed, blending the philosophy of the EIP with sustainable urban planning. The MUE is an integrated archetype of a sustainable business park. The MUE was defined and modeled taking into account its systemic nature. This systemic modeling approach offers a conceptual framework of the MUE.

The perspective of this systemic modeling approach is to create a baseline for the definition and evaluation of the MUE's performance, as a tool helping local governments with the sustainable development and management of their business parks. Capitalizing on successful experiences, performance indicators and their aggregation support the decision-making process by monitoring an MUE's development. Performance evaluation will also be a useful means to promote the benefits of collaboration initiatives among an MUE's members and stimulate sustainable planning of the park. Future work will define a system of coherent indicators to measure an MUE's performance. Once potential indicators are defined, the MUE's decision makers will be able to set targets in accordance with their specific strategy and to monitor their achievement. Overall, this future SPMS is intended to support a quick, easy and flexible evaluation. Moreover, this SPMS is expected to be complimentary to existing specific sustainability assessment methods designed for the EIP and urban planning project.

3

Développement d'un outil d'aide à la décision pour l'établissement du plan d'action d'un écoparc

Ce chapitre présente l'article intitulé "Using MACBETH for the Performance Expression of a Mixed-Use Ecopark", accepté par le Journal of Multi-Criteria Decision Analysis le 09 Juillet 2020. Un résumé de l'article en français introduit le chapitre.

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3.1 Résumé

Le déploiement, le pilotage et l'amélioration continue d'un parc industriel engagé dans une démarche de développement durable sont des tâches complexes et transdisciplinaires qui impliquent différents aspects. De manière générale, le pilotage d'un parc industriel durable comprend un éventail d'actions pour l'atteinte d'une durabilité, décomposée en objectifs fondamentaux. L'atteinte de ces objectifs requiert la définition, la redéfinition récursive et le pilotage continu d'un plan d'actions. Le gestionnaire du parc industriel a besoin d'information sur l'impact de ce plan d'actions, avant et pendant son exécution. Les expressions de performance (parfois appelées "utilités"), évoluent pendant l'exécution du plan d'actions et s'appuient sur de multiples critères puisque le parc industriel est un système complexe aux nombreux objectifs. Dans cet article, une utilisation innovante d'une méthode d'aide à la décision multicritère est présentée. La méthode MACBETH est utilisée pour exprimer l'évolution de la performance d'un parc industriel durable, dans un but soit de prédiction, soit de vérification. Un cas d'étude est présenté avec l'expression de la performance de l'éco-parc industriel Daniel Gaudreau.

3.2 Introduction

The industrial park is one of the most popular forms of planned economic development in developed countries. It is a "*large tract of land, subdivided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms*" ([United Nations Industrial Development Organization, 1997](#)). An industrial park is traditionally controlled by a designated manager who is in charge of making all the decisions concerning the park. Hence, this decision maker is a legal entity that can be a combination of several stakeholders such as public or private investors, local authorities, planners, developers, etc. ([Tessitore et al., 2015](#)). In the past few decades, the growing importance of the concept of sustainability - defined as the conjunction of its three pillars, namely, environmental, social, and economic ([World Commission On Environment and Development, 1987](#)) - and its operationalization through the implementation of Agenda 21 ([United Nations, 1992](#)) at local levels have led local authorities and planners to rethink the design and development of industrial parks. Indeed, industrial parks have to tackle economic, environmental, and social challenges deriving from waste handling, resource consumption, infrastructure aging, land rarefaction, labor shortage, road congestion, and lack of parking places, among others ([Lambert and Boons, 2002](#)).

With the goal of spurring the development of sustainable industrial parks, an archetype called mixed-use ecopark (MUE) was introduced ([Le Tellier et al., 2019](#)). This emerging archetype attempts to provide an answer to the shortcomings faced by mixed industrial parks in Europe and North America ([Lambert and Boons, 2002](#)). The MUE can be considered a system and, as such, is controlled by its observer. In a nutshell, the control of MUEs is defined as the range of actions that are undertaken to achieve the MUE sustainability. The sustainability of an MUE is a complex finality that has to be deployed and it involves a variety of different criteria. According to its classic framework, sustainability is the intersection of the economic, environmental, and social dimensions ([Passet, 1996](#)). Thus, the sustainability of MUEs can be deployed into several objectives related to its three dimensions. Moreover, it can also be deployed into objectives with different milestones, which are related to different stages of the MUE life cycle. The life cycle of the MUE consists of three main stages : (a) design and construction of the park, (b) operation of the park, and (c) transformation of the park through its retrofit or expansion. Moreover, the MUE life cycle involves a variety of stakeholders with various expectations. They can be the MUE owner, who is

traditionally the local authority represented by elected local officials, the resident companies, their employees, the local community, the natural environment, etc. For these reasons, the control of the MUE is a complex cross-sector endeavor that requires a structured framework and, notably, tools.

Accounting for its sequential nature, the Deming wheel and its approach of continuous performance improvement (*Plan–Do–Check–Act*) is a structured framework for MUE control (Deming, 1982). Thus, MUE control requires the definition of an action plan, which is a series of actions that must be taken in a given sequence, based on the deployment of its objectives (*Plan*) and its redefinition (*Act*) relying on the MUE performance expression (*Check*) after its execution (*Do*). Naturally, such a performance is evolving during the execution of its action plan and relies on a multitude of criteria due to the complexity of MUEs.

Subscribing to this vision, the method adopted for performance expressions is multi-criteria decision analysis (MCDA) because of its potential for dealing with singular, complex, and multiple variable contexts (Longaray et al., 2019). This article contribution lies in the innovative use of MCDA to express the MUE performance evolution during the execution of an action plan. Indeed, pieces of information are required for the control of an MUE, either at the *Plan* phase (prediction) or at the *Check* phase (verification). The goal is to answer the questions : Is the action plan satisfactory? What could be the impact of additional actions? Therefore, following the decision problem typology proposed by Roy (1996), is a description problem.

The MCDA method chosen is the Measuring Attractiveness by a Categorical-Based Evaluation TecHnique (MACBETH) method (Bana E Costa et al., 1999), since it has already been used to deal with industrial performance expression (Clivillé et al., 2007). MACBETH has been used for different types of decision problems : for selection problems (Karande and Chakraborty, 2014, 2013; Tosun, 2017), sorting problems (Ishizaka and Gordon, 2017) or ranking problems (Cox et al., 2013). Here it is used for a description problem (Longaray et al., 2015). MACBETH is used to express the performance increases at each step of the action plan execution. This is, to our knowledge, the first time that MACBETH is used unconventionally to express the performance of complimentary actions, instead of expressing the performance of alternatives.

An illustration of this innovative use of MACBETH is provided for the case of the Canadian MUE of Victoriaville, Quebec. This MUE was planned and built in a sustainable way and only welcomes companies that adopt sustainable business practices by participating in a local label certification process. The Victoriaville MUE is still relatively young and small, it was built in 2013 and was hosting only two companies at the time of writing. In 2016, the Victoriaville MUE decision maker published an action plan for the subsequent four years. The model presented in this article was applied to predict the performance of this MUE during the execution of its action plan.

This article is structured as follows. First, in Section 3.3 the MUE and its control are presented. In Section 3.4, the MCDA elements that will be useful for the expression of the MUE performance are described and the method chosen to answer this decision problem, MACBETH, is presented and adapted to the specificity of the problem. In Section 3.5, a case study of the method is presented for the prediction of the evolution of Victoriaville MUE performance expression. Section 3.6 concludes this article.

3.3 The MUE and its control

In this section, the MUE concept is introduced and its systemic nature is used as the starting point for the presentation of its control. Secondly, the multi-criteria nature of the control of MUEs and

the need for an interactive decision-making tool is discussed.

3.3.1 Emergence of the MUE

Industrial ecology is a systemic approach toward redesigning a more sustainable industrial system. Introduced in 1989 by Frosch and Gallopoulos, it uses an analogy with natural ecosystems, where waste from one species becomes food for another, to create closed-loop industrial ecosystems (Frosch and Gallopoulos, 1989; Korhonen, 2001; Lowe and Evans, 1995). Based on industrial ecology, the concept of industrial symbiosis emerged simultaneously. The most famous definition of industrial symbiosis was proposed by Chertow (2000) : “*The part of industrial ecology known as industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.*” The concept of eco-industrial parks (EIPs) emerged from the idea of applying industrial symbiosis principles to the design and management of an industrial park, commonly defined as “a large tract of land developed for the use of companies with specific infrastructures and provision of services for those companies” (Peddle, 1993). An EIP is a community of businesses that collaborate with each other and with the local community to efficiently share resources such as materials, water, energy, and infrastructure leading to economic gains, gains in environmental quality, and equitable enhancement of human resources for the businesses and the local community (U.S President’s Council on Sustainable Development, 1997).

Lambert and Boons (2002) have delivered a noteworthy explanation of the EIP and its boundaries. They consider that within the scope of EIPs, a distinction must be made between “industrial complexes” and “mixed industrial parks.” They argue that the focus on materials and energy exchange is only relevant to industrial complexes that concentrate “heavy” industries that are intrinsically mutually interrelated. On the other hand, problems related to mixed industrial parks, which consist of a variety of small- and medium-sized enterprises, are poorly investigated, although they have a major environmental and spatial impact. Lambert and Boons argue that research and initiatives of EIPs have not dealt with the challenges faced by mixed industrial parks, which are far more diverse and not confined to the exchange of materials and energy (Lambert and Boons, 2002).

The MUE model attempts to provide an answer to the economic, environmental, and social shortcomings faced by mixed industrial parks in Europe and North America. This integrated archetype of a sustainable mixed industrial park is based on the belief that sustainable planning is an important feature of a high-quality, high-performance, and green mixed industrial park. An MUE is defined as “*a community of businesses (of all sizes, from the manufacturing or service sectors) located on an industrial park planned and built in a sustainable approach, that cooperate with each other and with the local community to efficiently share information, materials, energy, infrastructure or services (for the companies or the employees), leading to economic environmental and social gains for the businesses and the local community*” (Le Tellier et al., 2019). This definition is based on the EIP consensual definition but adds two important features to this concept.

- An MUE is designed and built following the principles of sustainable urban planning, which includes the development of buildings, the use of land, and the design of urban infrastructures such as transportation, communication, and distribution networks.
- An MUE consists of service-based companies and the exchange of resources by the MUE companies can be services, including services for the companies (such as subcontracting, consulting services, or joint R&D agreement) or the employees (such as restaurants, day-care, or car sharing).

Essentially, the MUE is a complex concept that emerges at the intersection of industrial symbiosis, sustainability, urban planning and design, inter-company collaboration, and management (Le

Tellier et al., 2019).

3.3.2 The MUE as a system

By definition, the MUE is an integrated whole that is more than the sum of its parts, and it comprises companies that can be considered as nested systems. The MUE is self-organizing, resilient, and with a complex, nonlinear behavior. For these reasons, the MUE can be considered a system (Chapman et al., 2016) and can be modeled as one. The systemic modeling of an entity consists in the characterization of its finality, its environment and observer, its structure, its objectives, and its two behaviors : normal operation and transformation (Le Moigne, 1994). The systemic modeling of the MUE is presented in Table 3.1 (for additional details on MUE systemic modeling, see (Le Tellier et al., 2019)).

We consider that the MUE follows a life cycle similar to the one followed by industrial parks and EIPs (United Nations Environment Programme, 2001; Gibbs and Deutz, 2007; Potts Carr, 1998; Roberts, 2004). First, the MUE is designed and built. During this phase, the site of the MUE is chosen and developed and its specific strategy is outlined. Then, operation of the MUE begins. This phase consists in the normal, day-to-day operation of the MUE. During this phase the number of resident companies in the MUE varies between at least two resident companies and the maximum occupancy rate of the MUE. If needed, the MUE can go through retrofit or expansion phases. In

Tableau 3.1 – Systemic modeling of the MUE, adapted from (Le Tellier et al., 2019)

Systemic Characteristic	Modeling of the MUE
Finality	Sustainability
Environment	Suppliers and Clients of the resident companies
	Natural Environment
	Local Community
Observer	Owner (Local Authorities represented by elected officials)
	Decision maker (Manager designated by the owner of the MUE)
Structure	Companies
	Buildings
	Infrastructures
	<i>Inter-companies collaborations</i>
	<i>Eco-industrial synergies</i>
Exogenous objectives	Reducing the environmental impact of the MUE
	Generating economic benefits from the MUE operation
	Generating social benefits from the MUE operation
Endogenous objectives	See Figure 3.1
Behavior : Normal Operation	Sustainable urban planning and design
	Creation of inter-companies collaboration
	Creation of eco-industrial synergies
Behavior : Transformation	Transformation of the structure and/or new endogenous objectives statement

the retrofit phase, the existing infrastructures or buildings of the MUE are retrofitted in order to achieve the MUE objectives. In the expansion phase, a new site is developed in order to increase the occupancy rate of the MUE. Since this article is concerned with the control of MUEs, we will only examine the case of existing MUEs, or MUEs that have achieved their first phase. Naturally, MUEs that are not fully designed or built are not concerned with continuous improvement yet. It is also noteworthy that this article will additionally examine the case of existing industrial parks aspiring to become MUEs. Indeed, once the decision maker expresses an interest in transforming their industrial park into an MUE, this industrial park can be considered an MUE, since this concept is an archetype and not a strict certification.

The finality of a system reflects the observer's idea of the mission of the system at its highest level of abstraction (Mélèse, 1991). As the finality is not directly operational, it needs to be deployed. Traditionally, the finality is deployed into elementary objectives along organizational levels : strategic, tactical, or operational (Grabot, 1998; Berrah and Foulloy, 2013). An objective can be defined through a value, linked to a variable or criteria and has to be reached at a set date or at the end of a milestone (Berrah and Foulloy, 2013). Classically, one or several systemic deployments of the overall strategic objectives are carried out in order to obtain operational solutions in the form of fundamental objectives (Berrah and Foulloy, 2013). The deployments of the MUE finality are presented in Figure 3.1.

This deployment is based on the definition of an MUE, on its systemic modeling, and on the literature on urban sustainability and sustainability assessment of similar systems such as EIPs. The first level of deployment corresponds to the exogenous objectives, relating to the MUE output and its influence on its environment. This level of deployment relies on the definition of sustainability. The second level of deployment corresponds to the endogenous objectives, relating to the MUE structure that is required to achieve the exogenous objectives. This level of deployment relies on the definition of the MUE both as an industrial park designed and built following sustainable urban planning principles and as a community of companies collaborating with each other.

The last level of deployment corresponds to the MUE sub-objectives. This last level of deployment is described through the criteria listed in Table 3.2. The level of deployment relies on sustainability assessment of similar systems such as EIPs. In particular, Verma and Raghubanshi (2018) attempted to define urban sustainability in all of its aspects and identified issues faced in the develop-

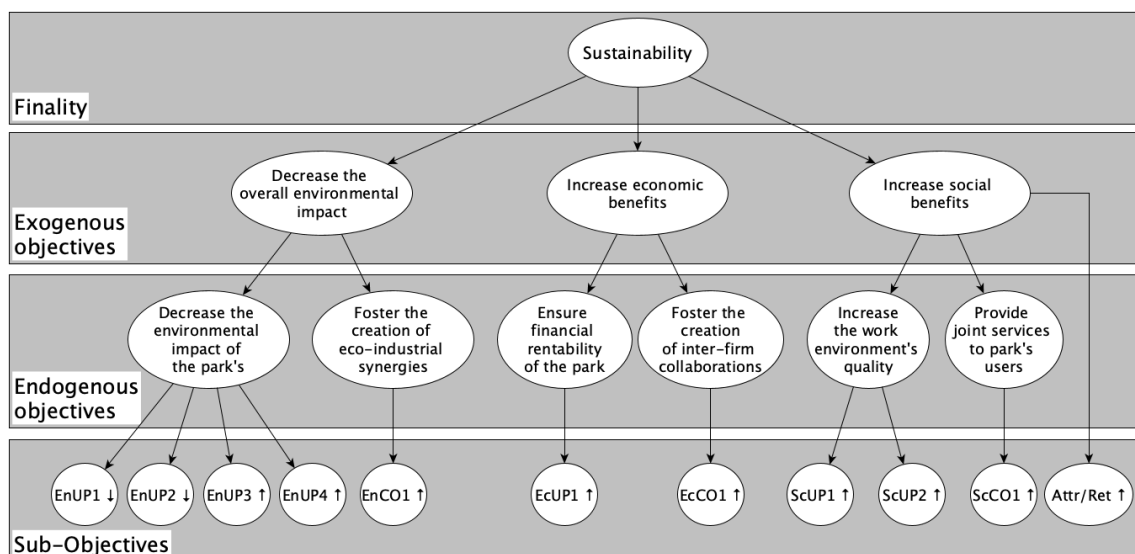


Figure 3.1 – Deployment of MUE finality (↑ means that the value of the criteria should be maximized and ↓ means that the value of the criteria should be minimized)

ment and implementation of sustainability indicators in an urban context. Zhao et al. (2017) built an index system to evaluate the performance of an EIP using economic criteria, social criteria, environmental criteria, ecological industry construction criteria, and management-level criteria. Valenzuela-Venegas et al. (2016) performed an exhaustive search and classification of indicators used to assess EIP sustainability.

Tableau 3.2 – Generic criteria (En, Environmental criteria; Ec, Economic criteria; Sc Social Criteria; UP, Urban Planning criteria; CO, Collaboration criteria.)

Criteria Code	Criteria Description
EnUP1	The buildings' environmental impact
EnUP2	The infrastructures' environmental impact
EnUP3	The use of sustainable transportation mode
EnUP4	The preservation of the surrounding natural environment
EnCO1	The number of eco-industrial synergies (exchange or sharing of materials, by-products, energy or water)
EcUP1	The land sales and buildings or offices rentals
EcCO1	The number of inter-companies' collaborations
ScUP1	The park architectural quality and comfort
ScUP2	The accessibility of the park
ScCO1	The provision of joint services to the employees
Attr/Ret	The creation, attraction or retention of jobs

3.3.3 Control of the MUE

Generally speaking, the control of a system is the range of actions that are undertaken to achieve the system finality, which is, in the case of an MUE, sustainability. The control of the MUE can therefore be specified by the three exogenous objectives of the MUE that can be deployed into endogenous objectives, which in turn can be deployed into sub-objectives. In parallel with the objectives statement, the decision maker defines a series of actions that must be taken in order to achieve these objectives and sub-objectives, namely, an action plan. This action plan is coupled with a schedule setting milestones for each action. Note that actions can be causally dependent when one or several actions need to be achieved before carrying out one or several other actions or when two actions must be carried out simultaneously. In practice, the definition of an action plan relies mostly on the personal expertise of the decision maker. Therefore, the decision maker would benefit from a more structured model for the control of MUEs.

Following the Deming wheel principles, the control of MUEs can be defined as an iterative process of comparing results with fixed objectives, leading to corrective actions if the fixed objectives were not achieved or improvements of the fixed objectives if they were achieved. The control of MUE therefore requires the repetitive execution of the following phases :

1. (*Plan*) The expression of the MUE needs, formalized by the statement of objectives and the associated action plan. At this phase, prediction of the MUE performance expression can support the construction of the action plan.
2. (*Do*) : The execution of the action plan.
3. (*Check*) : Verification of the obtained results through a comparison between the predicted performance and the achieved performance.

4. (*Act*) : The decision on the appropriate way to react (namely, continuing as scheduled, defining new objectives, defining new actions, etc.) given the execution of the first three phases and the reaction itself.

As mentioned in Section 3.2, this study aims to express the performance of an MUE during the execution of an action plan, namely in the *Plan* and *Check* phases. As described in its systemic modeling and finality deployment, the MUE control is concerned with multiple objectives related to the three dimensions of sustainability. Therefore, the MUE performance is a multi-criteria performance. Thus our proposition is to use MCDA for the performance expression of an MUE.

3.4 MCDA for the MUE performance expression model

This section introduces MCDA as the approach chosen to create such a model for the MUE performance expression. In the second part, the MUE performance expression is formulated as a multi-criteria evaluation problem using MCDA formalism.

3.4.1 Choosing MCDA for the MUE performance expression

We believe that the expression of the performance of an MUE action plan can be formulated as a multi-criteria evaluation problem for the following reasons :

- *Multiplicity of points of view*. As we can see from the systemic modeling in Table 3.1, the finality of the MUE can be deployed into a relatively large number of sub-objectives. Those sub-objectives are all different points of view that can be used to partially evaluate the performance of the MUE. Let us recall that according to [Bana e Costa and Vincke \(1990\)](#), "a point of view is any aspect within a specific decision context that at least one actor considered relevant to evaluation".
- *Qualitative information aggregation*. The MUE performance expression relies on the aggregation of the decision maker's expertise and knowledge and, as shown in Table 3.2, the criteria on which it relies are mostly qualitative.
- *Trade-offs*. The chosen approach should be able to address trade-offs between the different objectives.

MCDA has been regarded as a suitable set of methods to perform sustainability evaluations due to its flexibility and the possibility of facilitating the dialogue between stakeholders, analysts, and scientists ([Cinelli et al., 2014](#)). It has been recognized as a valuable method to elucidate trade-offs and mitigate negative impacts on sustainability assessments ([Morrison-Saunders and Pope, 2013](#)). Moreover, MCDA has already been used to assess the sustainability of an EIP ([Zhao et al., 2017](#)). Thus, it is expected that MCDA will help to deal with the complexity of the MUE performance expression.

Another approach for the MUE action plan performance expression could be the use of performance indicators and performance measurement systems. The performance indicator and the performance measurement system are the most traditional tools used to link objectives, actions, and measures in industrial systems ([Fortuin, 1988](#); [Neely et al., 1995](#)). However, considering the complexity of the MUE and the requirement of its decision maker for a decision-making tool for its control, we decided to use MCDA. Moreover, gathering the data required to supply a performance measurement system calls for the deployment and operation of measurement tools. Thus, harnessing the decision maker's personal expertise with MCDA offers a model that is quicker and easier to understand and use.

3.4.2 Formulation of the MUE performance expression problem

In MCDA formalism, the formulation of a multi-criteria evaluation problem naturally requires the comparison of multiple *alternatives* and the identification of multiple *criteria* to compare them with. This formulation of the problem will serve as a basis for the performance expression model of the MUE.

- *Criteria*. The considered *criteria* for the MUE action plan performance expression are chosen by the decision maker based on the generic criteria described in the MUE systemic modeling in Table 3.2. Even if their finality is the same, each MUE is different and follows a different strategy, therefore the generic criteria can be modified to suit the specific needs of one MUE. For example, criteria can be removed, changed, or added. Essentially, the generic criteria hierarchy serves as a guide, stimulating the MUE decision maker to define bespoke criteria for the three dimensions of sustainability, the two main points of focus of the MUE concept, urban planning and inter-company collaboration, and possibly the stakeholders' expertise.
- *Alternatives*. This specific MCDA problem goal is not to help the decision maker choose the "best" actions in a set of actions but to express the MUE performance increase throughout the progressive execution of its action plan. In other words, MCDA is used as an evaluation method and not as a comparison method. Rather than expressing the utility of *alternatives*, MCDA is used to express the improvement between two of the action plan milestones. Therefore, for the sake of clarity, in the upcoming discussion, the term *sets of actions* will be used instead of *alternatives* and *performance expression* instead of *utility*. Therefore an additional preliminary step is required to determine the evaluated sets of actions. Completed actions are aggregated on the successive milestones of the action plan schedule resulting in sets of actions that are partially temporally ordered. The novelty of our proposition is in this preliminary step which provides temporally steps of actions. For example, let us imagine an action plan with three actions ($A1$, $A2$, and $A3$) coupled with a schedule with two milestones ($T1$ and $T2$). For this action plan, there are two sets of actions since there are two milestones. According to the action plan schedule, $A1$ and $A2$ are completed at $T1$ and $A3$ is completed at $T2$. Therefore, the two sets of completed actions would be $(A1 + A2)$ and $(A1 + A2) + (A3)$.

One can see that using MCDA to progressively express the MUE performance throughout the execution of the action plan allows the decision maker to express smaller performance increments for one criterion instead of comparing the initial and final state of the action plan execution for all the criteria at once. Moreover, comparing sets of completed actions encourages the MUE decision maker to consider and capitalize on the potential synergies between actions.

3.4.3 The MACBETH method

The MCDA method chosen here is MACBETH since it is able to deal with a criteria hierarchy and with both quantitative and qualitative information through pairwise comparison. MACBETH proposes an robust procedure to transform the qualitative decision maker's preferences into coherent (*i.e.* by satisfying the commensurability and the significant conditions) quantified elementary and aggregated performances (Clivillé et al., 2007; Rodrigues, 2014).

The MACBETH method was first proposed in the 1990s by Bana e Costa and Vansnick (1997). The underlying principle of MACBETH is to translate the human expertise of the decision maker into interval scales. It is a multi-attribute value theory method that is based on pairwise comparison of alternatives (sets of action in our case) by a decision maker (Bana e Costa et al., 2005). The aggregation operator used is the weighted arithmetic mean. MACBETH is carried out by an analyst who guides the decision maker through the different comparisons they need to make and

to collect their semantic judgments (*null, very weak, weak, moderate, strong, very strong, extreme*) (Karande and Chakraborty, 2013). To ensure that the inter-criteria commensurability issue is solved, MACBETH requires that the decision maker set two base levels : one that is just satisfying, associated with the performance value of 0, also called "Neutral", and one that is fully satisfying, associated with the performance value of 1, also called "Good". The strength of MACBETH lies in the structure of its algorithm which is based on four linear programs (Bana e Costa et al., 2005; Bana e Costa, 1994; Bana e Costa et al., 2003). The first linear program detects inconsistencies in the decision maker's judgments. The second linear program suggests a numerical scale that represents the decision maker preferences. The two remaining linear program reveal the sources of inconsistencies in the decision maker judgments.

The MACBETH method observes the following procedure (Clivillé et al., 2007; Bana e Costa et al., 2002) :

1. *Definition of the decision problem* : This includes the identification of a hierarchy of criteria and a set of alternatives, including the description of the considered alternatives according to the set of criteria.
2. *Computation of the criteria weights* : The determination of the WAM weights is indirectly done through the pairwise comparison of some particular situations. The considered situations are the, possibly fictive, characteristic situations which are associated to elementary expression vectors such as $(0, \dots, 0, 1, 0, \dots, 0)$. Hence, the aggregated performance expression becomes : $p_i^{Ag} = w_i$ where p_i^{Ag} is the aggregated performance expression from the vector where $p_i = 1$ and all the other elementary expressions $p_g = 0$ with $g=1$ to n and $g \neq i$. To determine the n weights w_i 's (related to the n criteria involved), the manager have to make at least n pairwise comparison between the characteristic situations. When all those preferences and their intensity are collected, MACBETH computes the weights of the criteria with the same linear programming as before.
3. *Elementary performance expression* : The elementary performance expression corresponds to the computation of interval scales, also called value functions, of the criteria. This step is performed by directly comparing the sets of actions between them in terms of difference of attractiveness in each criterion. In this study, this step is performed without using descriptors of impacts (Bana e Costa et al., 2003). This step starts with the collection of the decision maker's preferences and the preference intensity between the sets of actions and the two base levels, considering a given criterion. When all preferences have been collected for the considered criterion, MACBETH builds an interval scale with linear programming. This step is repeated for the whole set of criteria. The resulting interval scales correspond to the elementary performance expressions of each sets of actions considering each criterion.
4. *Global performance expression* : Finally, MACBETH expresses the global performance of the sets of actions based on an aggregated value of the relative weighted attractiveness of the sets actions under the decision criteria. In other words, the global performance expression is supported by a single synthesis criterion mathematical equation. The results can then be checked and corrected through sensitivity analysis and robustness analysis.

3.4.4 Using MACBETH for the MUE action plan performance expression

The MACBETH procedure for the MUE performance expression is shown in Figure 3.2. Similar to the classic procedure of MACBETH, this procedure starts with the definition of the problem. In *Step 1.a*, for the identification of the criteria hierarchy, the decision maker is provided with the generic criteria hierarchy and asked to personalize it to the specificity of their MUE. In *Step 1.b*, instead of alternatives, this extension of MACBETH needs to be supplied with sets of actions defined thanks to the action plan. As explained in Section 3.4.2, to determine the sets of actions,

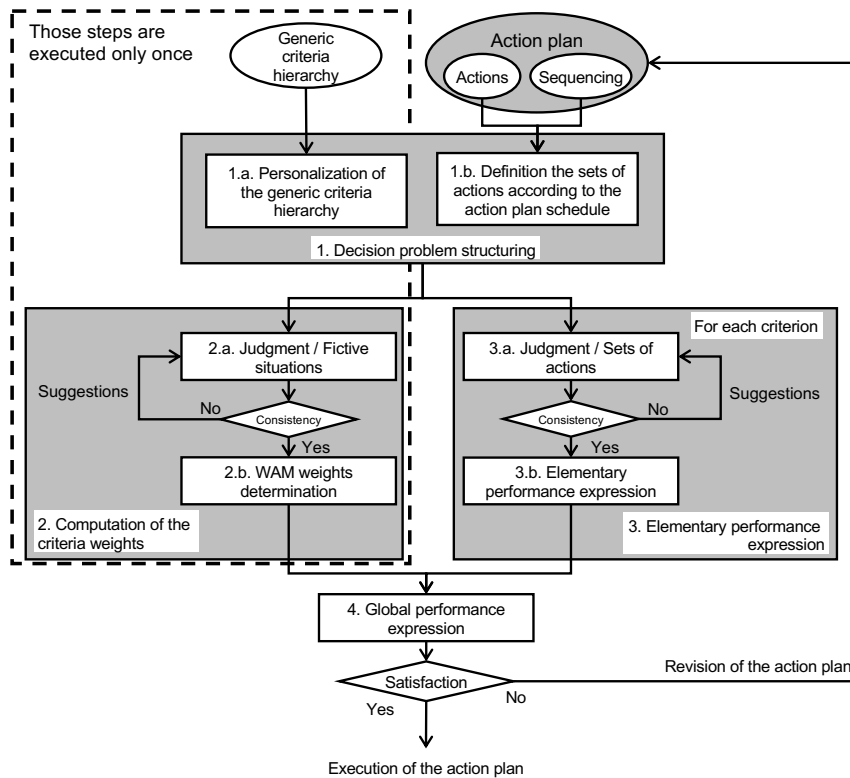


Figure 3.2 – The MACBETH procedure for the MUE action plan performance expression, adapted from (Clivillé et al., 2007)

completed actions are aggregated on the successive milestones of the action plan schedule, according to the actions dependencies and milestones. The computation of the criteria weights (Step 2), the computation of the interval scales (Step 3), and the expression of the global performance are executed in an identical manner to the classic procedure as described in 3.4.3. Step 2 and Step 3 are independent and therefore can be executed in any order. Step 2 is repeated only once, resulting in the WAM weights of each criterion. Step 3 is repeated considering each criteria, resulting in elementary performance expressions for each set of actions with respect to each criterion. Finally, in Step 4 the elementary performance expressions are aggregated with the WAM, resulting in the global performance expression of the MUE action plan. If the decision-maker isn't satisfied with the elementary and the global performance expressions, they are encouraged to revise their action plan. In that case, only Step 1.b, Step 3 (for each criterion) and Step 4 need to be performed again since Step 1.a and Step 2 are performed only once. The action plan is revised until the decision maker is satisfied with the performance expressions, which allows to initiate its execution.

3.5 Performance expression of Victoriaville MUE

In this section, MACBETH is applied to the case of a Canadian MUE located in Victoriaville. The model is used to predict the performance evolution of this MUE during the execution of their 2017 action plan.

3.5.1 Presentation of the case study

Victoriaville is a town in central Quebec, Canada, on the Nicolet River. It is a medium-sized town with 46,000 inhabitants and an area of 86 km². In 2008, after having identified wetlands in one of their industrial parks, the town of Victoriaville decided to transform this constraint into the opportunity to develop an industrial park that integrates and promotes this unique ecosystem. In 2013, Victoriaville inaugurated the industrial park, renamed Daniel Gaudreau Industrial Ecopark (DGIE) in 2018. DGIE was planned and built in a sustainable way and only welcomes companies that adopt sustainable business practices by participating in a local certification label called "Démarche d²" ("sustainable development approach" in English). DGIE is a small industrial park with 22 lots to sell, which represents an area of 111,400 m² and 93,000 m² of wetlands.

DGIE decision maker is the Community of Economic Development Corporation of Victoriaville and its region (CDEVR). The CDEVR is represented by the industrial commissioner and the advisor on sustainable development, who make decisions by consensus. In 2016, the CDEVR published an action plan for DGIE. The action plan is composed of eight global actions, subdivided into a total of 31 elementary actions, each associated with a milestone. In order to establish a reasonable number of alternatives, the sets of actions are built with the global actions. A summary of the action plan, detailing the global actions only for confidentiality reasons, is presented in Appendix 3.6 in Table 3.5.

3.5.2 Action plan performance expression

The order of the subsections follows the procedure shown in Figure 3.2. MACBETH is supported by M-MACBETH software (<http://m-macbeth.com>).

Step 1.a : Customization of the generic criteria hierarchy

The generic criteria from Table 3.2 were proposed to the decision maker. They felt that these criteria covered the objectives of DGIE well. Therefore, they decided to adopt the generic criteria as-is without adding or removing any. The only minor modification that they made was to limit the criteria *Attr/Ret* to the attraction and retention of employees and not the creation of jobs since this aspect of the criteria is irrelevant in the current regional context of labor shortage (Dupuis et al., 2019). To the best of their knowledge, the decision maker felt that, for all the criteria, the performance expression variations of a criterion did not have any impact on the performance expression of the remaining criteria, *i.e.* that the criteria were preferentially independent from each other (Keeney and Raiffa, 1993).

Step 1.b : Definition of the sets of actions according to the action plan schedule

DGIE action plan schedule is shown in the Gantt chart in Figure 3.3. Following the same milestones as the ones established by the decision maker, the sets of actions are determined for the beginning of May 2017, September 2017, January 2018, January 2019, January 2020, and beyond. The resulting sets of actions are described in Table 3.3.

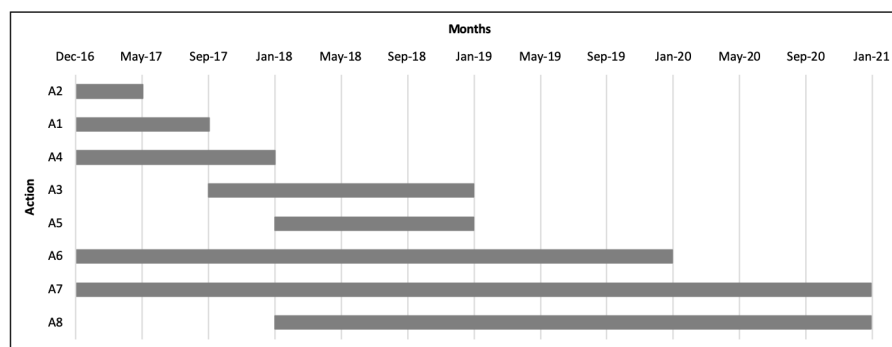


Figure 3.3 – Gantt chart for DGIE action plan (See Appendix 3.6 for a description of the actions)

Tableau 3.3 – Sets of actions used for the expression of DGIE performances

Date	Set of completed actions	Abbreviation
May 2017	(A2)	A2
September 2017	(A2)+(A1)	A2-1
January 2018	(A2)+(A1)+(A4)	A2-1-4
January 2019	(A2)+(A1)+(A4)+(A3+A5)	A2-1-4-35
January 2020	(A2)+(A1)+(A4)+(A3+A5)+(A6)	A2-1-4-35-6
Beyond January 2020	(A2)+(A1)+(A4)+(A3+A5)+(A6)+(A7+A8)	A2-1-4-35-6-78

Step 2 : Computation of the criteria weights

To determine the weights of the criteria, each particular situations corresponding to the full satisfaction of only one criterion are compared two by two. For example, the highlighted cell in Figure 3.4 should read : "A situation where only the *EnUP1* criteria (*Improving the environmental impact of the buildings*) is fully satisfied is preferred to a situation where only the *ScUP1* criteria (*Improving the architectural quality and comfort of the park*) is fully satisfied".

As this was their first use of the model, the decision maker felt more comfortable expressing preferences or nuanced intensities of preference between the fictive situations, but it is not ruled out that with further use of the model they would express more distinct intensities of preference. The collection of these preferences resulted in the weights given in Table 3.4.

As we can see, the most important criterion for DGIE decision maker is the preservation of the surrounding natural environment. This preference is consistent with the decision maker's first motivation behind the creation of DGIE : economic development that respects the wetlands discovered in the industrial park. The second most important criterion for DGIE decision maker is the land sale. This is consistent with the fact that DGIE is still a relatively young MUE with several vacant lots. Finally, it is interesting to note that DGIE decision maker attributes more importance to the number of inter-company collaborations than to eco-industrial synergies. This is consistent with the fact that an MUE is more of a mixed industrial park than an industrial complex (Lambert and Boons, 2002).

Weighting (Global)

	[EnUP4]	[EcUP1]	[EnUP1]	[EcCO1]	[Attr/Ret]	[ScCO1]	[EnCO1]	[ScUP1]	[EnUP2]	[ScUP2]	[EnUP3]	Initial state
[EnUP4]	no	positive	positive	positive	positive	positive	positive	positive	positive	positive	positive	positive
[EcUP1]		no	positive	positive	positive	positive	positive	positive	positive	positive	positive	positive
[EnUP1]			no	positive	positive	positive	positive	positive	positive	positive	positive	positive
[EcCO1]				no	no	positive	positive	positive	positive	positive	positive	positive
[Attr/Ret]				no	no	positive	positive	positive	positive	positive	positive	positive
[ScCO1]						no	positive	positive	positive	positive	positive	positive
[EnCO1]							no	positive	positive	positive	positive	positive
[ScUP1]								no	positive	positive	positive	positive
[EnUP2]									no	no	no	positive
[ScUP2]									no	no	no	positive
[EnUP3]									no	no	no	positive
Initial state												no

Consistent judgements

Figure 3.4 – Pairwise comparison matrix of the criteria for DGIE action plan performance expression (Extracted from M-MACBETH)

Tableau 3.4 – Criteria weights

Criteria code	Criteria	Weight
EnUP4	The preservation of the surrounding natural environment	18.60
EcUP1	The land, buildings and/or offices sales and/or rentals	16.27
EnUP1	The buildings' environmental impact	13.95
EcCO1	The number of inter-companies' collaborations	11.63
Attr/Ret	The creation, attraction or retention of jobs	11.63
ScCO1	The provision of joint services to the employees	9.30
EnCO1	The number of eco-industrial synergies	6.98
ScUP1	The park architectural quality and comfort	4.65
EnUP2	The infrastructures' environmental impact	2.33
ScUP2	The accessibility of the park	2.33
EnUP3	The increase of sustainable transportation mode	2.33

Step 3 : Elementary performance expressions

For a given criterion, the elementary performance expressions are given by the interval scale resulting from the pairwise comparisons of sets of actions. This process of pairwise comparisons is repeated for all the criteria. As detailed in Section 3.4.3, the sets of actions are compared with each other and with two base levels. The "Neutral" base level is called the "Initial State" and the "Good" base level is called "Objective".

An example of a pairwise comparison matrix is given in Figure 3.5 for criterion Attr/Ret (attraction and retention of jobs). As we can see, considering the criterion "Attraction and retention of jobs", DGIE decision maker considers that actions A2 ("Evaluate the possibility to build new building to offer turnkey solutions to prospective companies") and A1 ("Demystify DGIE to influential socio-economic stakeholder and prospective companies") will not have any impact (see preference intensity "1" in Figure 3.5 that means "no difference"). They consider that actions A4 ("Promote DGIE") will have a very weak to weak positive impact on this criterion (see preference intensity "1-2" that means "very weak difference to weak difference") but that the addition of A3 + A5 ("Create a financial incentive to attract companies"+"Enable mixed-use developments in order to

3.5. Performance expression of Victoriaville MUE

	Objective	A2-1-4-35-6-78	A2-1-4-35-6	A2-1-4-35	A2-1-4	A2-1	A2	Initiale State	Current scale	
Objective	no	vstrg-extr	positive	positive	positive	positive	positive	positive	100	extreme
A2-1-4-35-6-78		no	weak-mod	positive	positive	positive	positive	positive	62	v. strong
A2-1-4-35-6			no	weak-mod	positive	positive	positive	positive	46	strong
A2-1-4-35				no	mod-strg	positive	positive	positive	31	moderate
A2-1-4					no	weak-weak	positive	positive	8	weak
A2-1						no	no	no	0	very weak
A2							no	no	0	no
Initiale State								no	0	

Consistent judgements

Figure 3.5 – Pairwise comparison matrix of the sets of actions for the criterion "Attr/Ret" (Attraction and retention of jobs) and the resulting interval scale. (Extracted from M-MACBETH)

offer services to the companies' employees and create a pleasant living environment") will have a moderate to strong positive impact on the attraction and retention of jobs in DGIE (see preference intensity "3–4" that means "moderate difference to strong difference"). It is important to note that this information does not allow one to compare actions individually. In that scenario, it is unclear whether actions A3 + A5 have greater impact than action A4 and which actions between A3 and A5 have a greater impact. It may be possible that the conjunction of all the completed actions has a greater impact than the sum of their respective impact. This aggregation allows the method to accommodate a greater number of actions. Moreover, it encourages the decision maker to consider synergies of actions that could be more efficient than separate actions.

Step 4 : Global performance expression

The global performance expression of a set of actions is the weighted average mean of its elementary performance expressions. Figure 3.6 presents the predicted global performance expressions of DGIE during the execution of its action plan. These results are discussed in the following section.

Options	Overall	EnUP1	EnUP2	EnUP3	EnUP4	EnCO1	EcUP1	EcCO1	ScUP1	ScUP2	ScCO1	Attr/Ret
Objective	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
A2-1-4-35-6-78	0,54	0,57	0,00	0,33	0,67	0,33	0,65	0,38	0,50	0,44	0,55	0,62
A2-1-4-35-6	0,42	0,43	0,00	0,17	0,33	0,33	0,59	0,38	0,50	0,33	0,50	0,46
A2-1-4-35	0,31	0,43	0,00	0,05	0,00	0,25	0,47	0,38	0,50	0,22	0,45	0,31
A2-1-4	0,12	0,00	0,00	0,00	0,00	0,17	0,35	0,25	0,00	0,11	0,15	0,08
A2-1	0,07	0,00	0,00	0,00	0,00	0,08	0,24	0,12	0,00	0,11	0,10	0,00
A2	0,03	0,00	0,00	0,00	0,00	0,00	0,12	0,00	0,00	0,11	0,05	0,00
Initial state	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Weights :		0,1395	0,0233	0,0233	0,1860	0,0698	0,1627	0,1163	0,0465	0,0233	0,0930	0,1163

Figure 3.6 – Predicted elementary and global performance expressions of DGIE. (Extracted from M-MACBETH)

3.5.3 Discussion

Figure 3.7 illustrates the evolution of the predicted global performance expression of DGIE during the application of its action plan (see Figure 3.6 for the results). As we can see, the final global performance expression reached is 54%. This means that the decision maker considered that at the end of this action plan, DGIE will have reached half of what they consider to be the ideal performance. It should be noted that DGIE finality is sustainability, which intrinsically includes the notion of continuous improvement. The presented model is meant to be used continuously, on each iteration of the Deming wheel. It is not meant to help the decision maker elaborate one action plan that will make their MUE reach a performance of 100%, but to help the decision maker elaborate the most efficient action plan, at a given time, for a given milestone, with the available

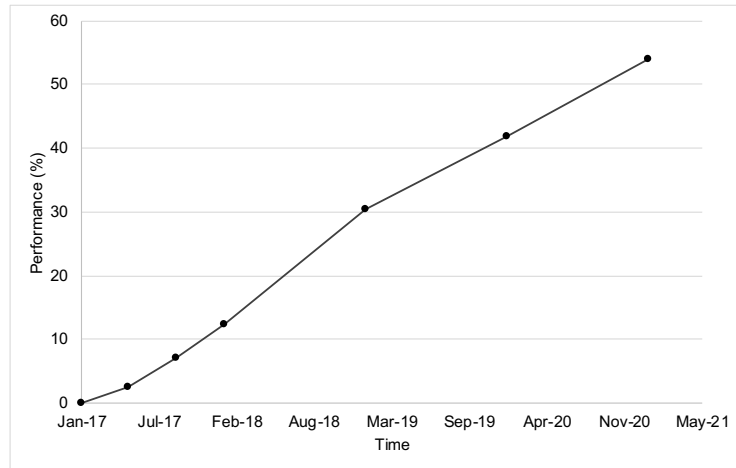


Figure 3.7 – Predicted evolution of the global performance expression of DGIE

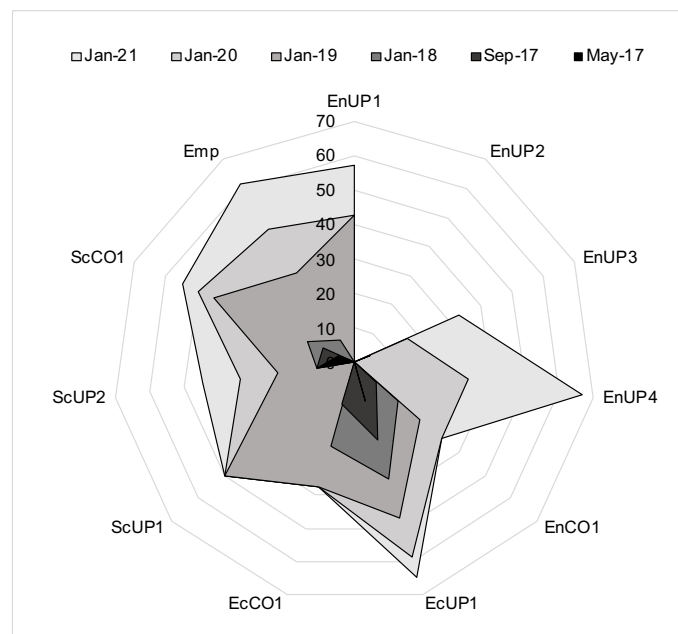


Figure 3.8 – Predicted evolution of the elementary performance expressions of DGIE

resources. At the time of this study, DGIE decision maker considered that 54% was a satisfactory performance expression considering that DGIE is still developing and that it was its first action plan. Therefore, they didn't wish to revise this action plan. It can be expected that the knowledge gained during the execution of the action plan will help the definition of subsequent action plans.

Figure 3.8 takes a closer look at the predicted elementary performance expressions of DGIE. After the execution of the action plan, DGIE reaches a relatively low performance in some objectives (EnUP3 and EnCO1 are at 33.33%, EnUP2 remains at 0%) compared with others (62% for Emp, 65% for EcUP1, and 67% for EnUP4). The influence of these relatively low scores on the global performance expression is only marginal since their associated weight is small (2% for EnUP2 and EnUP3, 7% for EnCO1) compared with others (19% for EnUP4, 16% for EcUP1, and 14% for EnUP1). Nevertheless, this shows that the application of the method can quickly indicate which objectives are not dealt with and can help the decision maker create new actions for their action plan. For example, these new actions could improve the relatively low elementary performance of EcCO1 and, to a lesser extent, the performance of EnUP3, EnUP2, and EnCO1.

It is important to note that the model presented here does not allow for a direct comparison of the elementary or global performance expression of two actions. Since this extension of MACBETH compares consecutive sets of actions instead of alternatives, the performance expressions of the sets of actions are systematically embedded with the interactions between two actions. Indeed, the performance of $A2 - 1$ is not the sum of the performance of $A2$ and $A1$. In other words, the performance expressions of the sets of actions take into account the synergies between the actions. As the objective of our research is to express the performance of an MUE throughout the execution of an action plan, we note here that our model accounts for the marginal effect of an action assuming that all the precedent actions have been completed, rather than its isolated effect. As an illustration, the performance of DGIE is 31% after the execution of $A2 - 1 - 4 - 35$ and 42% after the execution of $A2 - 1 - 4 - 35 - 6$, which informs us that, in this situation, the marginal effect of $A6$ on DGIE performance is 11%.

From these results, we can also conclude on the choice of MACBETH as an MCDA method for this evaluation problem. These results confirm the relevance of MACBETH for this problem. Indeed other recognized MCDA methods were considered for this study, such as the UTA (Siskos et al., 2005) or ELECTRE III (Figueira et al., 2013). The UTA method was not chosen for this evaluation problem since the decision-maker deemed themselves unable to describe the actions according to each criterion by a quantitative value and to determine preferences among a subset of reference actions in order to build their decision model. Indeed, the idea was not to make pairwise comparisons but to combine them step by step and to give the progress achieved at each step. Moreover, an outranking method such as ELECTRE III only results in a ranking of the alternative considered. In our case, this ranking is known from the elaboration of the action plan, since each new action will improve the global performance of the MUE. The only method that could have processed the available knowledge of the decision maker is the GRIP method (Figueira et al., 2009). Such a method, that applies robust ordinal regression, allows to build a preference model using more knowledge sources than MACBETH, notably the global comparison of a subset or reference actions. In this evaluation problem this type of knowledge is useless because, as we can see on Figure 3.7, the global performance expression of the sets of actions increases at each milestone of the action plan schedule. Therefore, the MACBETH method has been adopted due to its convenience of implementation. Nonetheless, such a method, which is based on a holistic repository of preferences, could enrich the model presented here given the difficulty to collect the decision maker's intensity of preferences.

These results highlight the potentialities of MACBETH as an useful method for the MUE action plan performance expression and design, but to fully support the MUE control, it needs to be integrated in the Deming wheel framework. Such a MCDA reading of the Deming wheel is illustrated in Figure 3.9 and will be the subject of future research. *Step 1*, *Step 2*, *Step 3* and *Step 4* constitutes the *Plan* phase. During this phase, MACBETH is used *a priori* to predict the performance of an action plan. *Step 1.a* and *Step 2* are performed only once. With the predicted performance expression, the decision makers are able to improve the initial action plan by performing several iteration of MACBETH. In the *Do* phase, which corresponds to *Step 5*, the impending set of actions of the overall action plan is executed. *Step 3'* and *Step 4'* constitutes the *Check* phase. In the *Check* phase, MACBETH is used *a posteriori* to express the achieved performance of the executed sets of action. At the *Act* phase, by comparing this achieved performance expression with the predicted one, the decision maker can decide to update their action action plan. In that case, the predicted performance expression of this updated action plan is expressed by re-starting the Deming wheel. If the decision makers consider that the difference between the predicted and achieved performance expressions is satisfactory, the execution of the action plan resumes.

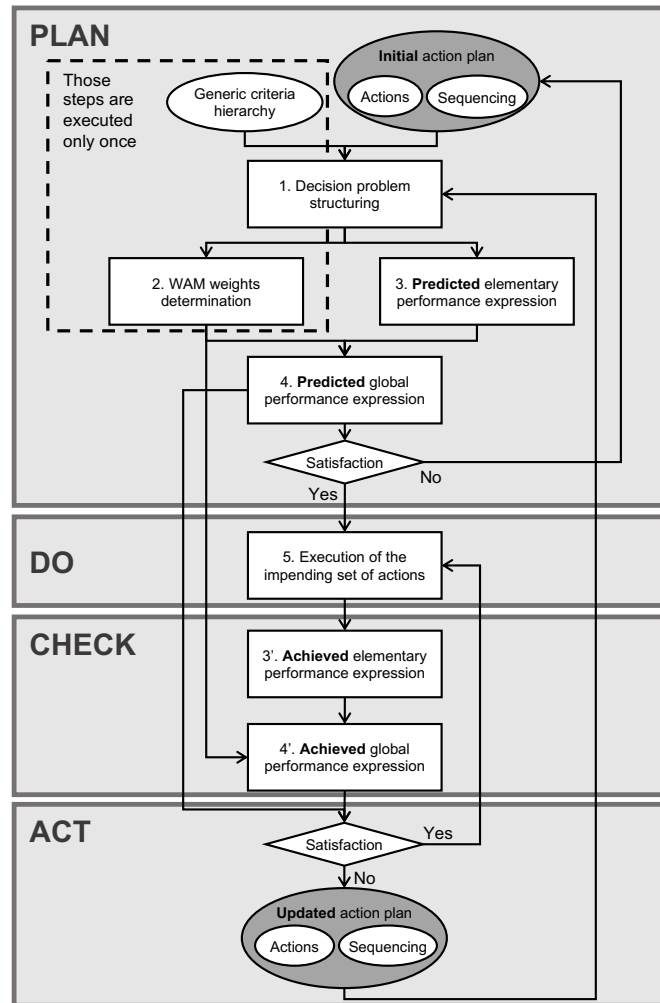


Figure 3.9 – Integration of MACBETH in the Deming wheel for the MUE control

3.6 Conclusion

In this paper, a model for the control of a MUE has been introduced. Following the Deming wheel principles, MUE control can be defined as an iterative process of comparing results with fixed objectives, leading to corrective actions if the fixed objectives were not achieved or improvements of the fixed objectives if they were achieved. Knowing that the MUE is a complex system managed by a designated decision maker and that its finality is sustainability in its consensual meaning, the MCDA was chosen as a suitable scientific method since it can deal with multiple criteria and trade-offs. In order to predict the performance of an MUE at each milestones of its action plan, the MACBETH method was used in an innovative way to express the performance of complementary actions. This was done through the aggregation of completed actions on the successive milestones of the action plan schedule. This extension of MACBETH was then applied to predict the performance of DGIE.

From the results of this case study, it appears that MACBETH is a suitable method to express the performance of a MUE. Indeed, it is able to capture and process qualitative information such as expertise, by offering an accessible framework that corresponds to the decision maker's perspective. The ability of MACBETH to directly compare actions without having to quantify their impact on the criteria is appreciated in this particular evaluation problem. MACBETH allows us to describe the marginal impact of one or several actions carried out simultaneously, which matches the deci-

sion maker's knowledge. Moreover, DGIE decision maker were satisfied with the flexibility of the method when gathering their preferences or the preference intensity. The ability to refine the decision maker's preferences as their expertise grows is an important feature that will allow for better results in future iterations of the method. The simplicity and clarity of the method are valuable assets that favors communication between the decision maker and the analyst, which should lead to more precise results. Finally, a crucial feature is the ability of MACBETH to account for synergies between actions in a set of actions, which is critical in the case of performance expression of an action plan.

Regarding the perspectives, the model presented here is to be further integrated into the MUE control process. In this case study, the model was used to predict DGIE performance throughout the application of an action plan. In other words, the model was used at the *Plan* phase of the Deming wheel. Another implementation of this model will be to monitor the performance of DGIE, by comparing the achieved performance with the predicted performance (*Check* phase of the Deming wheel). A third development is that the model could be used to help the decision maker select new actions, replace or remove actions, by comparing action plans which could be used in both the *Plan* and *Act* phases of the Deming wheel. Moreover, in the future, applications of the model on other MUEs are planned, namely, Savoie Technolac and Savoie Hexapole, two French MUEs in the Savoie region. It is expected that the model will benefit from the results of its application on a panel of MUEs with different characteristics such as size, maturity, geographic location, decision makers, or strategies.

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Appendix : Summary of DGIE action plan

Tableau 3.5 – Summary DGIE action plan

Code	Global Action
A1	Demystify DGIE to influential socio-economic stakeholder and prospected companies
A2	Evaluate the possibility to build new building to offer turnkey solutions to prospected companies
A3	Create a financial incentive to attract companies
A4	Promote DGIE
A5	Enable mixed-use developments in order to offer services to the companies employees and create a pleasant living environment
A6	Make DGIE accessible and known by the citizens in order to make it a source of regional pride
A7	Highlight the wet lands of DGIE
A8	Differentiate DGIE with a certification

4

Proposition d'un modèle d'agrégation de la performance pour l'expression de la performance durable de l'écoparc

Ce chapitre présente l'article intitulé "An overall sustainability performance evaluation model for the Mixed-Use Ecopark using Choquet integral", soumis au Journal of Ecological Indicators. Un résumé de l'article en français introduit le chapitre.

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4.1 Résumé

Cette étude traite du vaste sujet qu'est le développement durable et l'amélioration continue des parcs industriels et se focalise plus particulièrement sur l'évaluation de l'état de durabilité atteint par de tels systèmes d'organisations et infrastructures interconnectées. Bien que la durabilité fut introduite dans le discours politique général depuis plusieurs décennies, elle demeure compliquée à évaluer et donc à améliorer, plus encore dans le cas de structures élaborées comme les parcs industriels. Ainsi, dans le but d'étudier la problématique du pilotage des parcs industriels, l'approche proposée consiste en un cadre d'évaluation de la durabilité offrant deux niveaux d'évaluation : d'un côté l'évaluation des trois piliers de la durabilité - environnemental, économique et social - et d'un autre côté l'évaluation de la durabilité globale. Le modèle présenté est basé sur un principe de l'agrégation multicritère de compromis et s'appuie sur une décomposition systémique de la durabilité du parc industriel préliminaire. Dans ce sens, deux opérateurs d'agrégation sont utilisés : la moyenne pondérée, qui permet de considérer les poids des critères impliqués, et l'intégrale de Choquet, qui permet de considérer le poids mais aussi les interactions entre les critères. Pour garantir la cohérence mathématique de ce processus d'évaluation, un cadre méthodologique - MACBETH - est adopté. En guise d'illustration, le modèle présenté est utilisé pour évaluer la durabilité d'un cas d'étude réel (l'écoparc industriel Daniel Gaudreau à Victoriaville) afin d'aider ses gestionnaires à l'améliorer. Une discussion conclut ce travail.

4.2 Introduction

Industrial parks are tools of planned economic development in industrialized countries (Peddle, 1993). They can be described as "a large tract of land, subdivided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms" (United Nations Industrial Development Organization, 1997). Today, industrial parks face various challenges, depending on their geographic, economic, environmental, and social environment (Lambert and Boons, 2002). Some of these challenges, such as infrastructure aging, road congestion, land rarefaction, or labor shortage, impact on the attractiveness of industrial parks. Other challenges are related to the environmental impact of industrial parks and their resident companies, for example, waste handling, pollution, or intensive resource and land consumption. As a consequence, local authorities and planners are rethinking the design and development of these parks by introducing environmental and social considerations so as to improve their sustainability.

Against this background, a new archetype of sustainable industrial park has been introduced : the mixed-use ecopark (MUE) (Le Tellier et al., 2019). The MUE is "a community of businesses (of all sizes, from the industrial or service sectors) located on an industrial park planned and built in a sustainable approach, that cooperate with each other and with the local community to efficiently share information, materials, energy, infrastructure or services, leading to economic environmental and social benefits for the businesses and the local community." This new archetype aims to provide answers to the sustainability challenges faced by traditional industrial parks, notably in Europe and North America. Essentially, the MUE philosophy is based on the belief that sustainable planning and inter-company collaboration are important assets for creating sustainable industrial parks that are beneficial to their community.

At its highest level of abstraction, the mission of the MUE, the so-called finality, is its sustainability. In a broad sense, sustainability can be found at the intersection of three circles, commonly called "pillars", namely, society, environment, and economy, and emerges when balancing trade-

offs between seemingly equally desirable goals within these three circles (Purvis et al., 2019). In itself, sustainability is a complex concept (Pope et al., 2004) that cannot be reduced to a set of rules and formulas unless applied in a specific context. In the context of the MUE, additional complexity arises from the inherent intricacies of the MUE and the diversity of its instances. Indeed, MUEs can differ for a variety of reasons : their size, their juridical status, the type of companies they welcome, the life cycle stage they are at, etc., which have an impact on strategies for their sustainable development.

This paper deals with the broad subject of MUE sustainability. An overall assessment model devoted to MUE control is proposed. In particular this model is used to predict or to assess the sustainability of MUEs. Indeed, in a proactive way, the prediction of MUE sustainability can guide its manager with clearly defined action plans. In a reactive way, the assessment of MUE sustainability can support its manager in updating or redefining action plans. Moreover, information about the expected versus the attained sustainability states offers an overview of the MUE performance to its manager. This results in an easy, direct, and comprehensive way of communicating. Local communities and authorities can thus display the results and improvements achieved through visual management. Information about sustainability can also be used to promote the MUE to potential resident companies. Finally, information on sustainability may be used for benchmark studies and comparisons between several MUEs. It should be noted that information both about the global sustainability of the MUE and about its environmental, economic, or social performance can be used for control, promotion, or benchmark purposes.

Because of its complexity as an objective, MUE sustainability cannot be directly assessed. It needs to be deployed into so-called elementary objectives, whose achievement can be directly assessed, resulting in the so-called elementary expressions. The proposed approach is based on the aggregation of these elementary expressions into a multi-criteria decision analysis (MCDA) context (Figueira et al., 2005). The approach provides instantaneous assessment of MUE sustainability at a given point in time. Two different assessments of sustainability are expected : an assessment of the performance of each of the three pillars of sustainability and an overall sustainability assessment. Therefore, the proposed approach comprises several steps and relies on mathematical tools that take into account the specificities of this assessment problem. The presented approach is based on MCDA. From a formal point of view, it uses two operators from the compromise aggregation family : the weighted arithmetic mean (WAM) and the Choquet integral (CI). The WAM is used to handle the varying relative importance of the objectives and the CI is used to handle the interactions between them. The MACBETH method is chosen as a framework for the model to ensure mathematical consistency. This work can be considered a significant step forward in assessing the sustainability of industrial parks, and from an MCDA standpoint, the novelty of this research and of its potential improvements lies in its double aggregation mechanism. Thus, the aim of this study is the definition of an MUE sustainability assessment based on a multi-criteria aggregation philosophy.

This article is structured as follows. In Section 4.3, the intricacies of MUE sustainability are presented based on the definition of an MUE and of sustainability as a general concept. After presenting the outline, the detailed aggregation procedure is introduced in Section 4.4. In Section 4.5, the model is applied to a Canadian MUE whose manager wants an assessment of the sustainability improvement during the execution of its action plan. Finally, Section 4.6 concludes this work.

4.3 The MUE and its sustainability

4.3.1 The MUE

Definition

One of the oldest and most traditional forms of planned economic development in developed countries is the industrial park, as previously defined. In recent decades, the challenges for sustainable development have become inseparable from the design and development of industrial parks ([United Nations Environment Programme, 2001](#)). Indeed, the design, development, management, and retrofit of industrial parks are cross-sector endeavors involving a variety of stakeholders. Industrial park development can impact the achievement of several of the Sustainable Development Goals from Agenda 2030, such as Goal 8 (Decent Work and Economic Growth), Goal 9 (Industry, Innovation, and Infrastructure), Goal 11 (Sustainable Cities and Communities), and Goal 12 (Responsible Consumption and Production) ([United Nations, 2015](#)).

With the goal of spurring on the development of sustainable industrial parks, a new archetype called mixed-use ecopark (MUE) has been introduced ([Le Tellier et al., 2019](#)). The MUE is a sustainable industrial park that is planned and built with respect to principles of sustainable urban development, where companies collaborate in order to gain economic, environmental, and social advancements for themselves, their employees, and the community. This concept is derived from another established concept : the eco-industrial park (EIP). An EIP is an industrial park where a community of industries take part in a network of collaborative relationships, exchanging resources such as energy, water, materials, and by-products, in order to increase their economic performance by minimizing the environmental impact and creating benefits for the local community ([Côté and Hall, 1995](#); [U.S President's Council on Sustainable Development, 1997](#); [Côté and Cohen-Rosenthal, 1998](#)). The origins of the EIP can be traced back to the emergence of industrial ecology and circular economy ([Li, 2011](#); [Saavedra et al., 2018](#); [Belaud et al., 2019](#)). The main difference between an MUE and an EIP is that the focus of an EIP is on the creation of physical exchanges between industries, also called industrial symbiosis ([Chertow, 2000](#)). On the other hand, the MUE strategy for sustainability focuses on urban planning practices and collaboration between companies to foster eco-innovations, sustainable business practices, improved work conditions for employees, and economic and social advancement for the community.

The MUE is traditionally controlled by a designated manager. This manager is a legal entity that can be a combination of several stakeholders such as public or private investors, local authorities, planners, developers, etc. ([Lowe, 1997](#); [van Leeuwen et al., 2003](#); [Heeres et al., 2004](#); [Tessitore et al., 2015](#)). As described before, the manager is tasked with the general operation of the MUE, including activities such as defining its strategy, overseeing the execution of the sustainability action plans, as well as communicating about the park and promoting it.

Systemic modeling

By definition, the MUE is a system. More precisely, it is an open system that exchanges material, energy, people, capital, and information with its environment. A system is defined as "*a regularly interacting or interdependent group of items forming a unified whole*" ([Merriam-Webster.com, 2020](#)). A basic principle of a system is that it is something more than a collection of its parts, but other characteristics of a system are that it is self-organizing and resilient and that its behavior is complex and nonlinear ([Meadows, 2008](#); [Chapman et al., 2016](#)).

Systemic analysis considers a system as a whole and adopts diverse perspectives and organizational levels, looking at interactions between its constituent sub-systems ([Bertalanffy, 1950](#)). The systemic modeling of an entity consists in the characterization of its finality, its environment and observer, its structure, its objectives, and its two behaviors : normal operation and transforma-

Tableau 4.1 – Systemic modeling characteristics of the MUE (adapted from (Le Tellier et al., 2019))

Characteristics		Modeling of the MUE
1	Finality	Sustainability
2	Environment	Suppliers, Clients of the resident companies Natural Environment Local community
	Observer	Manager
3	Structure	Entities Companies Buildings Infrastructures Interactions Inter-company collaboration Eco-Industrial Synergies
4	Objectives	Deployment of the finality
5	Behavior	Operation Operation of the entities Transformation Evolution of the MUE structure

tion (Le Moigne, 1994). Therefore, systemic modeling answers questions such as : "What are the system purposes and objectives ?" ; "What elements constitutes the system ?" ; "How do they interact ?" ; or "What is the system's behavior ?" Like any other type of modeling, systemic modeling is described through a defined perspective, which is that of the observer of the system, namely, the MUE manager. The manager is a particular entity found on the border between the system and its environment.

The systemic modeling of the MUE is presented in Table 4.1 and additional details can be found in (Le Tellier et al., 2019).

In particular, a system's finality reflects the observer's idea of the mission of a system at its highest level of abstraction. The MUE finality is its sustainability. Indeed, sustainability fits Le Moigne's idea of finality perfectly, since it is a process of continuous improvement through decision-making and interactive learning (Le Moigne, 1994; Siebenhüner and Arnold, 2007).

4.3.2 Sustainability

Definition

One of the most cited definitions of sustainable development is from the Brundtland Report, which defines it as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission On Environment and Development, 1987). Completing the Brundtland Report, the Rio Declaration consists of 27 principles intending to guide future sustainable development, and Agenda 21, which articulates a plan for putting these principles into practice (United Nations, 1992). Both the Rio Declaration and Brundtland Report have facilitated the introduction of sustainability into mainstream policy discourse. Nevertheless, since then, various interpretations of the definition found in the Brundtland Report have been proposed, which shows that sustainability and sustainable development remain ambiguous and complex concepts ((Pope et al., 2004; Johnston et al., 2007) among many others).

A common interpretation of the concept is through its three interconnected pillars, which each include economic, social, and environmental objectives. In its most consensual paradigm, sustainability is often represented at the intersection of these three pillars. Sustainability emerges when balancing trade-offs between seemingly equally desirable goals within these three categorizations (see (Purvis et al., 2019) for an extensive analysis of the definition of the three pillars). While it has been criticized for its lack of theoretical development (Redclift, 2005), this popular and engaging description is successful in illustrating the complexity of sustainability that should emerge from the achievement of interconnected conflicting objectives (Cocklin, 1989). Two other paradigms are weak sustainability and strong sustainability. These paradigms are based on the notions of manmade capital, expressed by the ability to produce economic value, and natural capital, corresponding to the world's stock of natural resources. Strong sustainability assumes that manmade and natural capital are complimentary but cannot be substituted and that sustainability is equivalent to "*leaving the future generations a stock of natural capital not smaller than the one enjoyed by the present generation*" (Cabeza Gutiérrez, 1996). On the other hand, weak sustainability assumes that natural and manmade capital can be substituted, and that sustainability is equivalent to non-decreasing total capital stock (Daly and Cobb, 1994; Figge, 2005; Dietz and Neumayer, 2007; Chandrakumar and McLaren, 2018). Both paradigms of weak sustainability and strong sustainability have been criticized because their concept of sustainability lacks resilience (Atkinson et al., 2007) and practicability, respectively (Beckerman, 1994). However, Neumayer argues that both paradigms are scientifically compelling since they both rest on claims about the future that are irrefutable (Neumayer, 2010). The disparities in balance between the paradigms of weak and strong sustainability perfectly illustrate the ambiguity and complexity surrounding the concept of sustainable development. Hence, these disparities lead to different visions of sustainability, which translates into varying importance attributed to each of the three pillars and into diverse approaches to dealing with the trade-offs.

Assessment

Sustainability assessment can be defined as "*a tool that can help decision-makers and policy-makers decide what actions they should take and should not take in an attempt to make society more sustainable*" (Devuyt, 2001). Various sustainability assessment tools have been developed and several overviews and typologies of these tools can be found in the literature (Singh et al., 2009; Kaufmann-Hayoz et al., 2001; Sharifi and Murayama, 2013).

For instance, a categorization of tools that is worth mentioning is the one proposed by Ness et al. (2007). This categorization considers the focus of the tools (*i.e.*, product, organization, region, or policy), the temporal characteristics of the tools (*i.e.*, if they are used retrospectively or prospectively of the assessed project, of the introduction of the assessed policies, or of the design of the assessed product), and the integration of the three pillars of sustainability (*i.e.*, to what extent the tools combine environmental, social, and/or economic aspects). Sustainability assessment tools are then distinguished into the following three categories :

- Indicators and indices, which are retrospective tools that can focus on a wide array of systems and are either integrated or nonintegrated.
- Product-related tools, which are both retrospective and prospective tools that focus exclusively on products and are nonintegrated.
- Integrated tools, which are prospective tools that focus on projects or policies (most of them are established tools but do not necessarily pertain directly to sustainability issues only).

As we can see from Ness et al. (2007), various tools exist for assessing sustainability, whether they integrate its three pillars or not. Our work is consistent with this logic since it consists in an integrated tool for the assessment of MUE sustainability.

4.3.3 MUE sustainability

In the context of an MUE, sustainability is naturally defined through its three interconnected pillars. As a generic concept, MUE sustainability is complex because of the intrinsic complexity of the MUE. Certain elements of the complexity of MUE sustainability can notably be highlighted.

1. MUE sustainability is complex because it can be defined through numerous perspectives. Some of these perspectives are the entities of the MUE and the entities constituting its environment (see Table 4.1).
2. Because of the systemic nature of MUEs, the MUE entities and stakeholders interact with each other. Similar to the interconnectedness of the three pillars of sustainability, the interactions between the MUE entities increase the complexity of its sustainability.
3. Different MUEs may encompass different visions of sustainability. Indeed, just like regular industrial parks, MUEs can differ for a variety of reasons : their size, their juridical status, the type of companies they welcome, the life cycle stage they are at, the local culture of their community, their natural environment, their resources, their manager etc. These characteristics impact both the development strategy adopted by the manager of the MUE and the visions of sustainability.

The deployment of MUE sustainability is based on the systemic modeling of the MUE. Indeed, because of its complexity, MUE sustainability cannot be directly assessed and needs to be deployed into smaller objectives whose achievement can be directly assessed. This deployment draws on similar works with EIPs and urban sustainability (Verma and Raghubanshi, 2018; Valenzuela-Venegas et al., 2016; Zhao et al., 2017) and was validated through observations of MUEs (see (Le Tellier et al., 2019) for details on the MUEs observed). The elementary objectives resulting from the deployment are directly related to the entities of the system and their interactions, as detailed in Table 4.1. Figure 4.1 shows the proposal for MUE sustainability deployment. The results of this deployment are a hierarchy of criteria that are used to described objectives. The first level of deployment draws upon the definitions of the MUE and of the three pillars of sustainability. At this level, the finality is deployed into three criteria matching the three pillars. At the second level,

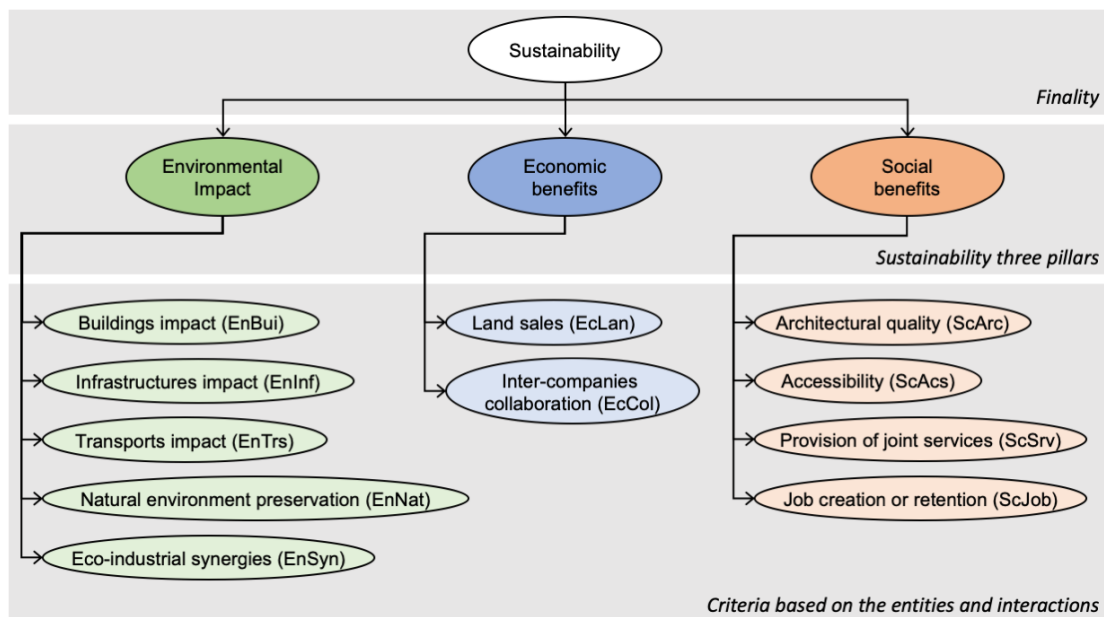


Figure 4.1 – Deployment of MUE sustainability

these criteria are further deployed. Each criterion is associated with one of the entities or interactions of the structure of the MUE, as described in Table 4.1. Criteria associated with entities of the MUE are *EnBui*, *EcLan*, and *ScArc*, with the *Building* entity, *EnInf*, *EnTrs*, *EnNat*, and *ScAcs*, with the *Infrastructure* entity, and *ScJob* with the *Company* entity. Criteria associated with interactions between entities are *EnSyn*, with the *Eco-Industrial Synergies* interaction, and *EcCol* and *ScSrv*, with the *Intercompany Collaboration* interaction.

4.4 A model for the assessment of MUE sustainability

4.4.1 Outline

Following the categorization suggested by [Ness et al. \(2007\)](#) presented in Section 4.3.2, the MUE sustainability assessment model can be classified into the integrated assessment category because it integrates the three pillars of sustainability. The only difference is that this model can be used prospectively as well as retrospectively.

The assessment amounts to expressing a performance, defined as the satisfaction of an objective. As mentioned earlier, the MUE overall sustainability assessment is provided by a (deployment, aggregation) mechanism. Once the deployment has been performed (see Figure 4.1), three successive steps have to be followed (Figure 4.2). The first step of the model is the determination of the elementary performance expressions of the three pillars. Then, the three-pillar elementary expressions are aggregated into the three-pillar aggregated performance expressions. Finally, the three-pillar aggregated performance expressions are aggregated into the overall sustainability expression. For the sake of conciseness, in the rest of this article, the three-pillar elementary performance expressions will be called the “elementary performance expressions”, and the three-pillar aggregated performance expressions will be called the “three-pillar performance expressions”.

Because of the complexity of MUE sustainability (see Section 4.3.3), the performance aggregation must comply with the following properties :

- Each criterion of MUE sustainability has a varying relative importance. This importance depends on the strategy and the vision of the MUE that is assessed. Therefore, the sustaina-

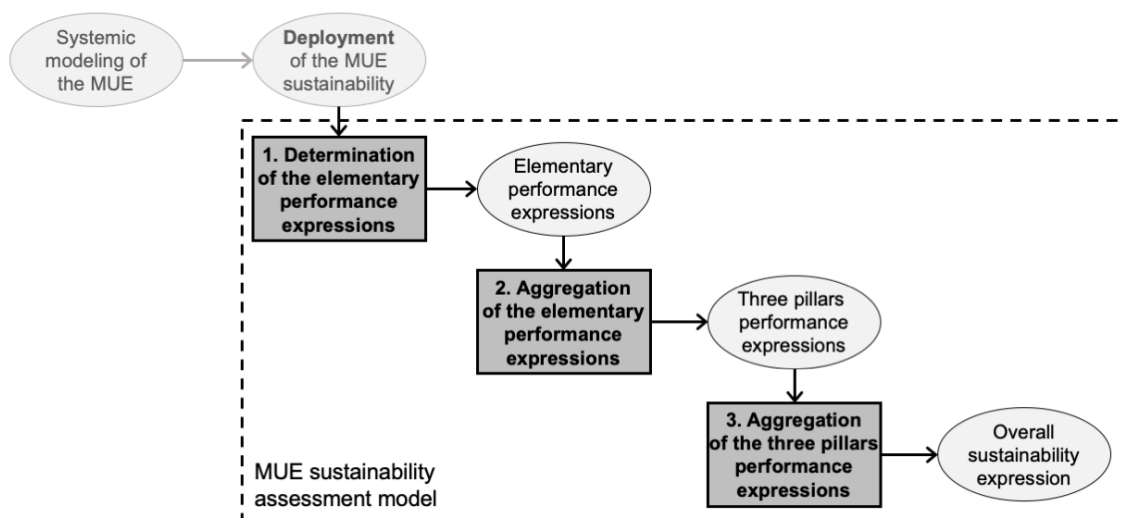


Figure 4.2 – Overall MUE sustainability assessment model

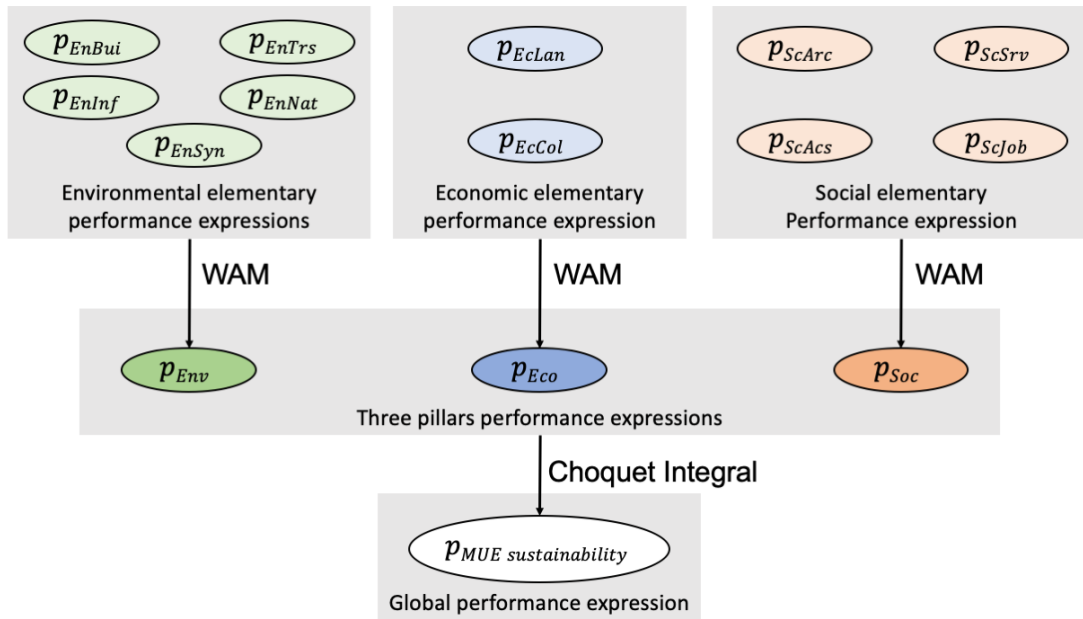


Figure 4.3 – Aggregation of the elementary performances into the overall sustainability expression of the MUE

bility assessment must be able to account for the relative importance of each criterion.

- The MUE entities and stakeholders interact with each other, and the three pillars of sustainability are interconnected. Because of this, the criteria are not independent and the assessment must be able to account for these interactions. In more concrete terms, there are two types of interactions : the first type occurs when the simultaneous satisfaction of two objectives is preferred over a unilateral satisfaction ; the second occurs when the satisfaction of either one of a pair of objectives is preferred to their simultaneous satisfaction.

It is important to note at this point that we hypothesize that, within one pillar, the elementary performance expressions compensate each other and that therefore the interactions between the elementary objectives are negligible. From now on, the model will consider the interactions between the three pillars.

Two operators from the compromise aggregation family are chosen for the aggregations : the WAM, which uses weights as required by our aggregation problem, and the CI, which handles interactions (see Figure 4.3). It should be noted that the CI has frequently been used to evaluate sustainability (Bottero et al., 2013; Merad et al., 2013; Bottero et al., 2014; Pinar et al., 2014; Zhang et al., 2014; Karnib, 2016; Zhang et al., 2016; Angilella et al., 2018). The MACBETH method is chosen as a framework for the sustainability assessment model.

4.4.2 Aggregation : weighted arithmetic mean & Choquet integral

Having presented the outline of the assessment model and its mathematical tools, we now provide more details on these tools. From a general point of view, aggregation can be seen as an operation that synthesizes pieces of information into an overall expression. Hence, performance aggregation can be formalized by the following mapping (Berrah et al., 2004; Berrah and Clivillé, 2007)¹ :

$$Ag : E_1 \times E_2 \times \dots \times E_i \times \dots \times E_n \rightarrow E$$

1. The mathematical notation used in this article is similar to the one developed by Clivillé et al. in their previous works (Clivillé et al., 2007; Berrah and Clivillé, 2007).

$$(p_1, p_2, \dots, p_i, \dots, p_n) \rightarrow p_{Ag} = Ag(p_1, p_2, \dots, p_i, \dots, p_n)$$

E_i is the universe of discourse of elementary expressions p_i and E is the universe of discourse of the overall performance expression p_{Ag} . The mathematical consistency of the aggregation requires the satisfaction of the following two conditions (Berrah and Clivillé, 2007) :

- *Commensurability*. The elementary expressions must be commensurate. This means that two identical values (e.g., 0.64) according to two different criteria (e.g., environmental impact of the infrastructures and creation of eco-industrial synergies) have the same meaning.
- *Significance*. The aggregation operator must be significant for the elementary expressions. The significance condition ensures that an elementary expression can be compensated by another one (Choo et al., 1999). For example, for the family of mean operators (arithmetic mean, WAM, CI, etc.), for each criterion, the same difference between two values (e.g., $(0.70 - 0.55)$ and $(0.34 - 0.19)$) has the same meaning. In this case, the values are defined on an interval scale. When the aggregation operator is the product, this condition applies to the ratio. In this case, the values are defined on a ratio scale.

The WAM is an operator of the form :

$$\sum_{i=1}^n p_i \times w_i \quad (4.1)$$

with w_i the weight associated with the criterion i such as $\sum_i w_i = 1$ for all $i \in \mathbb{N}$. It is appropriate for the aggregation of independent criteria and was, until recently, the most widely used aggregation operator (Marichal, 2002).

The CI is an operator of the form (Grabisch, 1997; Berrah and Clivillé, 2007) :

$$p_{Ag} = \sum_{i=1}^n v_i p_i - \frac{1}{2} \sum_{i=1}^n I_{ij} |p_i - p_j| \quad (4.2)$$

where $(p_1, \dots, p_i, \dots, p_n)$ is the vector of elementary expressions such that :

$$\left(v_i p_i - \frac{1}{2} \sum_{i=1}^n I_{ij} |p_i - p_j| \right) \geq 0 \quad \forall i \in [1, n] \text{ and } i \neq j \quad (4.3)$$

- v_i is the Shapley parameter. It represents the weight of each elementary performance expression in relation to all the other contributions to the overall performance expression. It satisfies $\sum_{i=1}^n v_i = 1$.
- I_{ij} is the interaction parameter of any pair of performance criteria i and j . It ranges between $[-1; 1]$.
 - a positive I_{ij} implies a synergy between objectives o_i and o_j (the objectives, respectively, associated with the criteria i and j).
 - a negative I_{ij} implies that o_i or o_j is redundant.
 - a null I_{ij} implies that no interaction exists; thus v_i acts as the weights in a common WAM.

4.4.3 MACBETH

Definition

The general framework for the assessment model is the MACBETH method (Bana e Costa et al., 2002, 2005). The MACBETH method is a multi-criteria decision analysis (MCDA) method and, more precisely, a multi-attribute utility theory method that satisfies the commensurability and significance condition. MACBETH was introduced in the 1990s by Bana e Costa and Vansnick

(1997) and it has been used in the industrial performance context (Clivillé and Berrah, 2012; Clivillé et al., 2013; Rodrigues, 2014). In this model, MACBETH is used to express the elementary expressions and to determine the parameters of the aggregation operators. Its underlying principle is to translate the human expertise of the manager into interval scales (Bana e Costa et al., 2005).

MACBETH allows for the assessment of situations (also called “options,” “alternatives,” “actions,” etc.) that are significant or well-known by the manager against multiple criteria. Besides the considered situations, MACBETH requires the use of particular and possibly fictive situations. These particular situations are known through their elementary expression vectors $(p_1, p_2, \dots, p_i, \dots, p_n)$ and the associated aggregated performance expressions $p_{Ag}^{(p_1, p_2, \dots, p_i, \dots, p_n)}$ where $\forall i, p_i \in \mathbb{N}$ and $p_i = [0, 1]$. To ensure commensurability, two fictive situations need to be set by the manager and act as references : one that is simply satisfying, associated with the performance value of 0, also called “Neutral,” and one that is fully satisfying, associated with the performance value of 1, also called “Good.” Therefore, a minimum of three situations are compared : a neutral situation, a good situation, and a real situation chosen by the manager. Beside the two references, particular situations are used for the determination of the aggregation operator parameters.

MACBETH is based on pairwise comparisons. Considering each criterion and for each pair of situations, the manager is asked to give their preference. If the manager is able to, they are encouraged to characterize the intensity of their preferences thanks to semantic judgment (*null, very weak, weak, moderate, strong, very strong, extreme*) (Karande and Chakraborty, 2013).

For the sake of conciseness, the detailed MACBETH procedure is described in the MUE sustainability assessment context.

Procedure

Beyond a preliminary step of describing the assessment problem, the traditional MACBETH procedure follows three steps. In the particular MUE case, four steps are involved, due to the double aggregation (see Figure 4.2).

Description of the assessment problem : Traditionally, when dealing with MCDA, the description of an assessment problem consists in the identification of the criteria and the situations to be considered. The matter here is the sustainability assessment of the MUE considered. As seen earlier, the criteria are provided by the deployment of the MUE sustainability (Figure 4.1). The considered situations correspond to the MUE assessed at different points in time. For example, a situation that is considered may be the current state of an MUE. Their number can vary depending on the assessment problem.

Determination of the elementary expressions : MACBETH proposes defining interval scales elaborated thanks to the manager’s preferences and the intensities of the preferences. The preferences of the manager can be expressed in the following forms :

- Let S_k and S_l be two compared situations and p_k and p_l be their respective performance expressions. If $S_k \geq S_l$ (*i.e.*, for a criterion i , the manager prefers situation S_k to situation S_l) then $p_k \geq p_l$.
- If $S_k = S_l$ (*i.e.*, for a criterion i , the manager considers that S_k is equivalent to S_l) then $p_k = p_l$.

Let us recall that if the manager is able to, they are encouraged to characterize the intensity of their preferences. This intensity of a preference is denoted by h , which can take seven values, from 0 for *null* strength, to 6 for *extreme* strength. In this case, the previous information becomes :

- If $S_k \geq_h S_l$ (*i.e.*, for criterion i , the manager prefers situation S_k to situation S_l with a strength h) then $\alpha(h - 1) \leq p_k - p_l \leq \alpha(h + 1)$ where α is a coefficient necessary to meet the condition p_k and $p_l \in [0, 1]$.

The elementary expressions are determined by solving the system of inequations issued from the expression of all the intensities of preference h between S_k and S_l .

Aggregation of the elementary expressions : Let us recall that this aggregation is the first of the two aggregations of the model. This aggregation of elementary expressions within the three pillars into three-pillar performance expressions is made with the WAM. The WAM weights are determined through the pairwise comparison of particular situations. These particular situations are associated with elementary expression vectors such as $(0, \dots, 0, 1, 0, \dots, 0)$. Hence, the aggregated performance expression becomes : $p_i^{Ag} = w_i$ where p_i^{Ag} is the aggregated performance expression from the vector where $p_i = 1$ and all the other elementary expressions $p_g = 0$ with $g = 1$ to n and $g \neq i$. To determine the n weights w_i 's (related to the n criteria involved), the managers have to make n pairwise comparisons between the particular situations. The result of each comparison is an inequation taking the following form :

$$\alpha(h-1) \leq p_i^{Ag} - p_g^{Ag} = w_i - w_g \leq \alpha(h+1) \quad (4.4)$$

The n pairwise comparisons lead to a system of n equations whose unique solution is the weights (w_1, w_2, \dots, w_n) .

Having identified the weights of all the criteria, the respective aggregation of the elementary expressions within the three pillars is straightforward with the WAM aggregation function (Equation 4.1).

Aggregation of the three-pillar performance expressions : The aggregation of the three-pillar performance expressions into the overall sustainability expression is made with the CI. The determination of the CI parameters is similar to that of the weights for the WAM. The difference is that more parameters have to be determined and that, therefore, the manager is asked to consider additional fictive situations (Labreuche and Grabisch, 2003; Cliville et al., 2004). In the case considered here, there are six CI parameters to be determined : three Shapley parameters $v_1 = v_{Env}$; $v_2 = v_{Eco}$; $v_3 = v_{Soc}$ and three interaction coefficients I_{12}, I_{13}, I_{23} .

Having identified the CI parameters, the aggregation is straightforward with the CI aggregation function (Equation 4.2).

An illustration of the complete procedure is provided in Figure 4.4.

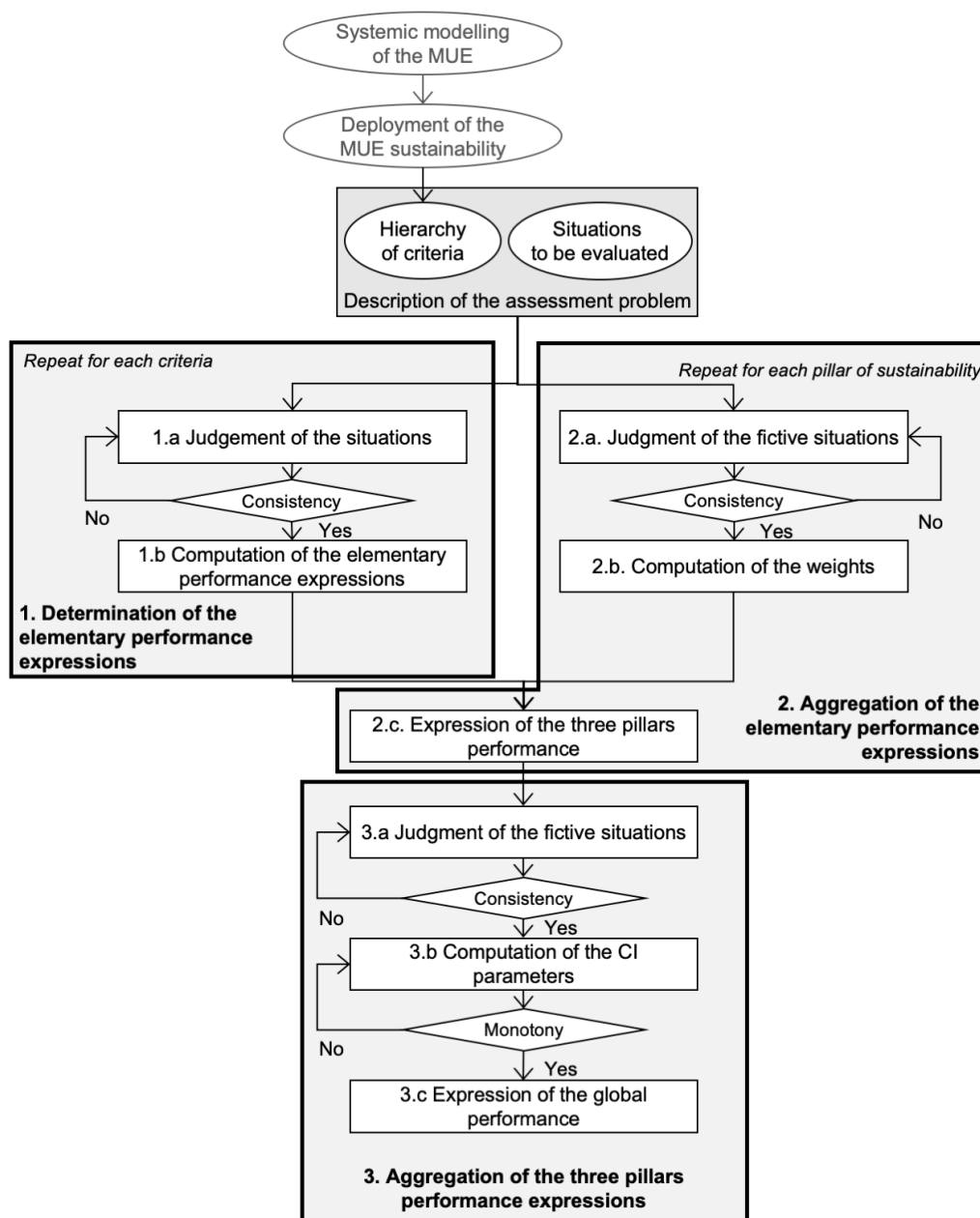


Figure 4.4 – Complete procedure for the overall sustainability assessment of the MUE

4.5 Case Study

4.5.1 Daniel Gaudreau Industrial Ecopark

The Daniel Gaudreau Industrial Ecopark (DGIE) is an MUE located in Victoriaville, a town in central Quebec in Canada. Victoriaville is a medium-sized town with 46,000 inhabitants and an area of 86 km². The DGIE was inaugurated in 2013, following the identification of wetlands in one of the town's industrial parks. Since wetlands are protected by Quebec law, this discovery hindered the development of the industrial park. However, Victoriaville decided to transform this constraint into an opportunity to develop an industrial park that integrates and promotes the unique ecosystem of wetlands. The DGIE was planned and built in a sustainable way and only welcomes companies that adopt sustainable business practices. These companies are required to participate in a local label certification process called "Démarche d² (*i.e.*, "Sustainable Development Approach"). The

DGIE is a small industrial park with 22 lots for sale, representing an area of 111,400 m² and 93,000 m² of wetlands. The DGIE manager is the Corporation of Economic Development of Victoriaville and its Region (CEDVR), which acts on behalf of the municipal council.

In 2016, the CEDVR published an action plan whose goal was to make the DGIE an example of an innovative and sustainable industrial park in Quebec. This action plan consisted of eight global actions, subdivided into a total of 31 actions, organized over a 4-year schedule. In the second half of 2019, the DGIE took part in a study on the definition of an MUE action plan and its control. It should be noted that the deployment of MUE sustainability resulted from this study. At the beginning of 2020, knowing that the action plan was almost completed and as a logical continuation of the 2019 study, the CEDVR requested more global information on DGIE sustainability. This information will aid in defining the subsequent action plan. It will also be used to communicate with the Victoriaville municipal council by displaying the results achieved via the execution of the first action plan.

The sustainability assessment model was applied to express the sustainability of the DGIE. The model was used to assess DGIE sustainability at three different points in time, corresponding to three different rates of execution of the action plan. This allowed us to assess the improvements in DGIE sustainability that were achieved during the entire execution of its action plan. The sustainability assessment was conducted with three members of the CEDVR in charge of DGIE development : Victoriaville's industrial commissioner, an advisor on sustainable development, and a sustainable development officer. We note that these three members have different roles but equivalent importance in DGIE development as they are all tactical managers.

4.5.2 Description of the DGIE assessment problem

As explained in Section 4.4.3, the description of the DGIE assessment problem requires the definition of respective criteria and situations to be considered :

- *Criteria.* The criteria used to express the sustainability of the situations are the criteria described in Figure 4.1.
- *Situations.* To represent the entirety of the DGIE development during the past 4 years, three situations were assessed, as listed in Table 4.2. These situations correspond to the results achieved at different execution rates of the action plan, which are the ratio of achieved actions against the total of actions. As explained earlier, these three situations are also compared with a good situation and a neutral situation. The neutral situation corresponds to the situation before the beginning of the action plan and, therefore, to an execution rate of 0%. The good situation cannot be expressed in terms of execution rates since it corresponds to an ideal that goes beyond the action plan.

Tableau 4.2 – Characteristics of the considered situations

Situation	Execution rate (Achieved actions)	Milestone
Neutral	0% (None)	January 2017
S ₁	38% (Actions A1, A2 and A4)	January 2018
S ₂	63% (Actions A1, A2, A3, A4 and A5)	January 2020
S ₃	100% (Actions A1, A2, A3, A4, A5, A6, A7 and A8)	January 2021
Good	N/a	N/a

4.5.3 Determination of DGIE elementary expressions

This step was carried out with Victoriaville's industrial commissioner and the advisor on sustainable development. For each criterion, the two members of the CEDVR were asked about their preferences and the intensities of the preferences, with respect to the different situations listed in Table 4.2. As explained in Section 4.4.3, the elementary expressions given in Table 4.3 result from the resolution of the inequation systems based on the preferences and intensities of preferences that were collected.

Tableau 4.3 – DGIE elementary performance expression

Situation	p_{EnBui}	p_{EnInf}	p_{EnTrs}	p_{EnNat}	p_{EnSyn}	p_{EcLan}	p_{EcCol}	p_{ScArc}	p_{ScAcs}	p_{ScSrv}	p_{ScJob}
S_1	0	0	0	0	0.17	0.35	0.25	0	0.11	0.15	0.08
S_2	0.43	0	0.05	0	0.25	0.47	0.38	0.50	0.22	0.45	0.21
S_3	0.57	0	0.33	0.67	0.33	0.65	0.38	0.50	0.44	0.55	0.62

4.5.4 Aggregation of DGIE elementary expressions : Three-pillar performance expressions

As mentioned before, the three-pillar performance expressions are provided by three aggregations with the WAM operator, whose weights have to be determined through a comparison of particular situations. These situations are listed in Table 4.4.

Tableau 4.4 – DGIE particular situations

Environmental pillar	Economic pillar	Social pillar
(1,0,0,0,0)	(1,0)	(1,0,0,0)
(0,1,0,0,0)	(0,1)	(0,1,0,0)
(0,0,1,0,0)		(0,0,1,0)
(0,0,0,1,0)		(0,0,0,1)
(0,0,0,0,1)		

Like the previous step, this one was carried out with Victoriaville's industrial commissioner and the advisor on sustainable development. The two members expressed the following preferences :

- Environmental pillar : $p_{Ag}^{(0,0,0,1,0)} < p_{Ag}^{(1,0,0,0,0)} < p_{Ag}^{(0,0,0,0,1)} < p_{Ag}^{(0,1,0,0,0)} = p_{Ag}^{(0,0,0,1,0)}$.
- Economic pillar : $p_{Ag}^{(1,0)} < p_{Ag}^{(0,1)}$.
- Social pillar : $p_{Ag}^{(0,0,0,1)} < p_{Ag}^{(0,0,1,0)} < p_{Ag}^{(1,0,0,0)} < p_{Ag}^{(0,1,0,0)}$.

The resulting weights are presented in Figure 4.5. The two members felt that the resulting weights were an accurate depiction of their expertise, which validates this step. With both the elementary expressions and the parameters of the WAM being defined, the three-pillar performance expressions are computed (see Table 4.5).

4.5.5 Aggregation of DGIE three-pillar performance expressions : Overall sustainability expression

This step was carried out with the CEDVR sustainable development officer. To determine the six parameters of the CI (three Shapley parameters $v_1 = v_{Emv}$; $v_2 = v_{Eco}$; $v_3 = v_{Soc}$ and three

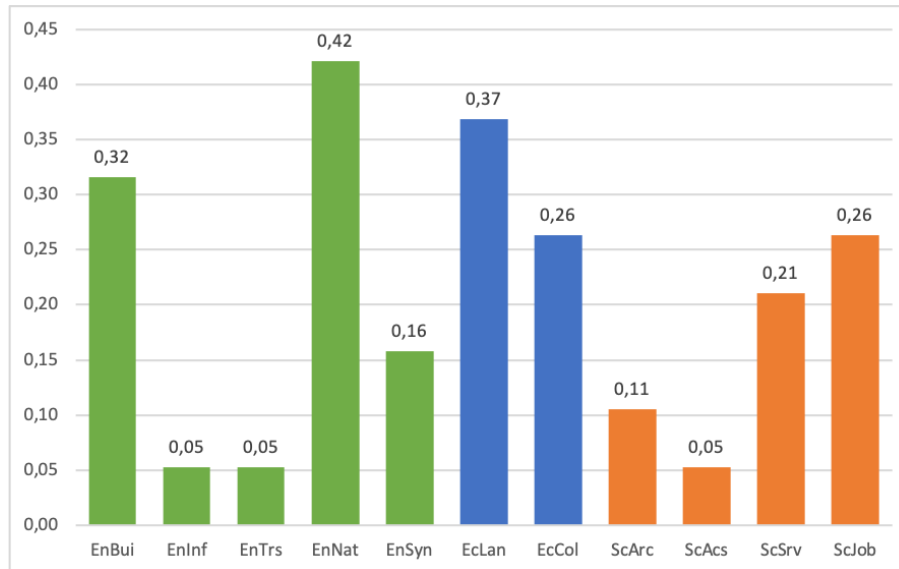


Figure 4.5 – WAM weights for DGIE

Tableau 4.5 – DGIE three pillars performance expressions

Situation	p_{Env}	p_{Eco}	p_{Soc}
S_1	0.19	0.06	0.08
S_2	0.27	0.21	0.21
S_3	0.34	0.35	0.37

interaction coefficients I_{12}, I_{13}, I_{23}), the sustainable development officer supplied information about six particular situations. These six situations are known through the three-pillar expression vectors ($p_{Env}, p_{Eco}, p_{Soc}$). The associated vectors are : $(1,0,0), (0,1,0), (0,0,1), (0,1,1), (1,0,1)$ and $(1,1,0)$.

The preferences and intensities of the preferences according to the sustainable development officer are :

- Preferences : $p_{Ag}^{(0,0,0)} < p_{Ag}^{(0,0,1)} < p_{Ag}^{(1,0,0)} < p_{Ag}^{(1,0,1)} < p_{Ag}^{(0,1,0)} < p_{Ag}^{(0,1,1)} < p_{Ag}^{(1,1,0)}$.
- • Intensity of preferences (the exponent formalizes the intensity of the preference) :
 - $p_{Ag}^{(0,0,0)} <^2 p_{Ag}^{(0,0,1)} <^1 p_{Ag}^{(1,0,0)} < p_{Ag}^{(1,0,1)} <^1 p_{Ag}^{(0,1,0)} < p_{Ag}^{(0,1,1)} <^5 p_{Ag}^{(1,1,0)}$;
 - $p_{Ag}^{(1,0,0)} <^2 p_{Ag}^{(0,1,0)}$;
 - $p_{Ag}^{(1,0,1)} <^6 p_{Ag}^{(0,1,1)}$.

The associated matrix of the complete system is given in the 4.6. The results of the parameter determination are synthesized in Figure 4.6. Let us note that the interaction parameters I_{12} and I_{23} are both positive. This means that the satisfaction of economic criteria cannot be compensated by the satisfaction of environmental or social criteria. On the other hand, the interaction parameter I_{13} is negative, which means that the CEDVR considers that simultaneous satisfaction of environmental and social criteria is not required. This result was expected by the three members of the CEDVR since they are aware that their strategy is currently heavily focused on attracting new companies to the DGIE. Aggregated performance expressions for the particular situations considered were presented to the manager (see Table 4.6). The member of the CEDVR was satisfied with these expressions, which validates the determination of the CI parameters.

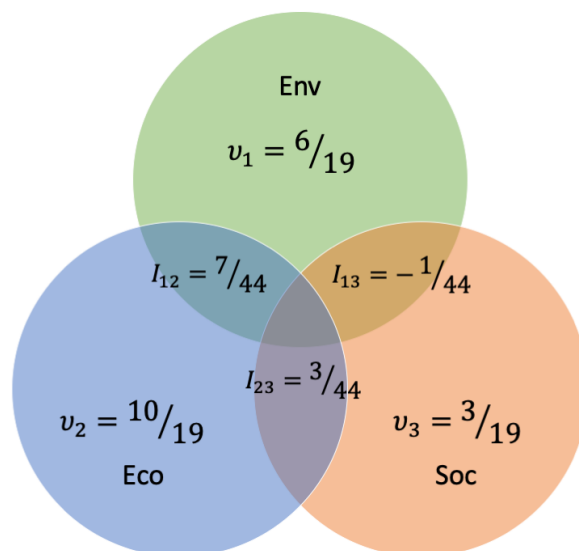


Figure 4.6 – CI parameters for DGIE

Tableau 4.6 – DGIE aggregated performance expression of the fictive situations

	$PEnv$	$PEco$	$PSoc$	PAg
$p_{Ag}^{(0,0,0)}$	0	0	0	0
$p_{Ag}^{(1,0,0)}$	1	0	0	0,11
$p_{Ag}^{(0,1,0)}$	0	1	0	0,26
$p_{Ag}^{(0,0,1)}$	0	0	1	0,16
$p_{Ag}^{(1,1,0)}$	1	1	0	0,53
$p_{Ag}^{(1,0,1)}$	1	0	1	0,21
$p_{Ag}^{(0,1,1)}$	0	1	1	0,79
$p_{Ag}^{(1,1,1)}$	1	1	1	1

With the three-pillar performance expressions and the parameters of the CI being defined, the overall sustainability expressions are computed. The DGIE three pillars and the overall sustainable performance expressions are summarized in Table 4.7.

The overall sustainability expression reached in the third situation is 54%. This means that the CDEVr considered that at the end of their action plan, the DGIE will have reached half of what they consider to be the ideal performance. As we can see, for all situations, the interaction is detrimental to the overall sustainability expression. We can see that the interactions have an influence on the overall sustainability expression of S_2 and S_3 of approximately 10% of their respective performance. This influence is even greater for S_1 (50%). Therefore, the influence of the interaction is non-negligible.

Tableau 4.7 – DGIE three pillars and overall sustainable performance expressions

Situation	$p_{Sustainability}$	Part of interaction
S_1	0.03	0.04
S_2	0.18	0.02
S_3	0.53	0.03

4.5.6 Discussion and outlook

As requested by the CEDVR, the overall sustainability of the DGIE was assessed throughout the execution of their action plan. This was done by applying our sustainability assessment model. Let us reflect on this application and the prospects of this study from a general standpoint and from the particular standpoint of the CI used.

From a general standpoint, the three members of the CEDVR believed that the model is a useful tool with which to assess the impact of their action plan on DGIE. They were satisfied with the simplicity and clarity of the proposed procedure, which facilitate its adoption. In the future, they plan to use the results from this application of the model as an input for the update and redesign of the DGIE action plan. Moreover, they plan to use the model as a way of communicating with Victoriaville's local council, by displaying the results and performance improvements achieved.

An unused potential of the model is that it can be used by several managers. Indeed, let us recall that the aggregation model consists of four aggregation sub-models : three aggregation sub-models, one for each of the three pillars, and one global aggregation sub-model. Thus, if the MUE is managed by a team, each sub-model can be delegated to the manager that has the most expertise or involvement in the pillar of sustainability under assessment. Moreover, the final aggregation could be delegated to a strategy manager while the three lower aggregation sub-models could be delegated to more tactical or operational managers. In other words, the aggregation model allows for a systemic assessment of the MUE. Future application models could take advantage of this potential of the model.

From a more mathematical standpoint, this research demonstrates a new use of an MCDA method for integrated sustainability assessment using a double aggregation mechanism with the CI. In particular, it reinforces the value of using the CI for sustainability assessment since it can express the different paradigms by taking synergy and redundancy into account.

An unexpected advantage of the model for the DGIE managers is that it helped them reflect on their current vision of sustainability and therefore their sustainability paradigm. Figure 4.7 illustrates estimates of potential CI parameters and performance expressions for each of the "traditional" sustainability paradigms described in Section 4.3.2. These estimates are based on the definition of the three paradigms. To be more precise, "weak" sustainability interaction parameters between the three pillars are null, because it is based on the assumption that manmade and natural capital can be substituted. Regarding "balanced" sustainability, the Shapley parameters and performance expressions are equal because it is based on the assumption that the three pillars have the same relative importance. The balanced sustainability interaction parameters are positive because this paradigm favors the simultaneous satisfaction of objectives in the three pillars. The "strong" sustainability is based on the assumption that manmade and natural capital cannot be substituted and that natural capital should not be depleted; therefore, it favors the environmental pillar, which leads to a higher Shapley parameter and performance expression.

As shown in Figure 4.6, the DGIE paradigm moderately favors the simultaneous satisfaction of economic criteria with environmental or social criteria. Therefore, we can infer that the DGIE

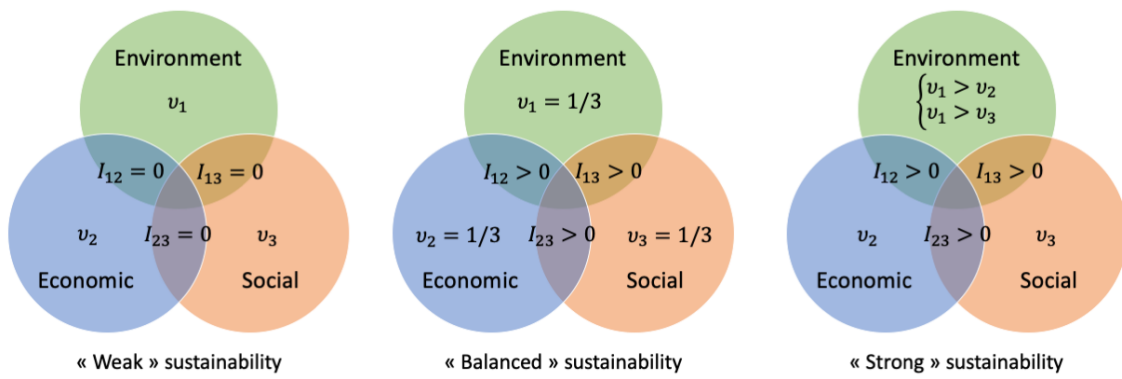


Figure 4.7 – Estimates of potential CI parameters for the three traditional paradigms of sustainability

sustainability paradigm is a combination between the weak and balanced paradigms, which can be explained by the fact that the DGIE is still a developing MUE. Indeed, the DGIE managers' first goal is to populate their MUE with resident companies, which justifies their emphasis on economic criteria. In the future, the DGIE manager expects stricter environmental regulations, an aggravation of Quebec's labor shortage, and the DGIE to reach a more satisfying occupancy rate. Thus, when the DGIE occupancy rate reaches 75%, the CEDVR plan to change their strategy in order to pursue a more balanced or "stronger" sustainability paradigm. Consequently, our assessment model that used the CI will be able to reflect this new vision.

With regard to the double aggregation, we hypothesized that the interactions between the elementary objectives are negligible and therefore we used the WAM as our first aggregation operator. One could argue that the CI should be used to directly aggregate the elementary expressions in an overall sustainability expression. However, an extensive amount of information is required to compute the parameters of the CI. Indeed, the manager is asked to make as many pairwise comparisons between particular situations as there are CI parameters. There are n Shapley parameters and $\binom{n}{2}$ interaction parameters, yielding a total of $\frac{n(n+1)}{2}$ parameters. For the MUE, 11 criteria have been identified (see Figure 4.1), which means that 66 two-by-two comparisons of vectors with 11 performance expressions are required to compute the CI parameters, which far exceeds the capacity of the manager. The development of an aggregation model exclusively using the CI could be the subject of future research.

4.6 Conclusion

The benefits of sustainability assessment are today acknowledged as a matter of fact, but the question of a sound processing of the set of environmental, economic, and social measurements is still open. In this sense, the present study deals with the sustainability assessment of a particular type of industrial park, that is, the MUE. The model proposed in this article is based on the broad framework of integrated sustainability assessment and is complementary to reflections on indicators, which deal with quantitative assessment of the respective environmental, economic, and social pillars. The postulates underlying the proposed model are that the assessment of sustainability is achieved via an expression of each pillar, on the one hand, and a global expression, on the other hand. Since the three pillars are interconnected in their associated objectives and actions, this ove-

Overall assessment will represent more than a synthetic value, as it will also convey all the interactions involved.

MUE sustainability cannot be assessed by applying an aggregation formula without variants. Hence, according to the complexity of the MUE and the multi-criteria characteristic of sustainability, the main idea of this work is to study MUE sustainability assessment in the context of multi-criteria decision analysis (MCDA) through a (deployment, aggregation) mechanism. Systemic deployment of MUE sustainability has thus been considered along with two aggregation operators from the compromise family. The WAM was chosen to handle the varying relative importance of criteria and the Choquet integral (CI) to handle the varying relative importance and interactions between the three pillars. The aggregation model was used to assess the sustainability of the Canadian MUE Daniel Gaudreau Industrial Ecopark (DGIE). The economic performance expression supported the DGIE in the definition and management of actions to improve the attractiveness of the ecopark, and the environmental performance and overall sustainability expressions have offered the DGIE a tool for communicating with local authorities. An unexpected finding of this case study is that using the CI encouraged the DGIE managers to reflect on their sustainability paradigm. They realized that their current vision of sustainability is not balanced, as it is heavily focused on economic performance and attractiveness; however, when DGIE occupancy reaches a satisfying rate, they plan to improve this balance.

Regarding the perspectives, additional applications are required to improve the model. The application of the model to the DGIE should be repeated when its managers change their vision of sustainability. Moreover, the model should also be applied to other MUEs. Indeed, we can expect that it will benefit from the results of its application on a panel of MUEs with various strategies related to their size, maturity, geographic location, or resident companies. Other prospective MUEs are the Savoie Technolac and Savoie Hexapole, two French MUEs in the Savoie region. Since these two MUEs share the same manager, along with several industrial parks in the Savoie region, the model could be used for comparison between several MUEs and benchmark purposes. Finally, future work could also reconsider the choice of aggregation operators and the MCDA method selected as the model's framework.

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Appendix A : Matrix for determination of the Choquet integral parameters

$$\begin{bmatrix} 1 & 0 & -1 & 0.5 & 0 & -0.5 & -5 \\ -1 & 1 & 0 & 0 & -0.5 & 0.5 & -6 \\ 1 & -1 & 1 & 0 & 0 & 0 & 1 \\ -1 & 1 & 0 & 0 & 0.5 & -0.5 & -2 \\ 1 & 0 & -1 & -0.5 & 0 & 0.5 & -1 \\ 0 & 0 & 1 & 0 & -0.5 & -0.5 & -2 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} v_{Env} \\ v_{Eco} \\ v_{Soc} \\ I_{EnvEco} \\ I_{EnvSoc} \\ I_{EcoSoc} \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Conclusion générale

Le travail de recherche présenté dans cette thèse s'est globalement intéressé à la question de l'expansion de l'activité humaine et à son impact sur la pérennité des systèmes. Durabilité, démarches de développement durable et zones d'activité au sens le plus large ont été les éléments structurants de ces travaux dont la problématique peut être spécifiée, sans perte de généralité, en la question suivante : *Comment accompagner un parc industriel à s'inscrire dans une démarche de développement durable ?* La notion de parc industriel a été retenue pour sa représentativité de la pratique et ses promesses d'organisation, mais aussi pour une sorte de similarité que nous avons pu ressentir avec l'entreprise quand celle-ci cherche à s'inscrire dans une démarche d'amélioration de sa performance. Démarche d'amélioration et performance deviennent de ce fait à leur tour des mots-clés permettant d'amener quelques éléments de réponse à la question posée. Plus précisément, l'approche présentée est systémique et globale appréhendant le développement durable d'un point de vue holistique, comme la conjugaison équilibrée de ses trois piliers (environnemental, économique, social).

Cette dernière partie du manuscrit est ainsi consacrée à une synthèse succincte des principales contributions de la thèse que nous présentons dans un premier temps, ainsi qu'aux perspectives que nous y voyons, décrites en second lieu.

Contributions de la thèse

De notre point de vue, trois contributions caractérisent ces travaux, relevant de l'ordre de la définition/modélisation de la notion de parc industriel durable, de la décision associée à cette durabilité et enfin de l'expression de la performance correspondante. Ces trois facettes viennent fournir progressivement des éléments de réponse à la question posée et constituent le cadre méthodologique que nous proposons dans cette thèse.

La première contribution de ces travaux a ainsi concerné la définition de la notion de parc industriel durable. En effet, une analyse de la littérature ainsi qu'une observation de la pratique, menées dans les premiers chapitres (Chapitres 1 et 2), nous ont amenés à introduire le concept d'écoparc d'activités (Mixed-Use Ecopark). Une modélisation systémique s'en est suivie permettant de mieux définir les contours de cette notion en vue de son pilotage vers le développement durable.

Plus précisément, la modélisation systémique nous a permis de caractériser et de décomposer les objectifs d'un parc industriel durable et de réfléchir à leur atteinte. Dans ce sens et toujours dans l'idée d'une analogie avec l'entreprise, nous avons associé l'atteinte d'un objectif à la définition d'un plan d'action à mener pour ce faire. Ayant vu cette définition comme une problématique de choix et de décision successives d'actions à mener, un modèle d'aide à la décision pour la définition d'un plan d'action a fait l'objet du Chapitre 3 de ce manuscrit. Inscrivant les objectifs et critères d'un écoparc d'activités dans une finalité de durabilité, la décision en est devenue multicritère et la méthode MACBETH (Measuring Attractiveness by a Categorical-Based Evaluation Technique) a été retenue en guise de procédure d'analyse et d'aide à la définition des plans d'action associés à ces différents objectifs.

Enfin, sur la base de sa modélisation systémique et de notre méthode d'aide à la décision pour l'éta-

blissement d'un plan d'action, nous avons proposé un modèle d'expression de la durabilité pour l'écoparc d'activités. Pour cela, nous avons considéré la durabilité comme un état que l'on peut atteindre progressivement et à des degrés différents. À la durabilité correspond ainsi une expression de performance, qui peut être améliorée de manière continue, conformément aux préceptes de la Roue de Deming et de ses quatre phases respectives (*Plan, Do, Check, Act*). Notre modèle d'expression de la durabilité se fonde sur un mécanisme de décomposition/agrégation tel que pratiqué dans les Systèmes d'Indicateurs de Performance (Performance Measurement Systems) développés pour le pilotage des systèmes industriels. L'idée est d'exprimer d'abord les expressions de performance élémentaires suivant la décomposition systémique de la finalité de l'écoparc d'activités considéré. L'agrégation se fait alors en deux étapes. Les expressions de performance élémentaires obtenues sont agrégées en trois expressions de la performance correspondant respectivement à chacun des trois piliers du développement durable. De telles expressions proposent en effet une vision synthétique des niveaux atteints, pilier par pilier, indépendamment les uns des autres. Elles permettent de ce fait au gestionnaire d'avoir une appréciation de son avancement et des améliorations à apporter selon chacun de ces derniers. Enfin, ces trois expressions de performance sont agrégées afin d'exprimer la durabilité de l'écoparc d'activités avec, cette fois, une intention de prise en compte des synergies entre elles, conformément à la définition de la notion de durabilité. Cette double agrégation est réalisée à l'aide de deux opérateurs d'agrégation : la moyenne pondérée pour la gestion des poids des critères, et l'intégrale de Choquet pour la gestion des poids et des synergies entre les critères. Outre d'effectuer l'opération d'agrégation, l'intégrale de Choquet a pu offrir la possibilité de réfléchir à la vision adoptée pour la durabilité de l'écoparc d'activités considéré, et ce, par le jeu de valeurs retenues par le gestionnaire pour ses paramètres (Indices de Shapley et Coefficients d'Interaction). Chaque gestionnaire peut ainsi mener son analyse sur sa stratégie de durabilité, selon qu'elle soit plutôt forte (pilier environnemental plus important sans substitution avec les autres piliers), faible (substitution totale entre les piliers) ou équilibrée (synergie et équilibre des piliers).

En résumé, ce travail a consisté à développer un cadre méthodologique pour l'accompagnement d'un gestionnaire de parc industriel dans une démarche de développement durable et ce, quel que soit sa maturité sur le sujet.

Nos diverses avancées ont été continûment validées auprès de nos cas d'étude. La diversité des parcs partenaires et de leur engagement dans une démarche de développement durable a permis des applications différentes des approches proposées. Dans un premier temps, la définition de l'écoparc d'activités et sa modélisation systémique ont été unanimement approuvées. En particulier, appliquée à Savoie Technolac (voir Annexe A), la modélisation systémique de l'écoparc d'activités a permis d'appréhender la complexité du parc et d'en faire ressortir les interactions entre les différentes entités. Elle a ensuite servi au déploiement de la durabilité, base de nos modèles d'aide à la décision et d'expression de la performance. Plus spécifiquement, le modèle d'aide à la décision a été appliqué à l'écoparc industriel Daniel Gaudreau à Victoriaville. Il a ainsi été observé que le plan d'action de cet écoparc permettait d'améliorer sa durabilité, en cohérence avec la vision de son gestionnaire, exprimée par les poids des critères considérés. L'écoparc Daniel Gaudreau a aussi appliqué le modèle d'expression de la performance dans le but d'affermir l'évaluation de sa durabilité. Cette application a permis de confirmer que la vision de la durabilité du gestionnaire de cet écoparc était relativement déséquilibrée en faveur du pilier économique. Ce déséquilibre s'explique par le fait que l'écoparc Daniel Gaudreau est un parc relativement récent et donc dans une phase de développement économique. Le parc Savoie Hexapole s'est quant à lui associé à nos travaux à des fins d'observation et de réflexion sur la manière d'améliorer sa performance dans un premier temps, car il était déjà particulièrement avancé dans sa démarche de développement durable. Enfin, notre proposition d'écoparc d'activités et notre vision de la durabilité des parcs industriels a suscité l'intérêt du gestionnaire des parcs du Grand Anecy. Ce dernier souhaite en effet diminuer l'impact environnemental de ses parcs tout en attirant de nouvelles en-

treprises, ce qui résulte en un paradigme de durabilité plus ou moins faible. Ainsi, au cours de ce travail de thèse, des réflexions ont été engagées dans le sens de ce déploiement de la durabilité. Ces réflexions ont permis à la fois de valider les critères retenus dans notre modèle et de faire avancer le modèle de durabilité de certains parcs du Grand Annecy vers une vision plus équilibrée.

Perspectives

L'accompagnement d'un parc industriel dans une démarche de développement durable peut susciter bon nombre de questions et interroger chercheurs et praticiens de disciplines diverses. En effet, si notre travail a permis d'aboutir à des approches d'expression de la performance et d'aide à la décision dans ce sens, bon nombre de perspectives s'offrent à nous dans ce contexte. De telles perspectives concerneront aussi bien les modèles proposés et leur utilisation que l'exploration de nouvelles pistes éventuelles en lien avec le développement durable des entreprises, parcs industriels et autres territoires.

Dans ce sens, nous reviendrons dans un premier temps sur les applications à venir du cadre proposé, en particulier aux partenaires de cette étude, puis nous considérerons les enrichissements potentiels de notre cadre. Nous terminerons enfin par l'évocation de quelques nouvelles pistes d'investigation.

Application du cadre méthodologique

L'application complète de notre cadre méthodologique à l'ensemble de nos cas d'étude n'aura pas pu se faire dans le temps imparti pour ce travail. Bon nombre d'arguments peuvent expliquer cela, en l'occurrence, la complexité plus ou moins grande des parcs considérés, la temporalité longue des plans d'action menés sur un système comme le parc industriel, le court terme relevant de l'année en général. Ce sera du reste une différence majeure entre cette notion de parc industriel et la notion d'entreprise. Un autre élément relevé aussi bien dans la littérature que dans la pratique réside dans le fait que les objectifs des différents parcs sont loin d'être identiques même s'ils s'inscrivent tous dans une démarche de développement durable. Par conséquent, si les gestionnaires des différents parcs considérés ont été sensibilisés à nos idées et les ont partiellement appliquées, quelques travaux restent encore à poursuivre. Voyons cela pour chacun des parcs partenaires.

Pour Savoie Technolac, le modèle d'expression de la performance permettrait d'étudier l'équilibre entre les trois piliers du développement durable. Le modèle d'aide à la décision pourra quant à lui être employé dans le cadre du projet d'extension du parc mis en oeuvre depuis 2015 qui a pour but d'augmenter la superficie de 21 ha, soit 27% de sa surface actuelle. Le modèle d'aide à la décision pourrait être utilisé par le gestionnaire pour des choix dans le cadre de l'aménagement ou de la construction de l'extension.

Pour Savoie Hexapole, le modèle d'expression de la performance pourrait être mis en place dans la continuité de leur processus de certification ISO 14001 obtenue entre 2007 et 2017. Cette application pourrait permettre un enrichissement des tableaux de bord d'ores et déjà mis en place par une prise en compte de l'ensemble des piliers du développement durable. L'application de notre cadre pourrait permettre au gestionnaire de s'inscrire dans une démarche d'amélioration de la durabilité, de manière plus autonome que celle induite par la certification ISO 14001.

Quant aux parcs du Grand Annecy, le focus pourrait être mis dans un premier temps sur le déploiement de la durabilité sur les différents parcs, en cohérence avec les réflexions commencées. Dans un second temps, une aide à la définition des plans d'action correspondants est envisagée.

Par ailleurs, l'application des modèles proposés est à étendre à d'autres parcs industriels, en particulier ceux en collaboration avec les partenaires de cette recherche. Ces futures applications permettront d'améliorer le cadre méthodologique, et plus particulièrement de conclure sur ses impacts réels sur l'accompagnement des parcs considérés dans leur démarche de développement durable. En outre, une analyse des résultats obtenus, des synergies entre objectifs et approches utilisées pour les atteindre sera à mener afin d'aboutir à une typologie des parcs selon des paramètres tels que leur proximité à la durabilité, leurs spécificités, leur taille, etc. Une telle typologie permettrait alors de préciser les modes d'utilisation du cadre proposé.

Enrichissement du cadre méthodologique

Le cadre méthodologique proposé dans ces travaux a cherché à répondre à la question de l'accompagnement du gestionnaire d'un parc industriel dans la transformation de ce dernier en éco-parc d'activités, soit en parc industriel durable. La démarche proposée permet la modélisation du parc et la déclaration d'objectifs, l'aide à la définition des plans d'action à mener pour les atteindre et enfin l'expression de performance associée. Si cette démarche est aujourd'hui proposée et validée, il n'en reste pas moins que bon nombre d'aspects restent à apporter, en guise d'approfondissement ou d'enrichissement des pistes avancées. Nous évoquons dans ce qui suit l'essentiel de ce qui peut être mené pour ce faire.

Implémentation informatique du cadre méthodologique

Pour faciliter la diffusion ainsi que l'utilisation des différents modèles fédérés dans notre cadre auprès des gestionnaires de parcs industriels, une intégration informatique est à envisager. En effet, un seul et unique outil permettra un traitement cohérent de la chaîne d'information entre les trois modèles.

Plus précisément, trois outils numériques différents sont actuellement utilisés, conformément aux formalismes respectivement utilisés dans les trois modèles, à savoir :

- UML pour la modélisation systémique (voir Annexe B) ;
- M-MACBETH pour l'utilisation de MACBETH ;
- Excel pour l'agrégation avec l'intégrale de Choquet.

Intuitivement, la première piste pour le développement d'un tel outil sera l'extension de l'utilisation de M-MACBETH à l'intégrale de Choquet et à la modélisation systémique. Une autre piste sera l'identification et l'adaptation de solutions logicielles déjà existantes dans des domaines similaires. Le développement de l'outil informatique nécessitera un travail sur la facilité de prise en main de son interface. Aussi bien les enrichissements apportés au cadre au fur et à mesure de son exploitation que les améliorations sur cet outil, à des fins de management visuel par exemple, seront alors à intégrer à cette première version initiale.

Bonne pratiques et indicateurs fétiches

Un travail entrepris dans le cadre de cette thèse a été l'inventaire des bonnes pratiques, soient des comportements et actions qui font consensus, pour la gestion d'un parc industriel durable (voir Annexe B). Cet inventaire a été effectué à partir de la littérature académique, de la littérature grise et des bonnes pratiques telles qu'elles ont été menées par nos différents cas d'étude. Pour chacune des bonnes pratiques recensées, les entités (*i.e.* entreprises, bâtiments, système de transport, espaces verts, réseaux, collaboration inter-entreprise ou symbiose éco-industrielle du parc) positivement impactées par son application ont été identifiées, et ce afin d'aider le gestionnaire dans ses prises de décision dans des situations comparables. Il s'agit donc maintenant dans un premier temps de poursuivre ce travail d'inventaire. En second lieu, viendra son intégration à l'outil évoqué

précédemment. Accompagnée d'une connaissance typologique des comportements des parcs, une telle base de données ainsi constituée permettra un étalonnage plus aisé aux gestionnaires, selon leur état d'avancement et les actions menées dans les parcs considérés comme similaires.

Dans la même logique, un inventaire des indicateurs de performance que l'on pourrait qualifier de "fétiches" (au sens de progrès remarquable effectué) pourra être entrepris et également intégré à nos travaux. De même, cet inventaire pourra notamment être fait à partir de la littérature académique, de la littérature grise et d'une observation des pratiques sur des systèmes similaires à l'écoparc d'activités, soient le parc éco-industriel ou l'écoquartier.

Benchmark et comparaison des écoparcs d'activités

Allant plus loin que le simple inventaire des bonnes pratiques, un outil de comparaison des écoparcs d'activités pourra être intégré au cadre méthodologique pour les gestionnaires souhaitant être à même de situer leurs parcs par rapport aux autres parcs engagés dans une démarche de développement durable équivalente. Cet outil de comparaison se rapprochera plus d'une logique de certification par la prescription d'un idéal commun ou d'un comportement type. Plus précisément, dans sa forme actuelle, notre proposition ne requiert pas l'adhésion du gestionnaire à tous les principes du développement durable et toutes les caractéristiques de la définition d'un écoparc d'activités, l'approche étant purement descriptive et relevant davantage du domaine des recommandations. Une nouvelle intention pourrait en effet être donnée à un tel cadre et qui consisterait à rassembler l'ensemble des conditions et étapes nécessaires à un parc industriel, quel qu'il soit, pour devenir durable. Il s'agira alors, à l'issue de la comparaison des parcs et de l'analyse des pratiques et indicateurs de performance utilisés, de réfléchir à un référentiel commun, qui définirait les critères de performance et leur niveau d'atteinte permettant à un parc industriel de se prévaloir de la qualité écoparc d'activités. Cette référence ou idéal à atteindre, évoluerait éventuellement au fur et à mesure que de nouveaux parcs industriels adhèrent à la démarche ou que de nouvelles règles soient proposées. Naturellement, le développement d'un tel outil nécessitera un travail sur une nombre extensif de cas ainsi qu'une observation régulière du contexte d'évolution de ces derniers.

Expression de la performance "temporelle"

Des travaux menés par notre équipe (en l'occurrence la thèse de H. Hamadmad) ont abouti à l'introduction de deux nouvelles expressions de la performance. Partant de la définition d'un objectif comme étant une valeur à atteindre à l'issue de l'horizon temporel associé à l'exécution du plan d'action correspondant, ce dernier peut également se définir par une trajectoire, marquée par un certain nombre de jalons. A chaque jalon correspond un objectif intermédiaire. Le dernier jalon identifie la fin de l'horizon considéré. Ces travaux stipulent l'idée d'une définition de l'expression de la performance sur la base d'un triplet (expression instantanée, expression tendancielle, expression prédictive). Conventionnelle, l'expression de la performance instantanée est celle atteinte au vu de l'objectif fixé, exprimée *a posteriori*, à l'issue de l'horizon temporel, soit au dernier jalon. L'expression de la performance tendancielle concerne, au jalon considéré, l'analyse de la manière dont l'objectif est atteint. Enfin, l'expression de la performance prédictive est définie à un jalon donné pour un jalon futur et renseigne de la manière dont l'objectif à ce jalon futur serait atteint au vu des résultats obtenus au jalon considéré. (Hamadmad, 2017).

Actuellement, le modèle d'expression de la durabilité d'un écoparc d'activités n'exprime que la performance instantanée. L'expression de la performance tendancielle et prédictive pourraient être ajoutées à nos modèles d'expression de la performance et d'aide à la décision. En effet, sur des horizons temporels aussi longs que ceux d'un parc industriel (1 an pour du court terme, plus de 5 ans pour du long terme), l'expression de la performance prédictive sera particulièrement appropriée car elle sera à même de simuler la trajectoire de la durabilité de l'écoparc d'activités. D'un autre

côté, l'expression de la performance tendancielle pourra être utilisée à des fins de comparaison du comportement des écoparcs d'activités.

Démarche de développement durable et roue de Deming

Rappelons brièvement pour commencer le principe de la roue de Deming. Celui-ci consiste en l'inscription de toute démarche d'amélioration de la performance dans un cercle structuré par les quatre phases successives suivantes : *Plan* pour planifier les objectifs et les plans d'action, *Do* pour mettre en oeuvre les plans d'action, *Check* pour exprimer la performance et vérifier l'atteinte des objectifs et enfin *Act* pour réagir aux résultats atteints et prendre les décisions corollaires. Le modèle d'aide à la décision présenté dans cette thèse accompagne le gestionnaire d'un parc industriel dans l'établissement de son plan d'action lors de la phase "*Plan*". Une idée serait d'intégrer notre modèle dans le processus d'amélioration continue de la roue de Deming, tel que présenté à la Section 3.5.3. Plus particulièrement, cette intégration consisterait à restructurer le processus de la méthode MACBETH pour qu'elle soit à même d'exprimer la performance *a priori* lors de l'établissement d'un plan d'action (phase *Plan*) et d'exprimer la performance *a posteriori* (phase *Check*) pour la révision du plan d'action (phase *Act*). Ainsi les expressions de la performance temporelle prendraient tout leur sens dans cette nouvelle structuration.

- L'expression de la performance instantanée et l'expression de la performance tendancielle seraient utilisées lors de la phase *Check* dans le but de vérifier l'atteinte de l'objectif ainsi que la manière dont celui-ci est atteint ;
- L'expression de performance prédictive serait utilisée lors de la phase *Plan* dans le but d'aider à la déclaration des objectifs. Elle pourrait être également utilisée dans la phase *Act* pour de l'aide au choix des plans d'action à adopter selon les évolutions prédites.

Retour sur la notion de gestionnaire

Pour rappel, dans ce travail nous avons postulé que l'écoparc d'activités était piloté par un unique gestionnaire, extérieur au système, qui définissait les règles pour ce dernier. La réalité est plus complexe. Premièrement, le gestionnaire d'un écoparc d'activités représente plus généralement une équipe constituée par des membres dont les points de vue sur le parc géré peuvent différer. De plus, le gestionnaire n'a qu'une compétence limitée à l'égard des entités et des relations entre ces dernières. Le gestionnaire applique des directives et doit rendre des comptes de ses actions à différents élus (communes, agglomérations, région, etc.).

Une première révision du modèle serait d'inscrire le problème d'aide à la décision dans un contexte de décision plurielle. Dans cette même idée d'ajustement de nos hypothèses à la réalité, un enrichissement conséquent du modèle serait d'intégrer l'ensemble des acteurs (entreprise résidentes, autorités locales, particuliers résidents à proximité de l'écoparc d'activités, associations citoyennes, etc.) dans le processus de décision. La théorie des jeux pourra servir de base de réflexion à cette perspective.

Enfin, une dernière piste pourrait consister à "bonifier" le rôle du gestionnaire en lui accordant un certain droit de regard sur le fonctionnement des entreprises de son écoparc d'activités.

Vers d'autres pistes de recherche

Ecoparcs d'activités et Chaînes logistiques

L'article de conférence présenté en Annexe C se penche sur le parallèle pouvant être fait entre les notions de parc éco-industriel et de chaîne logistique (ou d'approvisionnement). Pour rappel, un parc éco-industriel est un parc industriel siège d'une symbiose éco-industrielle qui repose sur un principe d'échange de ressources telles que l'énergie, l'eau, les déchets ou les produits. Une

chaîne logistique est un modèle d'organisation inter-entreprises qui peut être vu au travers d'une série de processus impliqués dans la production et la distribution d'un bien ou service. Il nous était donc apparu que les notions de chaîne logistique et de parc éco-industriel présentaient un certain nombre de similarités : ce sont toutes deux des groupements d'entreprises, souvent manufacturières, qui collaborent pour réaliser un objectif commun (production d'un bien pour la chaîne logistique et utilisation optimisée des ressources pour le parc éco-industriel), et qui prennent part à des échanges de ressources physiques ou d'information (biens produits pour une chaîne logistique et eau, énergie, déchets valorisables pour un parc éco-industriel). En conséquence l'idée de recourir à l'utilisation des outils de modélisation et de pilotage de la notion de chaîne logistique pour un parc éco-industriel a été mise en avant (voir Annexe C). Ainsi, le modèle SCOR (Supply Chain Operations Reference) a été utilisé pour cartographier les échanges au sein d'un parc éco-industriel. Il aura permis de distinguer différents niveaux d'abstraction et d'établir une première typologie des entités et de la nature des relations entre ces entités. Ce travail nécessiterait d'être poursuivi.

Dans cette idée, une piste d'amélioration de notre cadre méthodologique pourrait donc être apportée en continuant à nous inspirer des outils existants pour le pilotage de la chaîne logistique, et plus particulièrement, de ceux pour la chaîne logistique verte (*green supply chain*). Une chaîne logistique verte, est une chaîne logistique qui vise à réduire ses impacts environnementaux tout au long du cycle de vie du bien considéré. Ainsi la chaîne logistique verte et l'écoparc d'activités partagent un même objectif de réduction de leur impact environnemental, qui s'ajoute à la liste des points communs entre ces deux systèmes. Outre une analyse plus poussée de l'utilisation du modèle SCOR, une étude des approches proposées pour le pilotage des chaînes logistiques vertes serait à effectuer avant des tentatives d'application.

Ecoparc d'activités et Réseaux sociaux

Un réseau social peut être généralement défini au travers d'un ensemble organisé ou non d'acteurs (formalisés par des nœuds), ayant diverses relations entre eux (appelées liens), symétriques ou non (*e.g.* pouvoir, échanges de ressources, conseil). L'analyse de réseaux sociaux, méthode des sciences sociales issue de la théorie des graphes, est le moyen d'identifier des structures au sein de ses réseaux et de s'interroger sur leurs impacts (Forsé, 2008). Nous avons considéré l'écoparc d'activités comme un système et utilisé la modélisation systémique comme base de notre cadre méthodologique. Toutefois, l'écoparc d'activités pourrait être envisagé comme un réseau où les nœuds seraient des entreprises et les liens les relations inter-entreprises. Ainsi, de manière complémentaire ou alternative, l'analyse de réseaux sociaux pourrait enrichir ou devenir une nouvelle base des modèles d'expression et d'amélioration de la performance de l'écoparc d'activités.

En l'occurrence, l'analyse de réseaux sociaux a déjà été utilisée à l'échelle du parc éco-industriel de Gujiao pour en analyser la symbiose industrielle (Song et al., 2018). L'analyse de réseaux sociaux avait alors permis d'identifier les acteurs clés, la stabilité et la résilience de la symbiose (Domenech and Davies, 2009), soit sa capacité à absorber les perturbations tout en conservant sa structure fondamentale, son fonctionnement, sa capacité d'auto-organisation, sa capacité d'adaptation au stress et au changement Walker et al. (2004). Ainsi, l'analyse de réseaux sociaux permet par exemple d'anticiper le potentiel de participation des entreprises résidentes et donc les chances de succès d'une symbiose. Dans cette même idée, l'analyse de réseaux sociaux pourrait ainsi être utilisée par les gestionnaires de parcs industriels souhaitant animer le réseau d'entreprises résidentes d'une manière plus fine, tel que mentionné dans l'article de conférence présenté en Annexe A. A terme, l'analyse pourrait aider les gestionnaires à établir des relations entre les entreprises résidentes et à les orienter dans la création de relations potentiellement durables.

Prise en compte du fonctionnement des entreprises résidentes

Dans cette étude, nous avons adopté un point de vue systémique de la notion d'écoparc d'activités. Nous avons considéré les entreprises comme des sous-systèmes "boîte noire", dont le fonctionnement interne n'a en conséquent pas été pris en compte. Cette vision répondait au besoin des gestionnaires dont les missions, en tant que pilotes des parcs considérés, n'interféraient que très peu avec celles des entreprises constitutives de ces parcs. Dans le but d'une prise en compte plus complète de la notion de durabilité au sein d'un parc et en cohérence avec ce qui a été évoqué précédemment, une nouvelle piste de réflexion serait de considérer le fonctionnement des entreprises et d'y associer des objectifs relatifs à leur durabilité. Ces objectifs pourraient s'inspirer de la Responsabilité Sociale des Entreprises (RSE) ou de référentiels déjà existants comme les normes ISO14001 (relative au système de gestion environnemental), ISO9001 (relative à la qualité) ou ISO26000 (relative à la RSE). Un double point de vue pourrait de ce fait être adopté, celui externe au parc et celui interne à ce dernier. Conformément à ce qui a été évoqué précédemment concernant le gestionnaire, son identité et ses missions, cette vision ne pourra que mieux renforcer le bien-fondé des décisions adoptées.

Développement territorial viable

La recherche présentée dans cette thèse s'est restreinte au périmètre du parc industriel. Néanmoins, une nouvelle piste serait d'étendre les réflexions et le cadre développé à l'échelle d'un territoire plus conséquent comme plusieurs parcs industriels et entreprises isolées. En sociologie urbaine, le territoire est à la fois vu comme un système ouvert et un construit social, il est le résultat d'une proximité entre acteurs. Cette proximité n'est pas nécessairement géographique mais une proximité en termes de capital social cognitif, qui concerne le rapport des acteurs à leur territoire et les processus de confiance et/ou de conflits dans lesquels les acteurs s'engagent à travers des relations, flux, ou échanges [Perret and Gagnon \(2017\)](#).

Ainsi, si notre recherche s'inscrivait dans le cadre du développement durable, cette nouvelle piste de recherche aurait pour but le développement territorial viable, soit : *"l'expression d'un changement social caractérisé par la montée du partenariat, l'émergence d'acteurs multiples, la recherche de solutions alternatives à celles des superstructures économiques et l'introduction de critères sociaux et culturels à côté de rationalités purement économiques, et ce dans une perspective humaniste du développement de l'ensemble des territoires habités"* ([Gagnon et al., 2008](#)).

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Annexe 1 : Vers un modèle d'expression de la performance pour le pilotage d'un écoparc d'activités

Cette annexe présente l'article de conférence intitulé "Vers un modèle d'expression de la performance pour le pilotage d'un écoparc d'activités", présenté lors de la 13ème Conférence Internationale de Génie Industriel à Montréal en Juin 2019. Pour cet article, j'ai agi en tant que chercheuse principale et les coauteurs, mes directeurs de thèse ont passer en revue les ébauches successives aboutissant au manuscrit soumis.

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A.1 Résumé

Cet article traite du pilotage d'un éco-parc d'activités et de l'expression de sa performance. Un éco-parc d'activités est une zone d'activités économiques particulière dans laquelle les entreprises, industrielles ou tertiaires, souscrivent aux principes du développement durable pour elles-mêmes et la communauté locale. L'éco-parc d'activités obéit dans ce sens à des règles d'aménagement et de collaboration interentreprises spécifiques. L'idée proposée est d'appréhender l'éco-parc d'activités comme un système dont il s'agit, pour le gestionnaire qui le pilote, de conduire l'atteinte de ses objectifs globaux de développement durable via l'atteinte de sous-objectifs rattachés respectivement à ce que nous qualifierons d'aménagement durable et de collaboration interentreprises. La démarche proposée s'inspire de la pratique du pilotage en entreprise pour décrire les enjeux du pilotage de l'éco-parc d'activités. Pour ce faire, le concept d'éco-parc d'activités est défini et les grandes questions relatives à son pilotage sont posées. Des pistes de réponses sont alors proposées. Un focus sur le système d'indicateurs de performance est effectué, menant à la proposition d'un cadre méthodologique pour l'expression de la performance et ouvrant des perspectives pour la formalisation de ce cadre. Les réflexions menées le long de cet article sont illustrées par les enjeux soulevés dans le cadre du pilotage de l'éco-parc d'activités français Savoie Technolac.

A.2 Introduction

Le monde est actuellement perturbé par quatre crises : une crise économique, une crise écologique, une crise politique et une crise sociale [Audebrand \(2018\)](#). Les perspectives d'accélération du développement globale avec l'utilisation accrue des ressources et l'augmentation des impacts environnementaux et sociaux qu'il entraîne sont tous autant de signes que l'état actuel du développement économique n'est pas une option viable [Intergovernmental Panel for Climate Change \(2017\)](#); [World Wide Fund for Nature \(WWF\) \(2016\)](#). La notion de développement durable popularisée en 1987 vise à repenser les relations entre la nature, l'homme et l'économie [World Commission On Environment and Development \(1987\)](#). Plus récemment, de nouvelles notions telles que la transition énergétique, l'économie circulaire ou l'écologie industrielle soulignent l'importance de la nature holistique de l'approche à entreprendre pour aborder le défi d'un futur durable [Bocken et al. \(2014\)](#); [Kirchherr et al. \(2017\)](#); [Meadowcroft \(2009\)](#).

En particulier, l'écologie industrielle est à l'origine d'une réflexion sur les flux de matières et d'énergie et sur le bouclage de ces flux au sein d'un même écosystème industriel. L'application de cette idée à l'échelle d'une ZAE - Zone d'Activités Économiques (business park en anglais) accueillant des entreprises industrielles a donné naissance au modèle du parc éco-industriel (Eco-Industrial Park en anglais) [United Nations Environment Programme \(2001\)](#).

La vocation du parc éco-industriel est essentiellement la création d'échanges de matériaux et d'énergies. Des travaux récents introduisent un nouveau modèle, appelé éco-parc d'activités (Mixed-Use Ecopark en anglais) permettant d'étendre le concept de parc éco-industriel à des ZAE, accueillant aussi des entreprises tertiaires [Le Tellier et al. \(2019\)](#). L'éco-parc d'activités est une nouvelle forme de développement économique, conçue, bâtie et gérée selon les principes de l'aménagement urbain durable, où des entreprises collaborent pour créer des bénéfices économiques, environnementaux et sociaux. Un exemple est l'éco-parc d'activités français Savoie Technolac.

L'éco-parc d'activités est un système pilotable par un observateur appelé gestionnaire. Ce dernier peut être composé de plusieurs acteurs, tels que des investisseurs publics ou privés, les collectivités locales, des aménageurs ou des promoteurs. La finalité de l'éco-parc d'activités est la durabilité

(sustainability en anglais), définie comme l'équilibre de ses trois dimensions : économique, environnementale et sociale [Gasparatos et al. \(2009\)](#); [Le Tellier et al. \(2019\)](#).

Cet article traite du pilotage de l'écoparc d'activités dont la nature complexe requiert des méthodologies telles que celles offertes par les démarches d'amélioration continue [Wilkinson et al. \(2001\)](#). Dans le cas des parcs éco-industriels, concept voisin de celui des écoparcs d'activités, les études existantes traitent essentiellement de l'évaluation de l'impact du parc sur l'environnement [Boix et al. \(2017\)](#); [Tian et al. \(2014\)](#); [Valenzuela-Venegas et al. \(2016\)](#); [Zhao et al. \(2017\)](#) ou de l'optimisation des échanges de matériaux et énergie [Boix et al. \(2015\)](#); [Felicio et al. \(2016, 2013\)](#). Les travaux définissant et traitant le pilotage de l'écoparc d'activités de manière holistique sont relativement rares. Ainsi, dans un premier temps, cet article présente une définition du pilotage de l'écoparc d'activités et de ses enjeux. Dans un second temps, des pistes de réponses à ces enjeux sont introduites.

En reprenant la définition du pilotage comme suivant les principes de la roue de [Deming \(1982\)](#), le pilotage de l'écoparc d'activités se définit comme un processus itératif de comparaison des résultats avec les objectifs, donnant lieu à des actions correctrices. Cet article traite de deux enjeux du pilotage de l'écoparc d'activités : la décomposition des objectifs et l'expression de la performance. Pour servir de base à la définition du plan d'action, qui correspond à l'étape « Plan », une modélisation systémique de l'écoparc d'activité est présentée à travers son instanciation sur le cas d'étude de Savoie Technolac. Cette modélisation permet de proposer une décomposition des objectifs. Dans le cadre de l'expression de la performance, qui correspond à l'étape « Check », deux approches sont proposées : une approche qui considère les résultats et une autre qui divise le fonctionnement de l'écoparc d'activité selon l'aménagement et la collaboration. Car elles sont complémentaires, ces deux approches donnent lieu à la proposition d'un cadre méthodologique pour la formulation d'un système d'indicateurs de performance. Ce système d'indicateurs de la performance pourra ainsi servir d'outil d'aide à la décision dans le cadre de l'étape « Act ».

Cet article est structuré comme suit. Dans un premier temps, l'émergence du concept d'écoparc d'activités est présentée donnant lieu à sa définition dans la Section 2. Les enjeux du pilotage de ce nouveau concept sont présentés et illustrés par le cas d'étude de Savoie Technolac dans la Section 3. La Section 4 contextualise les enjeux du pilotage dans l'état de l'art actuel. La Section 5 détaille la vision du pilotage proposée avec la présentation de la modélisation systémique de l'écoparc d'activités et les premières réflexions concernant l'expression de sa performance. La Section 6 ouvre sur les perspectives de formalisation du modèle d'expression de la performance proposé avant de conclure sur cette étude et les réflexions qui y sont menées.

A.3 Le concept d'écoparc d'activités

A.3.1 Concepts fondateurs

Comme évoqué précédemment, le concept d'écologie industrielle est apparu à la fin des années 1980 avec la publication du papier fondateur de [Frosch et Gallopoulos](#) introduisant la notion d'écosystème industriel. Un écosystème industriel est une communauté d'entreprises qui décident d'interagir par l'échange de ressources matérielles telles que des énergies, de l'eau, ou des produits/coproduits/déchets [Frosch and Gallopoulos \(1989\)](#). Le principe de l'écologie industrielle est basé sur un parallèle avec les écosystèmes naturels. Dans un écosystème naturel, les déchets d'une espèce sont la nourriture d'une autre, l'énergie se répartit en cascade le long de la chaîne alimentaire et le seul intrant à ce système est l'énergie solaire [Korhonen \(2001\)](#). L'écologie industrielle souligne l'importance de la collaboration et l'interdépendance entre les entreprises pour la rési-

lience des écosystèmes industriels Côté and Cohen-Rosenthal (1998); Erkman (1997); Graedel (1996).

Une notion proche de l'écologie industrielle et apparue dans un article fondateur un peu plus tard est l'économie circulaire Bruel et al. (2019); Pearce and Turner (1989). L'économie circulaire « décrit un système économique basé sur des modèles d'affaires qui remplacent le concept de la fin de vie par la réduction, la réutilisation, le recyclage et la récupération des matériaux dans les processus de production, distribution et consommation, opérant au niveau micro (produits, entreprises, consommateurs), méso (parcs éco-industriels) et macro (ville, région, nation et au-delà), avec le but d'accomplir un développement durable » Kirchherr et al. (2017). Un exemple d'application des principes de l'économie circulaire est la chaîne d'approvisionnement verte (Green Supply Chain en anglais) Genovese et al. (2017) dont la gestion vise à minimiser voire éliminer les rejets incluant les déchets dangereux, les émissions, le gaspillage énergétique le long de la chaîne Ahi and Searcy (2013); Fahimnia et al. (2015); Srivastava (2007).

Comme l'écologie industrielle, l'économie circulaire est une approche systémique qui s'inspire des écosystèmes naturels pour repenser le système économique. Le concept phare de l'écologie industrielle est la symbiose industrielle Boons et al. (2011). « La partie de l'écologie industrielle connue comme la symbiose industrielle fait s'impliquer des industries traditionnellement séparés dans une approche collective aux avantages compétitifs consistant en des échanges physiques de matériaux, d'énergie, d'eau et/ou de coproduits. La clé de la symbiose industrielle est les possibilités synergétiques offertes par la proximité géographique » Chertow (2000).

A.3.2 De la notion de parc éco-industriel à la notion d'éco-parc d'activités

Au vu des industries qui y sont impliquées, les ZAE industrielles sont un lieu idéal pour appliquer les principes de la symbiose industrielle United Nations Environment Programme (2001). Plus précisément, une ZAE est définie comme un « grand terrain aménagé pour l'utilisation simultanée d'entreprises, caractérisé par des infrastructures partageables et la proximité immédiate d'entreprises » Peddle (1993). Les ZAE se distinguent par leur vocation et par les équipements et services aux entreprises qu'elles offrent. On peut les différencier en fonction des activités présentes sur leur site Peddle (1993) :

- les ZAE commerciales regroupent des commerces et accueillent le public ;
- les ZAE logistiques regroupent des activités de stockage et distribution ;
- les ZAE mixtes regroupent des entreprises de petite et moyenne taille, aux activités tertiaires ou industrielles « légères » (par opposition aux activités de production ou de transformation de matières premières) ;
- les technopôles regroupent des entreprises de haute technologie, des centres de recherche et des universités ;
- les ZAE industrielles regroupent des entreprises aux activités industrielles.

L'application des principes de la symbiose dans une ZAE industrielle donne naissance au parc éco-industriel. Un parc éco-industriel est une « grappe industrielle dans laquelle une communauté d'entreprises prend part à un réseau de relations collaboratives permettant d'exploiter de nouvelles opportunités commerciales afin d'accroître leur performance économique, tout en réduisant leur empreinte sur l'environnement et en retirant des bénéfices pour la communauté locale » Bellantuono et al. (2017). Selon Pellenbarg, la bonne approche pour comprendre le concept de parc éco-industriel est de prendre comme point de départ « l'intérêt écologique du comportement d'une entreprise plutôt que l'impact écologique de ses produits » Pellenbarg (2002). En effet, le facteur déterminant d'un parc éco-industriel n'est pas le produit ou le service, mais l'ambition commune d'entreprises manufacturières d'organiser leurs activités de manière stratégique, et ce, afin de retirer des bénéfices économiques et environnementaux. Un des plus célèbres exemples de

symbiose industrielle est le parc éco-industriel de Kalundborg au Danemark [Chertow \(2008\)](#). Ce parc est composé de neuf entreprises privées et publiques qui prennent part dans près d'une trentaine d'échanges d'eau, d'énergie ou de matériaux. Cette symbiose industrielle a commencé à se développer, graduellement et de manière non planifiée, en 1972 [Ehrenfeld and Gertler \(1997\)](#). Depuis la fin des années 1990, le parc éco-industriel de Kalundborg est considéré comme un modèle. Plus récemment, un certain nombre d'initiatives dans des pays développés et en voie de développement ont donné lieu à la création de parcs éco-industriels, plus ou moins aboutis [Sakr et al. \(2011\)](#); [Tessitore et al. \(2015\)](#); [Tian et al. \(2014\)](#).

Lambert et Boons considèrent que dans le contexte du parc éco-industriel, une distinction doit être faite entre les « complexes industriels », soient les ZAE aux activités industrielles « lourdes » (production ou transformation de matières premières), et les « parcs industriels mixtes », soient les ZAE mixtes, mais aussi les technopôles ou les ZAE logistiques. Les auteurs formulent l'argument que l'échange de matériaux et d'énergies n'est pertinent que dans le cadre d'un « complexe industriel » dont les activités sont intrinsèquement interconnectées. D'un autre côté, les problèmes liés aux « parcs industriels mixtes » sont peu analysés selon ces derniers, alors que leur impact environnemental, économique, social et spatial n'est pas négligeable. Lambert et Boons défendent l'idée que les initiatives de parcs éco-industriels n'ont pas entrepris de relever les défis des « parcs industriels mixtes » en se concentrant essentiellement sur l'exemple de Kalundborg et l'échange de matériaux et d'énergie [Lambert and Boons \(2002\)](#). C'est avec l'objectif de proposer un modèle adapté aux « parcs industriels mixtes » et en souscrivant à cette analyse que nous introduisons le concept d'écoparc d'activités.

A.3.3 Définition de l'écoparc d'activités

Tel qu'il a été introduit dans des travaux antérieurs, un écoparc d'activités ou écoparc se définit comme : « une communauté d'entreprises (industrielles ou tertiaires) localisées sur un parc planifié et construit de manière durable (bâtiments et infrastructure), administré par un gestionnaire désigné, qui coopèrent entre elles pour efficacement partager des ressources (informations, matériaux, énergie, infrastructure et services) dans le but d'obtenir des bénéfices économiques et une amélioration de la qualité environnementale et des ressources humaines pour ces entreprises et la communauté locale » [Le Tellier et al. \(2019\)](#). Le concept d'écoparc s'inspire donc de celui de parc éco-industriel dans le sens où il retire des bénéfices économiques environnementaux et sociaux de la collaboration entre des entreprises et la communauté locale. En plus de cette collaboration interentreprises caractérisant le parc éco-industriel, l'écoparc est également un site pour l'implantation d'entreprises, qui est conçu, construit, entretenu et rénové dans le respect des principes de l'aménagement urbain durable.

Selon l'UNEP, le parc éco-industriel suit les trois phases d'existence suivantes [United Nations Environment Programme \(2001\)](#) :

- une phase de conception et de construction où la fonction du parc, son site et l'emplacement des entreprises sont choisis;
- une phase de négociation où des entreprises s'implantent dans le parc;
- une phase d'exploitation ou de gestion des opérations quotidiennes.

En se basant sur les travaux concernant les parcs éco-industriels, des modifications et enrichissements sont apportés à ce cycle de vie [Gibbs and Deutz \(2007\)](#); [Potts Carr \(1998\)](#); [Roberts \(2004\)](#); [Varga and Kuehr \(2007\)](#). La Figure A.1 illustre le cycle de vie de l'écoparc. Premièrement, la phase de négociation s'effectue en même temps que la phase d'opération. En effet, la négociation avec des entreprises et leur implantation sur le site font partie des activités courantes du gestionnaire de l'écoparc. De plus, un écoparc est appelé à se transformer (s'étendre dans le cas d'un accroissement du nombre de ses infrastructures, ou se rénover (selon l'obsolescence de ces infrastructures). Enfin, dans des cas extrêmes, certains écoparcs ne réussissant plus à atteindre leurs

objectifs, pourront décider d'abandonner leur développement. Dans la pratique, l'observation de plusieurs cas d'étude, dont Savoie Technolac, a permis de valider ce cycle de vie.

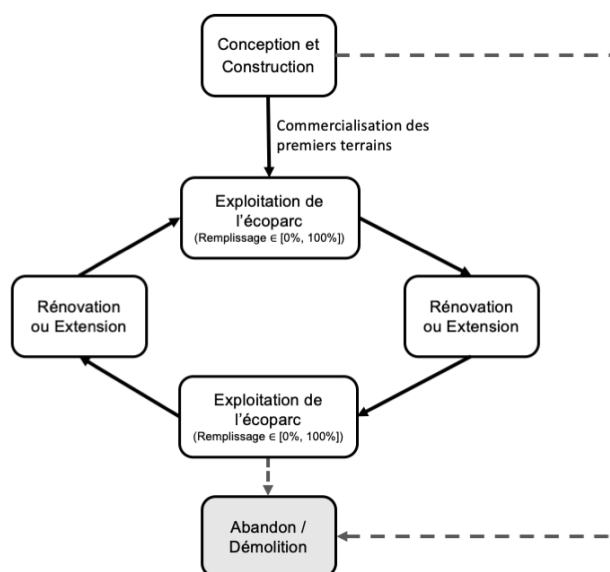


Figure A.1 – Cycle de vie de l'éco-parc

A.4 Les enjeux du pilotage de l'éco-parc

Dans un premier temps, les enjeux du pilotage de l'éco-parc sont illustrés par le cas d'étude du pilotage de Savoie Technolac. Par la suite, ils seront formulés de manière plus globale.

A.4.1 Le pilotage de l'éco-parc Savoie Technolac

Savoie Technolac est un technopole spécialisé dans le domaine de l'énergie, du bâtiment et du numérique, en opération depuis 1985 [Chambéry-Grand Lac Economie \(2018b\)](#). Il est localisé dans la région de la Savoie, en France, et est géré par la communauté d'agglomération qui regroupe les collectivités du bassin chambérien. Savoie Technolac accueille 230 entreprises et plusieurs composantes universitaires, totalisant ainsi 9000 usagers.

Actuellement dans une phase d'extension, Savoie Technolac a pour mission l'attraction et l'accompagnement à la création d'entreprises qui innovent ou se spécialisent dans le secteur « Énergie, Bâtiment, Réseaux » d'une part et qui se pérennisent sur le territoire d'autre part. Pour ce faire, le gestionnaire de Savoie Technolac inscrit l'éco-parc dans une démarche de développement durable en misant sur des constructions innovantes qui privilégient les énergies renouvelables et sur la valorisation des compétences locales en encourageant les collaborations interentreprises.

Dans le cadre de cette mission, un exemple d'objectif que s'est fixé le gestionnaire de Savoie Technolac fin 2015 est celui de doubler sa capacité d'accueil (de 9000 à 18000 personnes) dans les quinze prochaines années sans consommer plus d'énergie [Chambéry-Grand Lac Economie \(2015\)](#). L'atteinte de cet objectif permet de créer des bénéfices économiques (économies d'échelle pour les entreprises), environnementaux (diminution de la consommation d'énergie par usager)

et sociaux (création d'emplois par l'arrivée de nouvelles entreprises). Cet objectif étant complexe par la complexité de l'écoparc, la multiplicité des acteurs impliqués et la longueur de l'horizon temporel considéré, un dispositif de pilotage est nécessaire.

Conformément aux approches systémiques et à la pratique menée en entreprise [Keeney \(1997\)](#); [Simon \(1969\)](#), cet objectif nécessite d'être décomposé en sous-objectifs pour aboutir à un plan d'action [Berrah and Foulloy \(2013\)](#). Car un écoparc est un parc planifié et construit de manière durable, mais aussi un groupe d'entreprises qui collaborent, on postule que deux types d'actions peuvent être menées pour atteindre cet objectif : des actions touchant à l'aménagement du parc (construction de bâtiments à haute performance énergétique, construction de centrales de production d'énergies renouvelables, etc.) et des actions touchant à la collaboration interentreprises (réutilisation de la chaleur produite par un centre de données, connexion des entreprises à un réseau électrique intelligent, etc.). Le plan d'action pourra donc se répartir entre les actions d'aménagement et les actions de collaboration interentreprises, car ces deux processus impliquent des acteurs différents et des temporalités différentes.

Le gestionnaire de Savoie Technolac a donc besoin d'un modèle permettant de décomposer ses objectifs principaux, dont celui présenté à titre d'exemple, établir un plan d'action adapté, suivre son exécution et réagir selon les résultats atteints par le plan d'action vis-à-vis de l'objectif principal en établissant un nouveau plan d'action. Nous retrouvons ainsi le principe des démarches d'amélioration continue.

A.4.2 L'écoparc comme un système pilotable

L'écoparc est un système, soit « la représentation d'un phénomène actif, perçu comme identifiable par des projets, dans un environnement actif, dans lequel il opère et se transforme téléologiquement » [Le Moigne \(1994\)](#). Son observateur est son gestionnaire. Ce dernier peut être composé de plusieurs acteurs, tels que des investisseurs publics ou privés, les collectivités locales, des aménageurs, des promoteurs, etc. L'écoparc est un système pilotable par son gestionnaire.

Le pilotage d'un système est globalement l'ensemble des actions qui visent à atteindre sa finalité, soit la durabilité. La durabilité de l'écoparc est donc spécifiée selon trois buts, déclarés pour toutes les parties prenantes (les entreprises, leurs employés, la communauté locale, et l'environnement).

- Minimiser l'impact environnemental du site.
- Créer des bénéfices économiques.
- Créer des bénéfices sociaux.

Les enjeux du pilotage de l'écoparc peuvent se résumer en deux questions. Une première question concerne la décomposition des objectifs et l'établissement du plan d'action : **(i) Comment atteindre les buts principaux de l'écoparc ?** Une fois le plan d'action défini et exécuté, un suivi de son application et de ses résultats est nécessaire pour donner lieu à une réaction, un ajustement, voire l'établissement d'un nouveau plan d'action. Ceci nous amène à poser une seconde question : **(ii) Comment évaluer l'atteinte des buts principaux de l'écoparc ?**

Ayant ainsi présenté les enjeux du pilotage de l'écoparc, un état de l'art sur le pilotage de l'écoparc, en lien avec ces deux questions, est présenté.

A.5 Etat de l'art sur le pilotage de l'éco-parc

A.5.1 Pilotage de la chaîne d'approvisionnement et du parc éco-industriel

La chaîne d'approvisionnement est un concept comparable à celui de l'éco-parc. En effet, ces concepts sont tous deux des organisations d'entreprises œuvrant pour un objectif commun : la production d'un produit ou d'un service pour la chaîne d'approvisionnement, et la durabilité pour l'éco-parc. Ces deux concepts présentent aussi des différences, comme le fait que, contrairement à l'éco-parc, la chaîne d'approvisionnement ne repose pas sur l'idée d'exploitation des bénéfices d'une proximité géographique ou que, contrairement à la chaîne d'approvisionnement, l'éco-parc n'est pas centré autour de la production d'un seul produit ou service. Malgré ces différences, les outils de pilotage de la chaîne d'approvisionnement, en particulier la chaîne d'approvisionnement verte, peuvent être une opportunité pour le pilotage de l'éco-parc. En effet, le modèle SCOR offre la possibilité de représenter le fonctionnement d'un parc éco-industriel ou d'un éco-parc [Le Tellier et al. \(2017\)](#) et de le lui associer des indicateurs témoignant de l'atteinte de ses objectifs. Le modèle SCOR donne ainsi une vision de l'éco-parc qui nécessite d'être complétée afin de couvrir l'ensemble de ses spécificités. L'exploration de cette piste méritera d'être poursuivie dans des travaux ultérieurs, une fois le cadre global du pilotage de l'éco-parc posé.

Par ailleurs, des études ont fait l'objet du pilotage des parcs éco-industriels dans la littérature. Tessitore et al considèrent que le pilotage du parc éco-industriel consiste en la coordination de la collaboration interentreprises [Tessitore et al. \(2015\)](#), soit « les transactions, flux et relations persistantes qui ont lieu entre plusieurs organisations même environnement » [Oliver \(1990\)](#). Ce pilotage est généralement réalisé par un gestionnaire public issu du gouvernement régional ou municipal [Tessitore et al. \(2015\)](#). Parmi les travaux traitant du pilotage du parc éco-industriel, beaucoup ont porté sur la création et la sélection d'indicateurs de performance pour l'évaluation de ses bénéfices et de son impact sur l'environnement. Parmi ces travaux, Zhu et al ont développé un système d'indicateurs pour la sélection des entreprises voulant intégrer le parc éco-industriel [Zhu et al. \(2010\)](#). D'autres études ont porté sur la proposition d'indicateurs de performance composites pour l'évaluation de la performance d'une symbiose industrielle [Felicio et al. \(2013, 2016\)](#); [Tiejun \(2010\)](#). Couto Mantese et Capaldo Amaral ont développé un modèle multi-agent pour la comparaison de ces indicateurs [Couto Mantese and Capaldo Amaral \(2017\)](#). Enfin, Valenzuela-Venegas et al ont effectué une revue des indicateurs d'évaluation de la durabilité des parcs éco-industriels [Valenzuela-Venegas et al. \(2016\)](#). Dans l'ensemble de ces travaux, le pilotage du parc éco-industriel est essentiellement axé sur l'optimisation des échanges de matériaux et d'énergies et sur la minimisation de l'impact environnemental du parc.

Les outils pour le pilotage de l'éco-parc interprétant la durabilité dans une vision holistique sont rares. On retiendra néanmoins les travaux effectués par Zhao et Guo qui ont utilisé la méthode d'aide à la décision multicritère VIKOR pour l'évaluation de l'ensemble des bénéfices d'un parc éco-industriel [Zhao et al. \(2017\)](#). La méthode permet une classification de différents parcs éco-industriels selon les bénéfices qu'ils apportent à leurs entreprises, à la société et à l'environnement. Les critères d'évaluation utilisés sont répartis en cinq catégories : bénéfices économiques, bénéfices sociaux, bénéfices environnementaux, construction d'une industrie écologique et gestion du parc éco-industriel.

Les approches proposées ont ainsi, majoritairement pour objectif d'évaluer, dans une logique a posteriori, l'impact ou les bénéfices générés par la symbiose industrielle. Afin de permettre au gestionnaire un pilotage réactif, a priori et donc de l'atteinte des objectifs fixés pour son système, notre idée est de nous inspirer de la pratique en entreprise, succinctement rappelée ci-après.

A.5.2 Le pilotage en entreprises - Rappels

Selon l'AFGI - Association Française de Gestion Industrielle, le pilotage est défini comme « un mécanisme multi-niveau, hiérarchisé (chaque niveau cadrant le suivant) et bouclé (répercussion et correction des écarts). Ces niveaux [...] sont chacun caractérisés par leur horizon (visibilité), leur période (réactualisation) et leur maille (résolution). Le processus consiste alors, niveau par niveau, par cadrages successifs, à préparer formellement, progressivement, en cohérence et avec une exécutabilité croissante les conditions de la réalisation pour se terminer par l'émission d'ordres exécutoires vers le processus physique, il est fait de comparaisons, d'itérations, de simulations ... » française de gestion industrielle (1992). De manière globale et comme mentionné précédemment, le pilotage peut être vu comme s'inscrivant dans le cadre général proposé par la roue de Deming (Plan-Do-Check-Act) et sa philosophie d'amélioration continue, qui consiste en l'itération permanente d'un processus de déclaration d'objectifs, de définition et d'enclenchement de plans d'action, d'évaluation des résultats obtenus et de réaction au vu des résultats obtenus Deming (1982). Cette vision se retrouve dans le principe de la boucle automatique de rétroaction Ducq et al. (2001); Foulloy et al. (2019).

Le pilotage de tout système productif repose donc sur une déclaration d'objectif, soit l'état attendu, et l'acquisition voire le traitement d'une mesure, soit l'état atteint à l'aide des actions entreprises Berrah et al. (2000). Le pilotage s'appuie ainsi sur une expression de la performance qui alimente le processus de décision d'enclenchement d'un nouveau plan d'action. Les indicateurs de performance Fortuin (1988) et les systèmes d'indicateurs de performance (Performance Measurement Systems en anglais) Neely et al. (1995) sont les outils permettant de faire le lien entre les objectifs, les actions et les mesures, fournissant de ce fait le cadre pour l'expression de la performance dans ce contexte.

Cette expression de la performance fera désormais l'objet de nos réflexions dans la suite de l'article. Aussi, la première question posée au paragraphe 3.2 (Comment atteindre des buts principaux de l'écoparc ?) correspond-elle à l'étape « Plan ». À cette étape, une caractérisation du système est nécessaire pour offrir un cadre à la déclaration et décomposition des buts et objectifs de l'écoparc. Notons que la seule description du système ne pourra pas entièrement répondre à notre première question. Comme notre propos ici est l'expression de la performance, nous n'aborderons pas la définition du plan d'action. La seconde question posée au paragraphe 3.2 (Comment évaluer l'atteinte des buts principaux de l'écoparc ?) correspond, quant à elle, à l'étape « Check ». À cette étape, le déploiement d'un système d'indicateurs de performance est nécessaire pour accompagner l'exécution des plans d'action et exprimer la performance et donc à la fois l'atteinte des buts de l'écoparc mais aussi, de manière proactive, l'atteinte des objectifs intermédiaires, issus des décompositions effectuées.

Dans la section suivante, une description systémique de l'écoparc est proposée dans un premier temps. À partir des buts ressortis de ce modèle, les premières réflexions méthodologiques relatives à l'expression de la performance de l'écoparc sont présentées.

A.6 Vers un modèle d'expression de la performance pour le pilotage de l'écoparc

A.6.1 Modélisation systémique et décomposition des objectifs

Considérant sa nature systémique, nous proposons de décrire l'écoparc par une modélisation systémique selon l'approche proposée par Le Moigne Cliville et al. (2004); Le Moigne (1994); Le

Tellier et al. (2019). Celle-ci est résumée dans le Tableau A.1 et instanciée sur le cas de Savoie Technolac.

Plus particulièrement, une décomposition - systémique et générique - des objectifs de l'éco-parc est effectuée et présentée dans la Figure A.2. Une première décomposition de la finalité de l'éco-parc en des objectifs exogènes est effectuée. Ces objectifs se rattachent aux extrants de l'éco-parc par rapport à son environnement. La décomposition des objectifs exogènes donne alors les objectifs endogènes. Ces objectifs se rattachent à l'organisation requise pour que l'éco-parc puisse atteindre les objectifs exogènes. Car un éco-parc est un parc planifié et construit de manière durable, mais aussi un groupe d'entreprises qui collaborent, on peut différencier les objectifs endogènes en fonction de ces deux types de fonctionnements :

- L'aménagement du parc qui concerne les bâtiments et les infrastructures ;
- La collaboration qui concerne les relations entre les entreprises du parc.

Ainsi distingués, les objectifs endogènes sont à leur tour décomposés en sous-objectifs. Enfin, ces sous-objectifs sont associés aux entités de l'éco-parc, et pourront être décomposés sur autant de niveaux que nécessaire pour le pilotage.

A.6.2 L'expression de la performance

Deux types d'expression de la performance ont été introduits dans le cadre d'un pilotage réactif des processus industriels française de gestion industrielle (1992); Berrah et al. (2000); Lorino (1996) :

- L'expression a posteriori est exprimée à l'issue de l'exécution du plan d'action. Elle affiche un résultat et permet de vérifier l'atteinte de l'objectif.
- L'expression a priori est exprimée avant la fin de l'exécution du plan d'action. Elle permet de réagir de manière anticipée pour mieux atteindre l'objectif.

L'expression de la performance a posteriori de l'éco-parc identifie l'atteinte des objectifs exogènes. C'est le cas par exemple, de l'objectif de maximisation des bénéfices sociaux dont l'atteinte peut se mesurer par la création d'emplois sur l'éco-parc sur une plage temporelle donnée. L'expression de la performance a priori identifie quant à elle l'atteinte des objectifs endogènes. Par exemple, un éco-parc au stade de la conception mettra l'emphase sur l'aménagement, à un stade initial où les entreprises ne sont pas encore impliquées. De même, un éco-parc au stade d'exploitation avec un haut taux de remplissage mettra l'emphase sur la collaboration puisqu'une quantité élevée d'entreprises offre un plus grand potentiel pour la collaboration tandis que l'amélioration d'un aménagement existant représente un défi généralement coûteux.

Conventionnelles, les expressions de performance a posteriori sont d'ores et déjà mises en place à Savoie Technolac. Le gestionnaire de l'éco-parc utilise un tableau de bord constitué de 37 indicateurs. Ces indicateurs concernent des variables telles que la compétitivité, la spécialisation « Solaire Énergie Bâtiment » et la maîtrise budgétaire. Le

Tableau A.2 est un extrait de ce tableau de bord. Dans la pratique, ce tableau de bord a une vocation de reporting et de témoignage de l'atteinte des objectifs aux élus locaux. De manière complémentaire, le développement d'un système d'indicateurs délivrant les expressions a priori fait actuellement l'objet de nos réflexions communes.

A.6.3 Proposition d'un cadre méthodologique pour la construction d'un système d'indicateurs de la performance

En termes méthodologiques, le Tableau A.3 présente une proposition pour la construction d'un système d'indicateurs de la performance pour le pilotage de l'éco-parc.

Tableau A.1 – Modélisation systémique de l'écoparc

Caractéristique	Modélisation systémique de l'écoparc	Instanciation du modèle (Savoie Technolac)	
Finalité	Durabilité		
Environnement	Fournisseurs et clients des entreprises et infrastructures		
	Environnement naturel		
	Communauté locale	Collectivités du bassin Chambérien	
	Gestionnaire	Chambéry-Grand Lac Économie	
Structure	Bâtiments	55 Bâtiments	
	Entreprises	230 Entreprises (soit 3500 employés)	
		Université Savoie Mont-Blanc (5000 étudiants et 1000 employés)	
		Incubateur d'entreprises	
		Infrastructures de base (Voirie, espaces verts, stationnements, réseau d'eau et d'électricité, etc.)	
		Échanges et partages de services	Services aux employés (Restaurants, crèche, association sportive, etc.)
		Échange ou partage de services entre les entités	Échange ou partage de services entre les entités
	Échange ou partage d'informations	Échange ou partage d'informations entre les entités	
	Échange ou partage de ressources physiques (énergie, eau, matériaux)		
Objectifs exogènes	O1 : Impact environnemental minimal	Attirer ou d'accompagner la création d'entreprises qui innovent ou se spécialisent dans le secteur « Énergie, Bâtiment, Réseaux » et qui se pérennisent sur le territoire, pour la création de bénéfices économiques, environnementaux et sociaux.	
	O2 : Bénéfices économiques maximaux		
	O3 : Bénéfices sociaux maximaux		
Comportement	Fonctionnement : Aménagement durable, Collaboration des entreprises		
	Transformation de la structure et nouvelle déclaration des objectifs endogènes de l'écoparc		

Les expressions de performance a posteriori et a priori liées à l'aménagement sont toutes deux fournies par des indicateurs de performance sélectionnés à partir de la littérature, de l'observation de cas d'études et de référentiels existants.

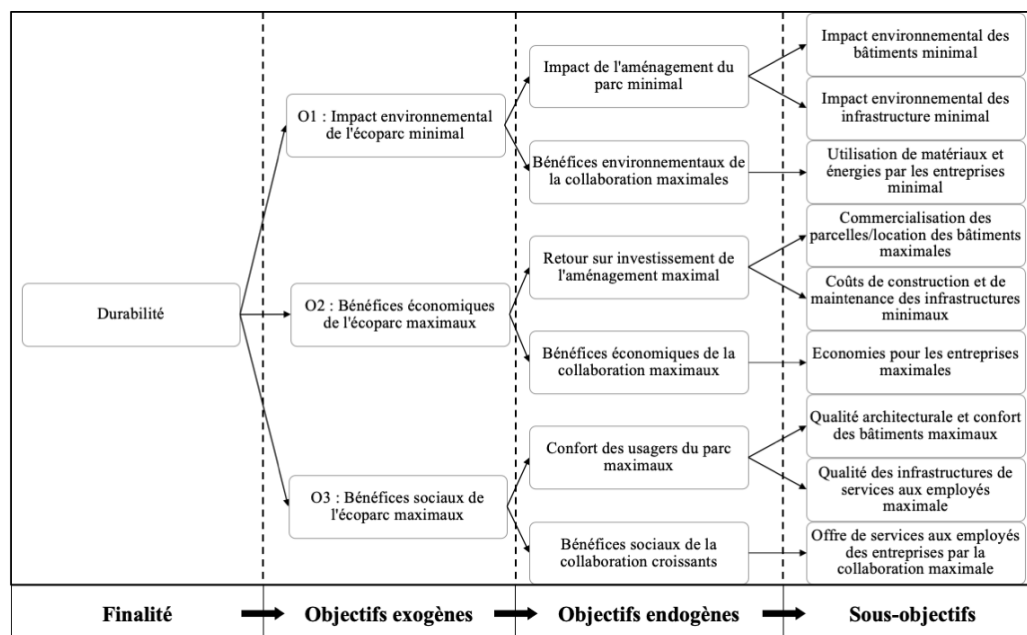


Figure A.2 – Décomposition des objectifs de l'éco-parc

Tableau A.2 – Extrait du tableau de bord de Savoie Technolac (dernière mise à jour en janvier 2017)

Dimension de la durabilité	Indicateurs collectifs	2012		2013		2014	
		Objectif	Réalisation	Objectif	Réalisation	Objectif	Réalisation
Dimension Environnementale	Surface bâtie ayant reçu un label environnemental / Surface bâtie produite dans l'année	50%	61,1%	50%	100%	50%	56%
	Centrales solaires installées sur Savoie Technolac (en m²)	850	900	1 000	255	1 500	1 817
Dimension économique	Production fiscale	3.1 M€	3.071 M€	3.2 M€	3.08M€	3.3 M€	2.9 M€
	Nombre de startups incubées	30	30	35	34	40	36
	Taux de survie à 3 ans des startups incubées	87%	87%	87%	78%	87%	86%
	Nombre d'implantations sur Savoie Technolac réussies	8	14	10	15	15	9
	Flux de collaboration Recherche et Développement Innovation	25	16	30	39	40	42
Dimension sociale	Nombre d'emplois nets créés / an	250	260	250	281	250	-18
	Masse salariale	/	99.6 M€	/	115.5 M€	/	107.9 M€

D'un autre côté, les indicateurs de performance liés à la collaboration évaluent la collaboration interentreprises de l'éco-parc à travers une analyse de réseau social. L'analyse de réseau social est une méthode bien établie dans les sciences sociales, qui étudie les relations entre individus d'une même structure sociale, comme un groupe ou une organisation, à l'aide de graphes et de mesures quantitatives Kadushin (2012). Elle utilise des mesures quantitatives afin de caractériser un réseau et l'implication de ses acteurs Butts (2008). L'analyse de réseau social a été utilisée pour l'étude des échanges de ressources matérielles d'un parc éco-industriel Song et al. (2018).

Le système d'indicateurs de performance considéré offrira un cadre holistique pour le pilotage de l'éco-parc. En effet, il permettra une vérification au premier niveau de l'atteinte des objectifs et donc de la durabilité de l'éco-parc, mais il permettra aussi un diagnostic des résultats atteints et un pilotage plus ciblé : orienté vers l'aménagement du parc ou la collaboration interentreprises. Une fois développé, ce système d'indicateurs pourra être utilisé par les gestionnaires de Savoie

Technolac.

A.7 Conclusion

L'écoparc est, sur le même principe que la chaîne d'approvisionnement verte, un nouveau type d'organisation recherchant la durabilité dans sa vision holistique. Plus qu'une simple ZAE verte, l'écoparc doit être un concept normatif permettant de réfléchir aux différents chemins de transition viable vers des systèmes hommes-environnement - économie plus durables.

Le pilotage de l'écoparc, effectué par un gestionnaire attitré, pour le compte d'une multitude de parties prenantes, requiert une expression de la performance reposant sur la déclaration et décomposition des objectifs afin de sélectionner des actions correctives appropriées pour une amélioration continue. Afin de servir de base au modèle d'expression de la performance de l'écoparc, une modélisation systémique de ce dernier a été présentée. Celle-ci permet la description du système et la décomposition de ses principaux objectifs.

Ensuite, deux approches d'expression de la performance, complémentaires pour le pilotage, de l'écoparc ont été présentées : une expression a posteriori et une expression a priori. L'une permet une vérification au premier niveau de l'atteinte des objectifs tandis que l'autre permet un diagnostic des résultats atteints et un pilotage plus ciblé. En intégrant ces deux approches, quelques réflexions sur un cadre global d'expression de la performance ont été présentées.

Les travaux futurs traiteront donc de la construction du système d'indicateurs de performance. En effet, les défis restants à relever sont la sélection des indicateurs de performance, la détermination des relations entre ces indicateurs et le choix d'une approche mathématique pour l'agrégation des expressions de performance élémentaires en expressions synthétiques.

Tableau A.3 – Cadre méthodologique pour la construction d'un système d'indicateurs de performance pour le pilotage des écoparcs

	Approche globale	Approche par fonctionnement	
	Ecoparc	Aménagement	Collaboration
Rôle du système d'indicateurs de performance	Évaluation de la performance économique, environnementale et sociale	Évaluation de durabilité de l'aménagement du parc	Évaluation de la collaboration à partir d'une analyse de réseau social générée à partir d'un recensement des flux internes à l'écoparc par sondage
Source de détermination des indicateurs de performance	Bonnes pratiques dans la littérature et les cas d'étude Référentiels existants (ISO14001, ISO26000, GRI, etc.)	Bonnes pratiques dans la littérature et les cas d'étude Référentiels existants (LEEDS, EcoQuartier, HQE2R, etc.)	Mesures quantitatives de l'analyse d'un réseau

B

Annexe 2 : A review of Actions Towards Circular Economy for Business Park Governance.

Cette annexe présente l'article de conférence intitulé "A review of Actions Towards Circular Economy for Business Park Governance", présenté lors de la Conférence Internationale Going Green CARE INNOVATION à Vienne en Novembre 2018. Pour cet article, j'ai agi en tant que chercheuse principale et les coauteurs, mes directeurs de thèse ont passer en revue les ébauches successives aboutissant au manuscrit soumis.

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B.1 Résumé

Un parfait exemple de parc industriel en accord avec le principe d'économie circulaire est appelé parc éco-industriel. Cependant, tout les types de parcs industriels, où des entreprises co-localisées peuvent prendre part à des relations synergétiques pour réduire ou recycler leurs ressources, ont un fort potentiel pour le développement d'une économie circulaire. Comme dans n'importe quelle autre organisation, le pilotage d'un parc industriel peut être considéré comme étant la définition de buts avec comme intention de les réaliser. Cet article fait partie d'un travail de création d'un outil d'aide à la décision pour l'usage des gestionnaires de parcs industriels les assistant dans l'accomplissement de leurs objectifs en terme d'économie circulaire. Un modèle systémique des composants d'un parc industriel est présenté dans le Langage de Modélisation Unifié (UML). À partir de littérature académique et opérationnelle, une revue des actions supportant la transition d'un parc industriel vers l'économie circulaire est présentée. Enfin, les impacts de ces actions sur le parc industriel sont analysées en utilisant la modélisation systémique proposée.

B.2 Introduction

Business park is one of the oldest and most traditional forms of planned economic development in Europe and North America. As defined by Peddle, an industrial park or estate, now called business park, is a "large tract of land, subdivided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms" (Peddle, 1993). Arising from an intent to separate industrial activities from residential urban areas, industrial parks provide an attractive means for businesses to locate in suburban areas and for communities to relieve pressures on the quality of life of a city (Lambert and Boons, 2002). Nowadays, the term business park is preferred to industrial park and can take many shapes : office parks, science and research parks, high-tech parks, biotechnology parks, warehouse parks, etc. Circular Economy (CE) promotes the shift from the traditional, linear, open-ended economic system to a circular economic system, with 'closing-the-loop' production patterns (Preston, 2012; Ghisellini et al., 2016; Ellen MacArthur Foundation, 2013). As highlighted by Kirchherr et al., the concept of CE is trending among both scholars and practitioners but suffers severely from a lack of clear and consensual definition (Kirchherr et al., 2017). They proposed an exhaustive definition of the concept : "A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations". This definition states that the two core principles of CE are the 4Rs (Reduce, Reuse, Recycle, Recover) and the systems perspective, and it links CE with sustainable development and its three dimensions. More than the 4Rs, other practices and concepts, like pollution prevention, ecological economics design for environment, product stewardship, or environmental labelling, work towards the transition to a CE (for a detailed discussion of those practices, see (Nakajima, 2000)). Industrial Ecology is a field of study that works towards the CE and is concerned with the material and energy flows in an industrial ecosystem. It supports the idea that an industrial ecosystem should develop an optimal web for the recycling and cascading of materials and energy, just like food webs in the natural ecosystem (Erkman, 1997; Frosch and Gallopoulos, 1989; Korhonen, 2001). Concepts developed within the scope of Industrial Ecology are dematerialisation, material substitution, pollution prevention, design for environment and, most famously, industrial symbiosis

(IS). IS is an Industrial Ecology concept focusing on the flow of resources through clusters of geographically proximate businesses in order to add value, reduce costs and improve environmental impacts (Chertow, 2000). An Eco-Industrial Park (EIP) is the direct implementation of IS in a business park. An EIP is a business park which aims at the collective improvement of its companies' environmental impact and economic benefits through IS (U.S President's Council on Sustainable Development, 1997). As a reminder, EIP is cited in Kirchherr et al.'s definition, at the meso-level of the circular economic system. Indeed, Industrial Ecology, and its related concepts such as IS and EIPs support a transition from a linear towards a more circular economy, creating different alternatives of the materials and their wastes through reuse, repair, recycling and remanufacturing (Nakajima, 2000), (Saavedra et al., 2018). Aside from EIPs, all business parks have the capacity to engage in the creation of a circular economic system. Indeed, business parks gather various economic activities and can be managed to encourage sustainability and collaboration between companies. The United Nations Environment Programme says that "An industrial estate combines large-scale and diversity in its industrial activities. It is unlikely that a single factory will cover as many different industry sectors, resulting in a wider range of environmental aspects and the possibility of synergies between effects." (United Nations Environment Programme, 2001). Moreover, at the other end of the spectrum, business parks planned, built and managed with little concern for their impact on the environment can be a source of environmental damages. Sustainability and circularity should therefore be one of the biggest parts of the business parks' agenda. In a nutshell, a sustainable business park comprises two different aspects (Brand and De Bruijn, 1999) :

- sustainable construction of the park with, for example, efficient use of space, high-quality and energy efficient buildings, infrastructure and systems, or integration of the site in its natural and cultural environment, etc.
- circular production processes thanks to, for instance, exchanges of material, energy and water, joint logistics, collective waste management, or production and use of renewable energy, etc.

As a result, business parks need to be properly managed even after their construction and this management needs to go further than renting/selling buildings/lots to companies. Business parks' managers can be called by various names : 'management body', 'governing body', 'coordinating body', etc. In this paper, the term 'governing body' is used as a way to combine decision making with managerial function. The paper's overall objective is to define the business park's governing body's range of actions to transition towards CE. The first contribution is a systemic modelling of a business park through its entities and their interactions. This model offers a layered description of the business park from its governing body's point of view. A business park is composed of three main entities : its infrastructures, diverse and maintained by the governing body, its buildings, owned by public or private proprietor, and its companies, implanted on the business park, in the buildings. This model is represented with a class diagram of the Unified Modelling Language (UML). The second contribution is a definition of the governing body's role, through its goals and CE-relevant actions. First, a state of the art of academic and grey literature on potential CE-relevant actions undertaken by business parks' governing body is presented. The identified actions are then classified using the UML systemic modelling. For each action, the class on which they have an impact is determined. This impact analysis of the reviewed actions will give decision makers a more coherent perspective on the concrete actions they can undertake for a transition towards CE in their business park. The paper is structured as follows. In Section 2, the business park is represented through systemic modelling, defining its entities and their interactions with particular focus on its governing body. Section 3 offers a state of the art from academic and grey literature of the CE-relevant actions that can be undertaken in business parks to transition to a more circular economy. Then, in Section 4, using the systemic model and the survey from previous sections, an impact analysis of each action will offer a repertory of good practices to business parks' governing bodies. The relationship of this repertory with the performance of circular business parks is discussed in the concluding Section 5.

B.3 Systemic Modelling of Business Parks transitioning towards CE

As a resilient, self-organizing, integrated whole of nested systems (companies) with non-linear behaviour, a business park transitioning towards CE can be considered as an artificial system (Chapman et al., 2016; Felicio et al., 2013; Romero and Ruiz, 2013). Hence, using its systemic nature, the business park can be modelled through its goals, its entities and their interactions. This model offers a representation basis that is suitable to every kind of business park with optional elements characterizing the transition towards CE. The Unified Modelling Language (UML) provides a standard way to visualize the design of a system (Object Management Group, 2017). UML is usually associated with software engineering but it has been used for organisations modelling. For example, Hein et al. provided a framework for EIPs using UML to model the park and more specifically the IS (Hein et al., 2015). As this paper's focus is broader than IS, an original model of the business park is presented. In UML, a class can be seen as a template for instances and a class diagram is used for defining classes and their relationships (Hein et al., 2015). Here, it is used for defining the organisation of a business park : its different entities, their attributes, and their relationships.

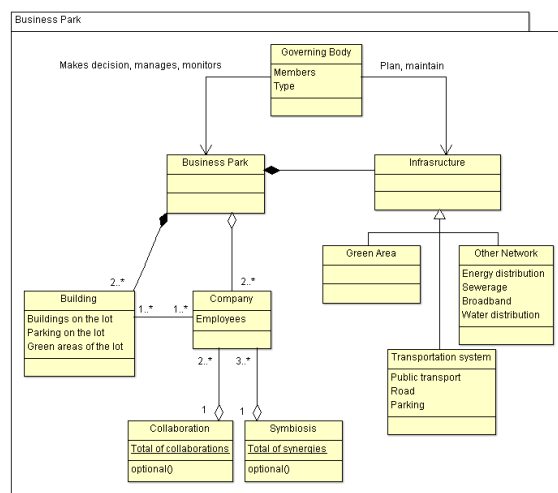


Figure B.1 – Class diagram of the business park

Figure B.1 is a class diagram of the business park transitioning towards CE; it shows the constitutive entities of a business park and their relationship. Those entities, or classes, and their potential attributes are presented in the following subsections. The logical connections between the classes are represented with different UML relationships.

- A simple line and an arrow are respectively called bi-directional and uni-directional relationship. They allow one instance of a class to cause another to perform an action on its behalf. For example, the Governing Body plans and maintains the instances from the class Infrastructure.
- A hollow triangle shape represents an inheritance. It indicates that one of the two related classes is considered to be a specialized form of the other. For example, Green Space, Transportation System or Other Network are all specialized forms of the class Infrastructure.
- A filled diamond shape represents a composition. It implies that a class (the one on the diamond shape end of the line) contains another class. When the containing class disappears, the contained class disappears as well. For example, if a business park is destroyed, the buildings and infrastructures are destroyed.
- A hollow diamond shape represents an aggregation. Contrary to the composition, in an aggregation the contained class doesn't disappear with the containing class. For example, the companies will not be destroyed when destroying the business park.

- The numbers on the ends of the lines are optional notation that give information on the multiplicity. The multiplicity is the range of number of instances that participate in the relationship from the perspective of the other end. For example, a business park is the composition of two or more buildings.

The business park is constituted of several classes. The central class of the business park is the ‘governing body’. This particular class and its role are detailed in Section 3.

The class ‘building’ relates to every building constructed in the park, which shelters the companies. An instance of this class includes a building and all the infrastructures of its private lot, like parking or green areas. The class ‘company’ relates to every tenant company of the park, including its employees. To be a member of a business park, a potential company should adhere to a set of principles and rules in terms of behaviour, structure and processes. This set of principles, or charter, can be assembled and enforced by the governing body. The buildings and companies are considered in two separate classes since a company does not necessarily own its premises and can both represent different stakeholders with different goals.

The class ‘infrastructure’ relates to all the elements of infrastructure managed by the governing body of the business park. The instances of this class are very diverse since it characterises roads, parking, green areas, or various distribution networks like sewerage, energy or broadband. The key aspects for high-performing infrastructures are their design, or sometimes redesign, and their maintenance.

An optional class for the business park system, that becomes mandatory for an EIP, is the class ‘symbiosis’. In an attempt to promote complex exchange network, Chertow introduced the 3-2 heuristic, which requires that “at least three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis” (Chertow, 2008). According to this heuristic, the class ‘symbiosis’ must involve at least three company instances and can involve up to all the companies of the business park. The creation of a mature and strong symbiosis between the companies is one of the most important goals of a business park wanting to transition towards CE.

Another optional class is the class ‘collaboration’. This class designates the collection of all immaterial relationships and flows of services or information between the tenants. For example, a company outsourcing a part of its operations to another company of the park, a car-sharing platform, offices renting, or a shared restaurant or day nursery, can all be collaboration opportunities. The development of a maximum of inter-firm exchanges and shared services will be beneficial to the business park by directly contributing to its development, the attraction of new tenants, the animation of the local economic and social fabric, the satisfaction of the tenants and the promotion of local know-how. Indirectly, the development of collaboration will also strengthen the transition towards CE by initiating the dialogue and building trust between the stakeholders.

B.4 Governing body of the business park : definition and its role

As its name indicates, the governing body is the decision maker for the business park, working towards its development. This body can be composed of several actors with different individual goals, shifting during the different stages of development of the business park. It can be composed of public or private investors, planners, local governments, designated decision makers of the business park, etc. For example, in the particular case of EIP governance, Tessitore et al. collected the type of governing body for several international EIPs (Tessitore et al., 2015). The majority of

cases were located in China, the rest were based in the UK, Brazil and the USA. In some rare cases, the identified governing body was the biggest company of the EIP, called ‘anchor company’ or ‘key enterprise’. In the majority of cases, governing bodies were public institutions or institutions mandated by local authorities. According to the United Nations Environment Program, a business park, or industrial estate, functions through an administration that assumes three roles ([United Nations Environment Programme, 2001](#)).

- A managerial role for enforcing restrictive covenants in leasing agreements, deciding on the entry of new companies into the estate, collecting rents and ensuring that taxes and charges are paid, and being responsible for maintenance and order on the estate.
- A technical role that covers responsibility for common facilities as well as training or other technical services.
- A financial role including overseeing loans to tenant companies on the estate or arranging bulk purchasing agreements for materials.

For Brand & De Bruijn, the role of a governing body could be twofold with an initiating and stimulating role (driving force) and a coordinating role between the different actions ([Brand and De Bruijn, 1999](#)). It should also be noted that the power delegated to the governing body is influenced by the country in which the business park or EIP is implanted. For example, as pointed out by Qu et al., in a command economy such as China, the EIP managers play a pivotal role in planning, designing, organising, and implementing the systems and processes for creating IS ([Qu et al., 2015](#)). In France, discussion with business park managers revealed that they had restricted capacity in controlling the behaviour of company or driving the creation of inter-firm synergies. In this model, the term governing body is used as a way to combine decision making (‘What should we do?’) with managerial function (‘How should we do it?’) ([Tricker, 2012](#)). In a simple manner, like in any other organisation, business park operation could be considered as the definition of goals with the purpose of achieving them. The accomplishment of these objectives requires decision making to identify appropriate strategies and actions, and monitoring of the undertaken actions. The selection of actions depends on the broadness of the range of actions available to the governing body. As guardian of the business park’s sustainable development, the governing body can act on the different classes of the system to shape a CE through IS. The following section provides a review of the potential actions that can be undertaken by a governing body to transition a business park towards CE.

B.5 Review of actions towards circular economy in business parks

B.5.1 Method and materials

In recent years, operational and academic literature on business parks, has considered the management topic and investigated the strategies implemented for the sustainable development of the parks, the tenants and their relationships. Whether called ‘management body’, ‘governing body’ or ‘coordinating body’, the importance of a team catalysing the development and functioning of a business park, and more particularly an EIP, has been cited in many papers ([Tessitore et al., 2015](#); [Qu et al., 2015](#); [Mirata, 2004](#); [McCarthy et al., 2018](#)). The following three phases of existence of a sustainable business park were proposed by the UNEP ([United Nations Environment Programme, 2001](#)).

1. The planning and construction phase, where the environmental concept can be moulded as a function of the type of business park that is envisaged (for example heavy industry,

technology- or science-based industry, or service industry), the choice of site and how industries will be located within it.

2. At the stage where companies are negotiating to come into the business park, the environmental criteria used by the business park's management will be crucial in setting the scene for the type of company that will eventually locate there and what kind of environmental footprint the park will have.
3. The operating phase, or day-to-day running of the business park, which will require the creation of a coherent environmental program, such as through the use of an Environmental Management System (EMS).

It is also important to differentiate the revitalisation of existing business parks and the sustainable creation of new ones. One should note that the review of actions for the creation of CE in business parks only relates to the management of the park, not its planning. According to the three phases described above, the following review is mostly relevant to the second and third phases. The information presented in the next sections is logged in Table ?? and B.2 in the Appendix section. It was retrieved from academic literature in the industrial ecology field, principally on eco-industrial parks ((Brand and De Bruijn, 1999; Qu et al., 2015; Erdmenger, 1998; Tikhonov et al., 2016)) and from operational literature on industrial park environmental management ((United Nations Environment Programme, 2001; AMRP Gent University, 2008; Chamber of Commerce and Industry of Marseille Provence and ANIMA Investment Network, 2010)). After reviewing an article, the identified actions were logged with their respective authors and redundant actions were eliminated. Lastly, actions relating to the creation of a governing body, like "Establish a liaison mechanism with relevant local authorities" or "Establish a monitoring and coordination unit for the liaison mechanism with relevant local authorities" in the PALME (Parc d'Activités Labellisé Maîtrise de l'Environnement) guidelines, were eliminated since the presence of a governing body is considered as a mandatory feature of a business park. It should be noted that an extensive body of literature was reviewed but, to the best of our knowledge, very few publications addressed the topic of the governing body's actions. Indeed, most articles presented general policies or concepts that could be planned or implemented into business parks and EIPs, but few articles discussed the subject from the governing body's perspective and at the operating phase.

B.5.2 State of the art on the actions supporting the transition to a CE in a business park

Operational literature

The Veurne Industrieterrein I business park, located in Flanders, presented their actions to achieve sustainable development. Those actions mainly seem to be orientated towards environmental performance of the park and are not concerned with the operation of the business park (AMRP Gent University, 2008). They identified four strategies with actions.

- Moving towards a more efficient use of resources, with actions relating to heat exchange, energy-efficient light system and clustering of services related to energy.
- Promoting sustainable mobility, with actions relating to bike mobility, sustainable use of cars and connection to public transport network.
- Increase energy production from renewable sources, with actions relating to collective solar and wind energy production.
- Sustainable living and working environment, with actions relating to green areas, common security system and shared facilities.

Tessitore et al. investigated Italian EIPs' management and concluded that i) the management body of an EIP represents the link between the companies and the public authorities and ii) it promotes the development of the EIP and the environment protection (Tessitore et al., 2015). They observed

that the local community participated in the development of the EIP thanks to the management body, which identified the needs and requests of the companies.

In a report addressed to business park managers, the Chamber of Commerce and Industry of Marseille identified the key elements for a sustainable performance of their parks ([Chamber of Commerce and Industry of Marseille Provence and ANIMA Investment Network, 2010](#)). Those key elements are ‘management and maintenance of the park’, ‘animation of the park’, ‘shared services’, ‘animation of the local economic fabric’, ‘strategic services to the tenants’, ‘functionality of park planning’, ‘quality of park planning’ and ‘promotion and communication’. The particularity of those principles is that they are not solely orientated towards IS but also towards sustainable management and urban planning.

In a similar manner, the French eco-label for industrial parks PALME, provides a different interpretation of the sustainable industrial park. PALME does not emphasise process coupling and by-product exchange, instead the requirements of the label give priority to environmental planning and management of the park ([United Nations Environment Programme, 2001](#); [Côté and Cohen-Rosenthal, 1998](#)).

Academic literature

Qu et al. identified three types of environmental practices in an EIP ([Qu et al., 2015](#)).

- Instituting environmental norms such as setting up environment management systems, setting up regulations about pollution or securing the ISO 14001 certification.
- Building IS, for instance by establishing a by-product exchange platform, encouraging enterprises to exchange by-products, establishing water cascade between the tenants or sharing information between the enterprises.
- Providing guidance to key enterprise, for example by implementing energy audit and material flow analysis in the key enterprises or encouraging them to implement cleaner production or to secure the ISO 14001 certification.

Tikhanov et al. proposed similar practices ([Tikhanov et al., 2016](#)): "Raising the standards of ecological and energy efficiency of the park's resident enterprises; Enhancing and expanding inter-firm cooperation in production, research and marketing; Assistance to residents provided by the management company in order to attract financial and non-financial state support for the development of production on the territory of the park."

B.6 Impact analysis of the actions on the entities of the business park

Using the systemic modelling presented in Section 2, the actions presented in Section 3 are classified according to the classes of business park on which they have a significant impact. This impact analysis offers a repertory of ‘good practices’ according to the business park’s management perspective. This allows decision makers to select the most adequate action(s) according to their situation while taking into account their sometimes limited, range of options. For each action, the entities on which they have an impact are identified. For example, the action ‘Set up requirement of energy exhaust for enterprises in the EIP’ ([Qu et al., 2015](#)) has an impact on the instances of the class ‘company’ exclusively, while the action ‘Set up collective solar energy production’ ([AMRP Gent University, 2008](#)) will have a benefit on the development of a symbiosis and in turn will have an impact on the buildings and the green areas where the solar energy production systems will likely be installed. Table ?? and B.2 in the Appendix section represents the impact matrix resulting

from this analysis.

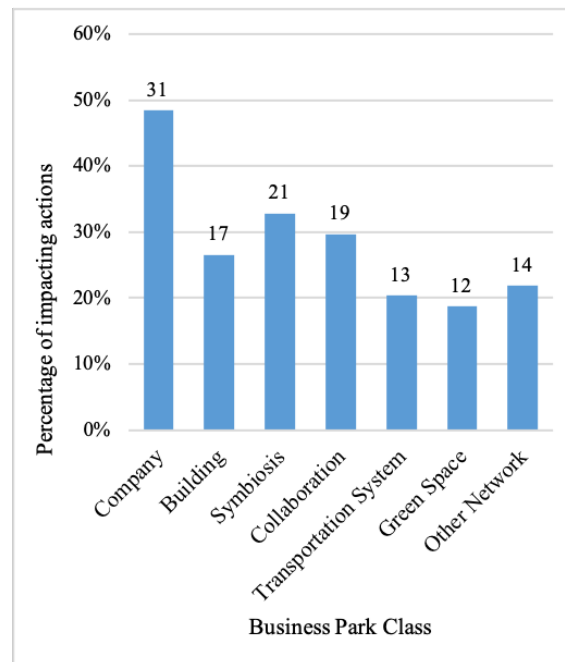


Figure B.2 – Percentages of actions impacting business park class

Figure B.2 gives a summary of the impact analysis. The results are that the inventoried actions supporting the transition toward CE in business park focus mostly on the companies. The rest of the entities have a relatively similar number of actions impacting them. This observation can seem surprising since the companies are the entities the governing body usually has the least power over, but it emphasizes the importance that the companies play in the circularity and therefore, sustainability, of the park. Indeed, the symbiosis is an important feature of CE but not the only one. This analysis underlines the relevance of the review of the governing body's actions. It also highlights the relevance of a systemic model with diverse entities and the presence of a governing body coordinating those entities. The fact that the inventoried actions do not contradict one another is also noteworthy. Lastly, it should be noted that this analysis doesn't account for the significance of an impact on the transition towards CE.

B.7 Conclusion

Due to relentlessly growing environmental concerns and distrust in the concept of sustainability, the concept of CE has gained a lot of attention in academic and operational literature. Defining CE, a concrete application of the concept at the meso-scale was found to be the EIP. An EIP is a business park which openly aims at the collective improvement of its companies' environmental and economic performance through collaboration and resources exchanges. More than EIPs, every business park, from simple industrial or office parks to more specific science and research parks or high-tech parks, can support the transition towards CE and benefit from it. Indeed, all business parks have the potential to be 'EIPs', or at least, more circular and sustainable. The potential of a business park needs to be harvested by a governing body, acting as a decision maker ('What should we do (to create a CE)?') and a manager ('How should we do it?').

After presenting a UML systemic model of a business park, a review of the potential actions that

can be undertaken by the governing body of such business park was provided. This review, from the academic and operational literature was then analysed through the prism of such systemic model. This analysis underlines, to some extent, the relevance of the review and the systemic model. This work set up the basis toward the development of a Performance Measurement System, with goals and metrics associated to each goal. Moreover, for practitioners, this work provides the first state-of-the-art repertory of good practices in the area of circular business park's governance.

Appendix

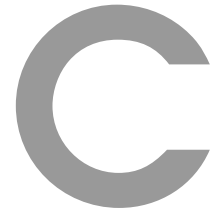
Annexe B. Annexe 2 : A review of Actions Towards Circular Economy for Business Park Governance.

	Actions	Business Park Class							Ref.
		C	B	Sy	Co	Tr	Gr	O	
Impacting all classes	Set up appropriate environment management system for the EIP	1	1	1	1	1	1	1	(Qu et al., 2015), (CCIMP, 2010)
	Secure the ISO 14001 EMS certificate	1	1	1	1	1	1	1	(Qu et al., 2015)
	Evaluate the environment impact of the EIP on the local areas	1	1	1	1	1	1	1	(Qu et al., 2015)
	Prepare an initial baseline “State of Environment” report for the site	1	1	1	1	1	1	1	(UNEP, 2001)
	Ensure compliance with (environmental) regulations and by-laws, and adherence to operational guidelines	1	1	1	1	1	1	1	(UNEP, 2001)
Impacting several classes	Establish an energy management plan for the site	1	1	1	1			1	(UNEP, 2001)
	Set up collective solar energy production	1	1	1			1		Veurne Industrierrein I
	Factor qualitative and environmental criteria for the implantation of companies (charter, specifications, advice and support for the implantation, monitoring of building permits, ...)	1	1						(CCIMP, 2010)
	Advise enterprises on noise reduction measures and materials for buildings and machinery	1	1						(UNEP, 2001)
	Establish a plan for solid waste management	1		1	1			1	(UNEP, 2001)
	Establish a plan for industrial wastes and effluents	1		1	1			1	(UNEP, 2001)
	Share information among the enterprises in the EIP	1		1	1				(Qu et al., 2015)
	Ensure the existence of a tenants association	1		1	1				(CCIMP, 2010)
	Identify an animator of the park	1		1	1				(CCIMP, 2010)
	Set up collective wind energy production		1	1					Veurne Industrierrein I
	Set up a common security system		1		1				Veurne Industrierrein I
	(Re)Think the integration of the park in its environment		1			1	1	1	(CCIMP, 2010)
	Prepare a site development plan, and have available the relevant regulations and guidelines		1			1	1	1	(UNEP, 2001)
	Enhance and expand inter-firm cooperation in production, research and marketing			1	1				(Tikhanov et al., 2016)
	Establish a plan for management of rainwater and surface runoff, and construction of any necessary installation					1	1	1	(UNEP, 2001)
Investigate alternative energy sources						1	1	(UNEP, 2001)	
Impacting Company class	Set up requirement of energy exhaust for enterprises in the EIP	1							(Qu et al., 2015)
	Set up requirement of pollution discharge and carbon emission for enterprises in the EIP	1							(Qu et al., 2015)
	Establish the relationship between the enterprises in the EIP and their suppliers outside	1							(Qu et al., 2015)
	Establish the relationship between the EIP's enterprises and their customers for the environment protection	1							(Qu et al., 2015)
	Implement energy audit and material flow analysis in the key	1							(Qu et al., 2015)
	Encourage the key enterprises of the EIP to implement cleaner production	1							(Qu et al., 2015)
	Encourage the key enterprises of the EIP to secure the 14001 EMS certificate	1							(Qu et al., 2015)
	Induce the key enterprises of the EIP to use renewable resource and cleaner energy	1							(Qu et al., 2015)
	Support the key enterprises of the EIP to produce green products	1							(Qu et al., 2015)
	Support the animation of the park in collaboration with the tenants	1							(CCIMP, 2010)
	Set up gatherings between the tenants	1							(CCIMP, 2010)

Tableau B.1 – Review of the actions towards CE and their impact on the business park classes (C = Company, B = Building, Sy = Symbiosis, Co = Collaboration, Tr = Transportation system, Gr = Green Space, O = Other network). The table is structured in sub-groups according to the number of classes impacted (all class, several and just one).

	Actions	Business Park Class							Ref.
		C	B	Sy	Co	Tr	Gr	O	
Impacting Company class	Organisation of open-houses, collaborating with academia	1							(CCIMP, 2010)
	Deployment of communication tools (newsletter, website ...)	1							(CCIMP, 2010)
	Set up meetings and thematic work session between the tenants	1							(CCIMP, 2010)
	Organisation of events related to the activities of the companies and the theme of park	1							(CCIMP, 2010)
	Raise the standards of ecological and energy efficiency of the park's resident enterprises	1							(Tikhonov et al., 2016)
	Establish an advisory service for clean technologies	1							(UNEP, 2001)
Impacting Building class	Monitor available constructible land and available buildings		1						(CCIMP, 2010)
	Integrate regulatory requirements regarding the use of natural light in buildings in permits for refurbishment and new buildings construction		1						Veurne Industrieterrein I
	Establish a landscaping plan and architectural requirements for buildings		1						(UNEP, 2001)
	Develop and implement a 'clean construction site' programme		1						(UNEP, 2001)
Impacting Symbiosis class	Establish the by-product and wastes exchange platform			1					(Qu et al., 2015)
	Build eco-industrial chains in the EIP			1					(Qu et al., 2015)
	Establish water cascade among the enterprises			1					(Qu et al., 2015)
	Build energy cascade among the enterprises			1					(Qu et al., 2015)
	Encourage the enterprises in the EIP to exchange by-products			1					(Qu et al., 2015)
	Establish heat exchange			1					Veurne Industrieterrein I
	Promote clustering of services related to energy			1					Veurne Industrieterrein I
Impacting Collaboration class	Support the setup of services for the companies and users				1				(CCIMP, 2010)
	Provision of services to the companies: wastes collect, green areas and buildings maintenance, security system, commuter plan or office renting				1				(CCIMP, 2010)
	Provision of services to the employees: Restauration, day nursery, sports facilities, convenience stores, hotels etc.				1				(CCIMP, 2010), Veurne Industrieterrein I
	Guidance of targeted companies (business incubator or accelerator)				1				(CCIMP, 2010)
	Provision of equipment (laboratories, research units, innovative materials ...)				1				(CCIMP, 2010)
	Mutualise equipment (laboratories, test platform, IT platform, ...)				1				(CCIMP, 2010)
Impacting Transportation system class	Organise the logistics of the park (transport of goods and peoples, parking management, security, ...)					1			(CCIMP, 2010)
	(Re)Think the location and accessibility of the services					1			(CCIMP, 2010)
	Promote bicycle mobility					1			Veurne Industrieterrein I
	Promote sustainable use of cars (with car-sharing or car-pooling services)					1			Veurne Industrieterrein I
	Improve the connection to public transport network					1			Veurne Industrieterrein I
Impacting Green Space class	Design of the public spaces (sustainable gardening, materials, street furniture, urban, architectural and environmental quality, ...)						1		(CCIMP, 2010), Veurne Industrieterrein I
	Implement a public awareness and information programme concerning natural environmental and conservation						1		(UNEP, 2001)
Impacting Other Network	Maintenance/Renovation of the networks							1	(CCIMP, 2010)
	(Re)Size and manage the different networks (lighting, sewerage, water, energy, broadband, ...)							1	(CCIMP, 2010)

Tableau B.2 – (continued)



Annexe 3 : From SCM to Eco-Industrial Park management : Modelling Eco-Industrial Park's symbiosis with the SCOR model

Cette annexe présente l'article de conférence intitulé "From SCM to Eco-Industrial Park management : Modelling Eco-Industrial Park's symbiosis with the SCOR model", présenté lors de la Conférence Internationale Advances in Production Management Systems en Septembre 2017. Pour cet article, j'ai agi en tant que chercheuse principale et les coauteurs, mes directeurs de thèse ont passer en revue les ébauches successives aboutissant au manuscrit soumis.

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C.1 Résumé

Dans le milieu industriel, les initiatives de mise en œuvre du concept de développement durable sont prises à la fois au niveau intra-entreprise et inter-entreprises. Au niveau inter-entreprise, le concept d'écologie industrielle utilise l'exemple des milieux naturels comme analogie pour la conception de systèmes industriels durables comme les parcs éco-industriel. De la même manière qu'un chaîne logistique, un parc éco-industriel est une communauté d'entreprises indépendantes qui coopèrent les unes avec les autres pour efficacement échanger des ressources (matérielles ou informationnelles). Cependant, si la coopération au sein d'une chaîne logistique se focalise sur la fabrication d'un produit, la coopération au sein d'un parc éco-industriel a pour objectif de générer pour les entreprises des gains économique, une réduction de l'impact environnemental et une amélioration de la qualité de vie au travail qui n'aurait pas été possible individuellement. Dans le vaste corps de littérature multidisciplinaire qui étudie les parcs éco-industriels, le manque d'un cadre pour évaluer les performance et les bénéfices d'un parc éco-industriel est régulièrement soulevé. Après avoir observé des similarités entre les chaîne logistiques et les parcs éco-industriels, l'intérêt de l'utilisation des outils de management de la chaîne logistique pour la description des synergies existant au sein d'un parc éco-industriel est démontré. Un modèle hérité du modèle SCOR est proposé pour cartographier cette symbiose et son application est illustrée par un cas d'étude. Même si la chaîne logistique et le parc éco-industriel ne partagent pas les même objectifs, nous démontrons la pertinence d'utiliser le modèle SCOR pour la gestion des parcs éco-industriels.

C.2 Introduction

With the growing presence of environment and energy security concerns, it has become clear that human activities and business activities in particular are having a preoccupying negative impact on our planet. Rising population sizes and increasing urbanisation call for an efficient use of resources embodied by the concept of sustainability as introduced in the Brundtland Report, by the United Nations World Commission on Environment and Development in 1987 ([World Commission On Environment and Development, 1987](#)). From a business perspective, initiatives dealing with sustainability are initiated at both inter-company level and intra-company level, those initiatives are regrouped within the spectrum of 'Eco-Industrial Development'. At inter-company level, 'Industrial Ecology', a subset of Eco-Industrial Development, uses natural ecosystems as metaphors to design sustainable industrial systems ([Frosch and Gallopoulos, 1989](#)). Industrial Ecology aims to transform traditional linear industrial ecosystems into cyclic, or quasi cyclic, ecosystems (where the output of a process becomes the input of another one). This instrument of Industrial Ecology is called 'Industrial Symbiosis'.

An Eco-Industrial Park (EIP) is a type of industrial or business park implementing a long term Industrial Ecology strategy through, among other initiatives, Industrial Symbiosis. The most famous definition of an EIP was proposed by the U.S. President's Council on Sustainable Development in the mid-1990s : "*a community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, energy, infrastructure and natural habitat), leading to economic gains, improvements in environmental quality and equitable enhancement of human resources for businesses and the local community*" ([U.S President's Council on Sustainable Development, 1997](#)). An extensive body of literature is available on the study of EIPs and, more generally, Industrial Ecology. A number of authors highlight the lack of a robust framework to evaluate the performance and benefits of an EIP and to support its sustainable development ([Chertow, 2003](#); [Tudor et al., 2007](#); [Valenzuela-Venegas et al., 2016](#)). Indeed, it is a rather

complex task to monitor an EIP's performance over time. A multi-disciplinary and international community has been working on this topic over the last decades. As a way to contribute to this topic, we suggest the use of endorsed industrial practices and tools.

In parallel, since the 1980s, a lot of work has been done in the field of Supply Chain Management (SCM). The Supply Chain (SC) is also an inter-company organisation model that integrates increasingly sustainable development purposes. It is defined as *the life cycle processes comprising physical, information, financial and knowledge flows whose purpose is to satisfy end-user requirements with products and services from multiples liked supplies* (Ayers, 2001). Managing the Supply Chain leads to various contributions in terms of its design, scheduling, planning, performance evaluation, and operation of its processes for the satisfaction of the final customers (Villa, 2001).

As we can see from their definitions and management objectives, EIPs and SCs present some similarities : they are both communities where businesses collaborate to reach a common goal. Both definitions introduce the notions of physical and information exchanges : *shared resources* for an EIP and *flows* for a SC. Among its various goals, SCM aims to measure and improve the performance of the global SC, objectives that are also shared by EIP management. From these observations, the use of SCM tools for EIP management is proposed.

The objective of this prospective article tackles the first step of EIP management which is the description of its resource sharing with a SCM tool that addresses inter-company flows modelling, namely the SCOR model. This work is encompassed in a much larger task : the implementation of a performance evaluation framework for the management and development of EIPs.

This article is structured as follows. First, we examine the concepts of EIP and SC, providing a comparison between both paradigms. Then we present the use of the SCOR model as a management framework for EIPs through a case study on one of the most famous EIPs : Kalundborg in Denmark. Finally, we finish this article with concluding remarks and directions for future work.

C.3 Eco-Industrial Parks and Supply Chains, definition and comparison

C.3.1 Eco-Industrial Park as an application of Industrial Ecology

The Eco-Industrial Park (EIP) paradigm relies on a very rational and intuitive idea : Industrial Ecology. Industrial Ecology, introduced by Frosch and Gallopoulos in 1989 (Frosch and Gallopoulos, 1989), is a systemic approach that studies materials and energy flows. Jelinski proposed three development models for Industrial Ecology, starting from the linear and immature ecosystem (Type I) that is unsustainable to the semi-matured ecosystem (Type II) through to a mature materially closed ecosystem that is ultimately sustainable (Type III) (Jelinski et al., 1992; Agarwal and Strachan, 2006). These three development models are illustrated in Figure C.1. As we mentioned before, Industrial Ecology means to transform traditional type I industrial systems into type III, or at least type II, systems (Lowe, 1997). This concept, also called 'Industrial Symbiosis' uses natural ecosystems as analogies to design sustainable industrial systems.

A large body of symbioses has been documented and studied, such as Kalundborg EIP (further described in section C.5); the Austrian province of Styria; the Ruhr region of Germany; the Jyväskylä region in Finland (Korhonen and Wihersaari, 1999); the petrochemical complex of Sarnia (Desrochers, 2001); and the Burnside Cleaner Production Centre in Burnside, Nova Scotia in Canada

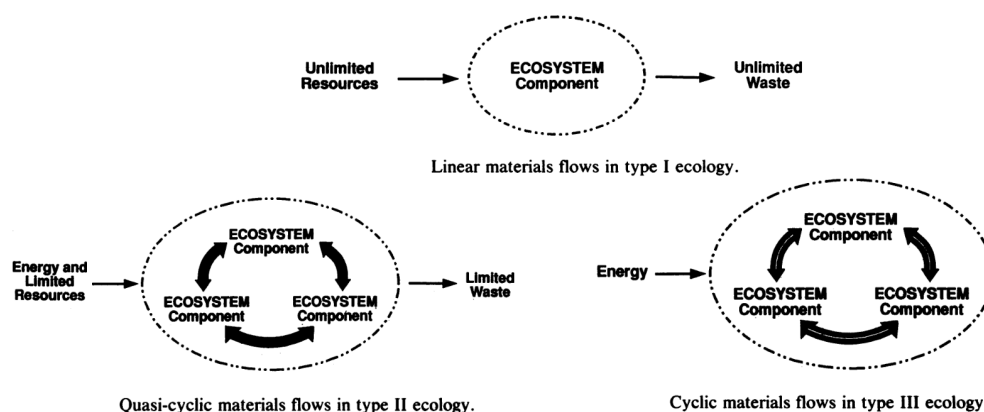


Figure C.1 – The three types of ecology, from linear to cyclic industrial systems (Jelinski et al., 1992)

(Côté et al., 2006). These prosperous symbioses, and several other varyingly successful attempts to realize Industrial Ecology, resulted in different criteria defining an Eco-Industrial Development. Chertow (2000) proposed the following taxonomy of different material exchange types :

Material exchanges taxonomy from Chertow (2000) :

- Type 1 : through waste exchanges
- Type 2 : within a facility, firm, or organizations
- Type 3 : among firms co-located in a defined eco-industrial park
- Type 4 : among local firms that are not co-located
- Type 5 : among firms organized “virtually” across a broader region

Types 3–5 offer approaches that can readily be identified as industrial symbioses and this paper will be restricted to EIP, precisely corresponding to Type 3. The symbiosis in an EIP is built around two main types of collaborations : substitution synergies (bilateral materials or energy exchanges) and mutualisation synergies (pooling of resources between two or more companies)

Recent work on the concept of EIP deals with the evaluation of its performance through the definition of new indices (Tiejun, 2010; Valenzuela-Venegas et al., 2016) and the use of multi-criteria decision making approaches (Zhao and Li, 2015; Zhao et al., 2017). Researchers in Industrial Ecology are increasingly moving away from the natural ecosystem metaphor towards more complex, dynamic and systemic approaches (Dijkema and Basson, 2009; Felicio et al., 2016). Indeed, the design of industrial symbiosis was investigated through optimisation methods (Boix et al., 2015), the use of system engineering (Haskins, 2007) or the use of agent-based modelling (Couto Mantese and Capaldo Amaral, 2017).

C.3.2 Supply Chains and Supply Chain management

The network of relationships between companies from the first supplier to the final customer is called Supply-Chain (SC). As we have mentioned before and according to Huan et al. (2004), SCM research can be classified into three categories : Operational, Design and Strategic. Operational SCM is concerned with the daily operations along the main functions of the SC ; Design SCM focuses on the location of decision spots along the SC and the achievement of the objectives of the chain ; and Strategic SCM intends to understand the dynamics of a supply chain and development of objectives for the whole chain in order to help decision-makers in the evaluation of alternative

SC configurations and partnerships. The SCOR model has emerged as a standard tool in Strategic SCM.

Another area in SCM that is close to EIP management and that has gained a lot of interest in the last two decades is Green SCM. Green SCM aims to minimise or eliminate wastages including hazardous chemical, emissions, energy and solid waste along SC (Chin et al., 2015; Srivastava, 2007).

C.3.3 Comparison between EIP and Supply Chain

From the definitions in section C.3.1 and C.3.2, we observe that EIPs and SCs show some similarities. The parallel between SC and Eco-Industrial Parks has been exploited by Zhu and Cote with their study of the evolution of the Guitang Group, a Chinese sugar complex, towards an eco-industrial development by applying integrated Green SCM (Zhu and Cote, 2004). Li et al. (2015) support the idea that green SC should be built inside EIP to create a "green economy".

We propose a non-exhaustive comparison of both concepts in order to demonstrate the pertinence of using SCM tools for EIP's symbiosis management. We inventoried the differences and similarities in Table C.1.

Tableau C.1 – Comparison between an EIP and a SC

Similarities	
Both are groups of companies	
Companies involved are production companies (of goods or services)	
Both concepts are based around the organisation of a collaboration between the involved companies	
All involved companies are working towards a common goal (but their goals are different)	
Exchanges of flows exist in both organisations (physical or information)	
The exchanges are based on long term deals (several years in most cases)	
Both concepts show a strong interest in logistics issues	
Differences	
SC	EIP
If the SC don't involve a vertically integrated firm, it will be organised around a focal company, the primer manufacturer	An EIP can be organised around a focal company but it will likely be managed by an external observer
Well defined roles for each company	Each company's role depends on the chosen perspective
The output of a SC is focused on common products	The output of EIP is the collection of each member's products
Geographical proximity is not mandatory	All the companies are co-located in a defined area.

SCs and EIPs were created around different philosophies and motivations. SCs are focused on the production of a common product and the satisfaction of a final customer. Their management goal is to improve quality, productivity and security. Members of an EIP do not collaborate for the production of a product but for the reduction in costs and environmental impacts, and the improvement of their employees' work conditions.

The outcome we draw from this comparison is that there are no real arguments against the use of

SCM tools to model the industrial symbiosis of an EIP. A SCM tool that addresses inter-company collaboration modelling is the SCOR-model, hence we proposed the use of the SCOR-model for the description of EIPs' flows.

C.4 Supply Chain management applied to EIP

C.4.1 Presentation of the SCOR model

The Supply-Chain Operations Reference-model (SCOR) is a cross-industry standard for SC management developed by the Supply-Chain Council (SCC). It is a diagnostic tool for practitioners describing the processes of a SC from the first supplier company to the last customer company. SCOR model integrates the well-known concepts of business process re-engineering, benchmarking, and process measurement into a framework which includes (Huan et al., 2004) :

1. standard descriptions of management processes ;
2. a framework of relationships among the standard processes ;
3. standard metrics to measure process performance ;
4. management practices that produce best in class performance ;
5. standard alignment to software features and functionality

As we can see in Figure C.2, in the most recent version of the SCOR model, the processes are of six types :

1. *Plan* describes the activities associated with developing plans to operate the supply chain
2. *Source* describes the ordering (or scheduling of deliveries) and receipt of goods and services.
3. *Make* describes the activities associated with the conversion of materials or creation of the content for services.
4. *Deliver* describes the activities associated with the creation, maintenance and fulfilment of customer orders
5. *Return* describes the activities associated with the reverse flow of goods.
6. *Enable* describes the associated with the management of the supply chain.

The processes can be approached at four levels of abstraction, from the most generic (level 1) to the most particular (level 4). Level 1, or 'Top Level', defines the scope and content for the SCOR-model (performance targets). At level 2, or 'Configuration level', companies implement their operations strategy through the configuration they choose for their SC. At level 3, or 'Process Element level', companies 'fine tune' their operations through process elements definition, process performance metrics and advice on the best practices. The last level, called 'Implementation level' is not included in SCOR's scope.

As SCOR model provides this well equipped cross-functional framework, we believe that it would be beneficial to use it for the evaluation, benchmarking and decision making for the development of an EIP.

C.4.2 The SCOR model transferred to the EIP

The interactions between two members of an EIP can be of two different types : a bilateral exchange called substitution synergy or a pooling of resources called mutualisation synergy.

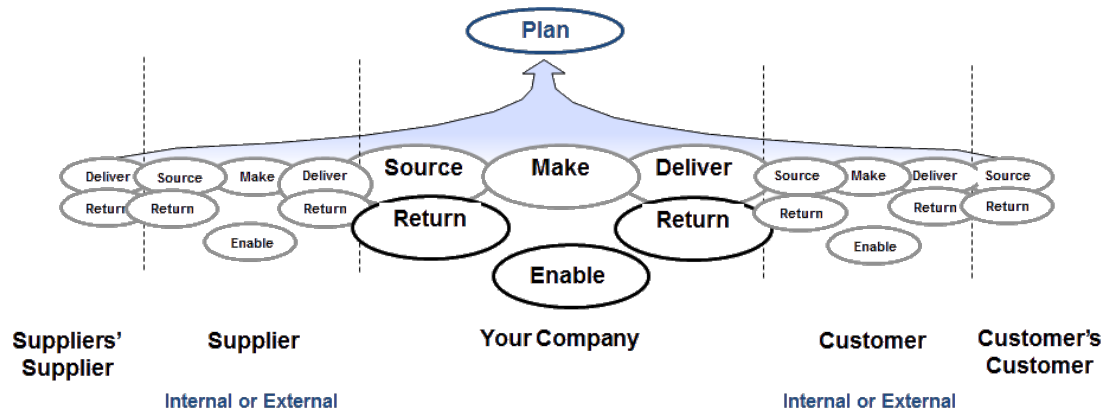


Figure C.2 – The SCOR overall Supply Chain processes structure (APICS, SCOR 11.0 Overview Booklet, 2014)

Substitution synergy

A substitution synergy is a bilateral exchange of energy or materials. Using SCOR's process structure, a substitution synergy is the link between the *Source* process of a company and the *Deliver* process of another. Since one of EIPs' goals is to optimise their inputs in a circular way, a material exchange could be of various ancillary products. The materials emitted by a company can be of four types (Zhu and Cote, 2004) :

1. *Products*, the desired output of the process ;
2. *Co-products*, which represent substantial value even if they are not the intended product of the process ;
3. *By-products*, unintentionally produced, that represent a lesser, but positive, value than the original raw material ;
4. *Residual products*, or waste, with a negative value.

For example, a sugar refinery's product is sugar, two co-products are molasses and bagasse, and a residual product is filter sludge. The bagasse can be used in a pulp plant. The emissions of the pulp plant are the pulp (product), black liquor (by-product), and waste-water (residual product).

Because of these different types of materials, the *Deliver* process can sometimes be coupled to an ancillary *Make* and *Deliver* processes (*Make'* and *Deliver'*) to either tailor them for their next use (co-products and by-products) or to treat them to respect regulations (by-products and residual products). Therefore, we propose to represent the members of an EIP as shown in Figure C.3. Because substitution synergies are focused on materials, we ignore the processes *Plan* and *Enable*. Moreover, for this first modelling, we neglect the *Return* process.

Mutualisation synergy

Using SCOR's process structure, a mutualisation synergy is the pooling processes between two, or more, companies. In theory, all the processes can be shared, but in practice, the most common pooling will likely be the *Deliver* and *Source* process. For example, two, or more, companies can come to an agreement to be delivered by the same carrier at the same time to minimise the shipping cost and environmental impact. In a similar fashion, the carrier importing materials in the EIP can be used to export finished products outside the EIP. With a bit more planning, the *Return* process can be organised in a collaborative way. Companies can share resources used in the *Make* process, such as quality control or information systems. A very common collaboration inside a EIP will be residual product treatment at the *Make'* process.

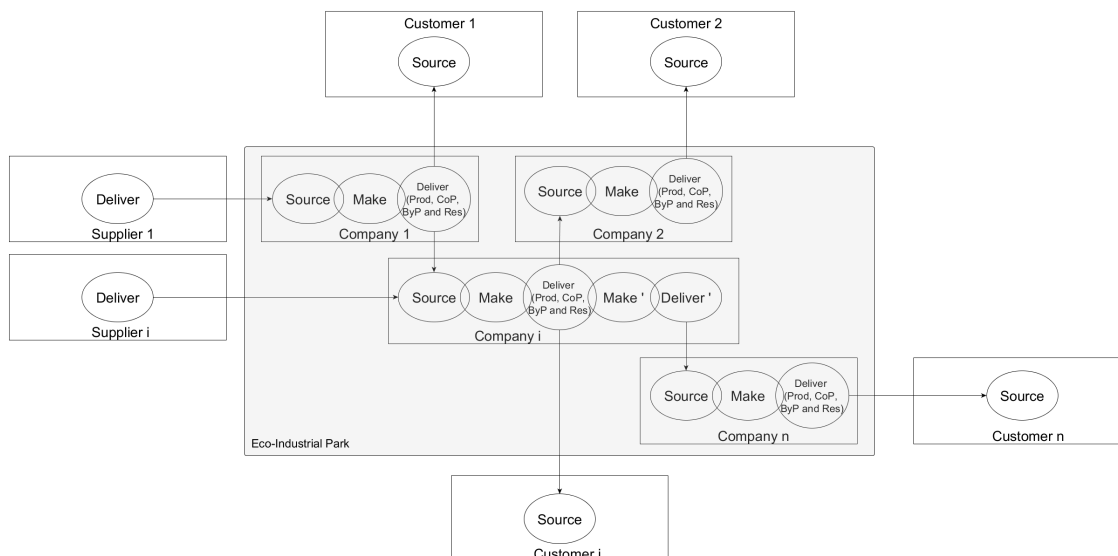


Figure C.3 – Processes structure of an EIP of n companies inherited from the SCOR model (Prod=Product, CoP=Co-Product, ByP=By-Product and Res=Residual Product)

C.5 Case Study

C.5.1 Some elements about Kalundborg EIP

The most famous and documented industrial symbiosis is located in Kalundborg in the Denmark (Ehrenfeld and Gertler, 1997). Kalundborg's industrial symbiosis was built spontaneously, its development was progressive and with no planning. Since 1972, more than thirty materials or energy exchanges were established between the members of the symbiosis : six processing companies, a waste handling company and the municipality of Kalundborg. These bilateral agreements allowed to avoid production of waste and saved a consequential amount of resources. Only seeking economic profit, the members also reaped non-negligible environmental benefits and, following on from this success, Kalundborg has become the exemplary model for Eco-Industrial Development.

C.5.2 Application of the SCOR-inherited model to Kalundborg EIP's symbiosis

As an example of the application of the SCOR model to an EIP, we chose to represent Kalundborg Symbiosis with the process structure described in paragraph C.4.2. Information on Kalundborg's EIP were provided by Kalundborg's symbiosis official website¹ to obtain the most up-to-date data. Indeed, Kalundborg's symbiosis is dynamic : new substitution synergies are sometimes created or broken. With the data gathered, we mapped Kalundborg's symbiosis, as can be seen in Figure C.4. Except for Lake Tisso's surface water, we chose to only represent co-product, by-product and residual product flows within the EIP and their recovery outside the EIP. For the sake of clarity, the EIP members' products and imported primary materials are excluded of the figure and we differentiated energy, water and materials flows. The members of Kalundborg's EIP are :

1. Novo Nordisk, the world's largest producer of insulin ;
2. Novozymes, the world's largest producer of enzymes ;
3. Gyproc, producer of gypsum board ;
4. Kalundborg Municipality, which handles the water and heat supply for Kalundborg's 50,000 inhabitants ;

1. <http://www.symbiosis.dk/en/diagram>

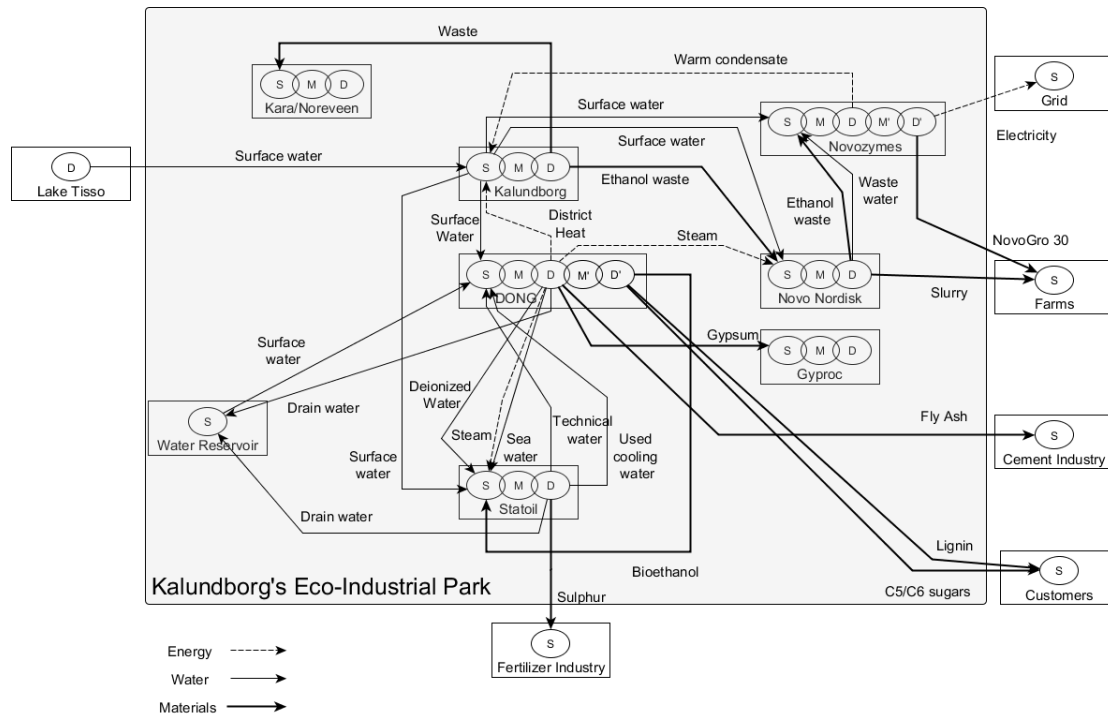


Figure C.4 – Kalundborg symbiosis represented with the inherited SCOR process structure

5. Dong Energy, owner of the Asnæs Plant, the biggest coal fuelled power plant in Denmark ;
6. Statoil, owner of Denmark's biggest oil refinery ;
7. Kara/Novoren, a small waste treatment company ;

As we can see in Figure C.4, DONG Energy and Novozymes both have ancillary *Make'* and *Deliver'* processes. Besides Asnæs Plant, DONG Energy owns Inbicon, a world leading ligno-cellulosic biomass conversion technology that uses Asnæs Plant surplus steam. Novozymes also owns a waste water treatment facility that uses Novozymes' biomass and Novo Nordisk's ethanol waste to produce NovoGro 30, used as a fertilizer by the farms nearby. Finally, since Kalundborg EIP is not focused on mutualisation synergies, our SCOR-inherited model only offers a mapping of the substitution synergy network.

The SCOR model is shown to be a standard enabling the mapping of EIP symbiosis. This first work addressed the use of the SCOR model as a descriptive model, but the SCOR framework offers other services such as benchmarking and performance metrics. Knowing that the SCOR can be adapted to describe an EIP is a first promising step towards the use of all its utilities. Since the philosophy and the goals of an EIP and a SC are not similar, additional work should be done to tailor the SCOR model for the performance evaluation of an EIP.

C.6 Conclusion

Owing to growing environmental concerns, the concept of Industrial Ecology has gained a lot of attention through its concrete application : EIPs. Observing some similarities between EIPs and SCs, we proposed the use of a SCM tool to describe an EIP's symbiosis. The SCOR-model, is Strategic SCM tool helping with the description and performance evaluation of the processes

along the SC, was adapted to map the substitution synergies among an EIP. Applying our SCOR-inherited model to Kalundborg EIP, we have shown that it offers a standardised and original way to represent the processes inside an EIP. In the near future, we wish to apply our SCOR-inherited model to other EIPs : Savoie Technolac, a French Technopole with a philosophy close to the EIP's ; Pomacle-Bazancourt EIP in France, one of the most successful example of bio-refinery in Europe ; and the developing EIP of Victoriaville in Quebec

This prospective work introduces the possibility to use the SCOR model at its fullest, for the evaluation, benchmarking and decision making for the development of an EIP. It also allows the use of other SCM tools associated with the SCOR-model such as performance measurement systems, multi-criteria decision making tools, and aggregation operator, such as the Choquet Integral ([Berah and Clivillé, 2007](#)). Finally, this work means to inspire further research using tools endorsed in the industrial sector for the management and performance measurement of EIPs.

Modèle d'évaluation de la performance et d'aide à la décision pour le développement des écoparcs d'activité

Application aux contextes français et québécois

Résumé

Les parcs industriels, communément définis comme des espaces physiques aménagés pour l'usage simultané de plusieurs entreprises et gérés par un gestionnaire, font aujourd'hui face à des enjeux relatifs à leur aménagement et à leur fonctionnement. La prise en compte du concept de développement durable, vu comme la conjugaison équilibrée de ses trois piliers, respectivement environnemental, économique et social, apparaît comme une réponse à ces enjeux. Ce travail concerne le développement d'un modèle accompagnant les gestionnaires de parcs industriels dans une démarche de développement durable. L'approche présentée est systémique et globale, elle vise l'amélioration continue sur de longs horizons temporels. Le modèle proposé est composé d'une modélisation systémique du parc industriel durable appelé écoparc, d'une méthode d'aide à la décision pour l'établissement d'un plan d'action et d'un sous-modèle d'expression de la performance. Le modèle a été validé auprès de parcs industriels français et québécois offrant un panel diversifié par leur taille, leur maturité et leur engagement dans la démarche de développement durable. Cette diversité a nourri la réflexion et a renforcé la genericité du modèle développé.

Mots-clés : Ecoparc, Parc industriel, Développement durable, Expression de la performance, Aide à la décision multicritère

Abstract

Industrial parks, commonly defined as physical spaces developed for the use of several firms simultaneously and managed by a designated manager, currently face challenge pertaining to their development and operation. Sustainable development, regarded as the conjunction of its three pillars, respectively environmental, economic and social, appears to be the answer to those challenges. This thesis is concerned with the development of a model supporting industrial park managers with their commitment to sustainable development. The presented approach is systemic and global, it seeks continuous improvement on long time horizons. The proposed model consist of a systemic modelling of the sustainable industrial park called mixed-use ecopark, a decision marking method for the establishment of an action plan and a performance expression sub-model. The model was validated with industrial parks from France and Quebec that offers a diverse panel of size, degree of maturity and commitment to sustainable development. This diversity enriched the reflection and strengthened the genericity of the developed model.

Keywords : Mixed-Use Ecopark, Industrial park, Sustainable development, Performance expression, Multi-criteria decision analysis