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Unfolding industrial ecosystems:

Conceptualisation and analysis from a strategic niche management perspective

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Unfolding industrial ecosystems:
Conceptualisation and analysis from a strategic niche management perspective

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With all my imagination, dedicated to my angels, Melek Nursel and Mavi Lluna.

Tüm hayalgücümle, meleklerime ithafen, Melek Nursel ve Mavi Lluna.

Abstract

This thesis confronts the challenge of sustainability problems in traditional industrial production systems which work under linear production routines. It focuses on the industrial ecology approach as one prominent way of addressing those problems. Industrial ecology theory argues for the need of realising circular production routines to overcome the unsustainable linear practices. The overarching principle of industrial ecology thinking is based on achieving the symbiotic resource exchanges among the actors of industrial production systems which can evolve into industrial ecosystems with an analogy to mimic the natural ecosystems. To achieve this, the established routines are subject to some substantial changes, and such changes are related to both technical and social aspects of industrial ecosystems. That also enforces the need to recognise and consider the systemic innovation nature of industrial ecology and calls for a socio-technical approach when studying industrial ecosystems.

Industrial ecology literature provides comprehensive industrial ecosystem case studies distributed over different spaces. These cases mostly remain sustainable fringe experiences and cannot penetrate the mainstream industrial production system development. The existing knowledge in the industrial ecology literature does not explain how transitions into industrial ecosystems following industrial ecology principles can take place; neither establishes the cognitive grounds for understanding unfolding fringe industrial ecosystems. Industrial ecology as a systemic innovation model to drive for transitions of industrial production systems has not found enough attention in the literature, neither the co-evolution of the social and technical aspects of industrial ecosystems. The industrial ecology literature requires to be expanded in both conceptual and empirical accounts, considering those underexplored aspects.

Thereby, this thesis aims to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems. The focus is on two most-studied scales of industrial ecosystems: local and regional. This differentiation also enables a scale rendered approach which provides the grounds for conceptual pluralisation and a deeper understanding of the dynamics of potentially unfolding industrial ecosystems through different scale applications of industrial ecology.

Particularly for conceptualisation ambitions, the thesis initially indicates a missing link between the industrial ecology domain and sustainability transitions field from innovation studies. It argues that middle-range theories of the sustainability transitions field which adopt a systemic view on socio-technical transitions can be insightful for conceptualising unfolding industrial ecosystems. The thesis chooses and engages with the strategic niche management framework from sustainability transitions research. In that sense, industrial ecology is approached as a systemic innovation model and industrial ecosystems as a socio-technical construct, more specifically, as prominent strategic niches for transitions of industrial production systems.

The thesis embodies three research studies with inquiries on unfolding industrial ecosystems. Refined conceptualisations of unfolding industrial ecosystems are proposed taking the niche, experiment, and experimentation concepts as central to the analytical design on niche emergence. The niche-building processes, which are the articulation of expectations and visions, social network-building, and learning processes, are among the core contours of overall conceptualisation. Then, each research study proposes a different conceptual framework for the operationalisation and empirical assessment of unfolding industrial ecosystems.

The thesis relies on methodological pluralisation constructed by employing different methods in the research studies. The first research study follows a case survey through a systematic literature review for analysis of already studied local industrial ecosystem cases (n=104) in the industrial ecology literature through reinterpretation building on the proposed conceptual framework. The second research study employs a multiple case study methodology for analysis of three unfolding local industrial ecosystem cases in the Italian context. Finally, the third research study adopts a single embedded case study methodology for the analysis of an unfolding regional industrial ecosystem in Spain.

Conducted research studies show that the strategic niche management framework provides appropriate and fruitful insights and grounds for conceptualisation and analysis of unfolding industrial ecosystems. The findings suggest that three niche-building processes steer the industrial ecosystem experimentation journey. Moreover, the spatial context has a mediating influence on the interaction and functioning of those processes. Continuous experimentation with industrial ecology projects is vital to maintain the momentum going for unfolding industrial ecosystem niches. If a broad and deep industrial ecosystem niche network emerges, and if it designs and implements appropriate learning tools, then that niche can destabilise the regulatory, normative, and cognitive rules of the existing industrial production systems. Finally, the established linear production routines may experience a shift into circular production routines, and industrial ecology-inspired transitions may occur.

Keywords: Industrial ecology; industrial ecosystems; sustainability transitions; strategic niche management; industrial production systems.

Resumen

Esta tesis se enfrenta al desafío de los problemas de sostenibilidad en los sistemas de producción industrial tradicionales que funcionan bajo rutinas de producción lineal. Se centra en el enfoque de la ecología industrial como una forma destacada de abordar esos problemas. La teoría de la ecología industrial argumenta la necesidad de realizar rutinas de producción circulares para superar las prácticas lineales insostenibles. El principio general del pensamiento ecológico industrial se basa en lograr intercambios de recursos simbióticos entre los actores de los sistemas de producción industrial que pueden evolucionar hacia ecosistemas industriales con una analogía de los ecosistemas naturales. Con el fin de lograr esto, las rutinas establecidas se sujetan a algunos cambios sustanciales y dichos cambios están relacionados con los aspectos técnicos y sociales de los ecosistemas industriales. Eso también impone la necesidad de reconocer y considerar la naturaleza de la innovación sistémica de la ecología industrial y exige un enfoque sociotécnico en el estudio de los ecosistemas industriales.

La literatura sobre ecología industrial proporciona estudios de casos completos de ecosistemas industriales distribuidos en diferentes espacios. La mayoría de estos casos siguen siendo experiencias marginales sostenibles y no pueden penetrar en el desarrollo del sistema de producción industrial convencional. El conocimiento existente en la literatura de ecología industrial no explica cómo pueden tener lugar las transiciones a los ecosistemas industriales siguiendo los principios de la ecología industrial; ninguno establece las bases cognitivas para comprender el desarrollo de los ecosistemas industriales marginales. La ecología industrial como modelo de innovación sistémica para impulsar las transiciones de los sistemas de producción industrial no ha recibido suficiente atención en la literatura, así como tampoco la coevolución de los aspectos sociales y técnicos de los ecosistemas industriales. La literatura sobre ecología industrial debe ser ampliada en los bases conceptuales como empíricos teniendo en cuenta esos aspectos poco explorados.

Por consiguiente, esta tesis tiene como objetivo avanzar en la comprensión de las transiciones inspiradas en la ecología industrial al enmarcar conceptualmente y analizar empíricamente los ecosistemas industriales en desarrollo. La atención se centra en las dos escalas de ecosistemas industriales más estudiadas: local y regional. Esta diferenciación también permite un enfoque basado en la escala que proporciona las bases para la pluralización conceptual y una comprensión más profunda de la dinámica de los ecosistemas industriales potencialmente desplegados a través de diferentes aplicaciones de escala de la ecología industrial.

Particularmente para las ambiciones de conceptualización, la tesis inicialmente marca un eslabón perdido entre el dominio de la ecología industrial y el campo de las transiciones de sostenibilidad de los estudios de innovación. Sostiene que las teorías de rango medio del campo de las transiciones de sostenibilidad que adoptan una visión sistémica sobre las transiciones sociotécnicas pueden ser de gran utilidad para conceptualizar los ecosistemas industriales en desarrollo. La tesis elige e interactúa con el marco de gestión de nicho estratégico de la investigación de transiciones de sostenibilidad. En ese sentido, la ecología industrial se aborda como un modelo de innovación sistémica y los ecosistemas industriales como una construcción sociotécnica, más específicamente, como nichos estratégicos destacados para las transiciones de los sistemas de producción industrial.

La tesis incluye tres estudios de investigación con preguntas sobre el desarrollo de ecosistemas industriales. Se proponen conceptualizaciones refinadas de los ecosistemas industriales en desarrollo tomando los conceptos de nicho, experimento y experimentación como elementos centrales del diseño analítico sobre la aparición de nicho. Los procesos de creación de nichos, que son la articulación de expectativas y visiones, la construcción de redes sociales y los procesos de aprendizaje, se encuentran entre los contornos centrales de la conceptualización general. Posteriormente cada estudio de investigación propone un marco conceptual diferente para la operacionalización y la evaluación empírica de los ecosistemas industriales en desarrollo.

La tesis se basa en la pluralización metodológica construida mediante el empleo de diferentes métodos en los estudios de investigación. El primer estudio de investigación sigue una encuesta de casos a través de una revisión sistemática de la literatura para el análisis de casos de ecosistemas industriales locales ya estudiados (n = 104) en la literatura de ecología industrial a través de la reinterpretación basada en el marco conceptual propuesto. El segundo estudio de investigación emplea una metodología de estudio de casos múltiples para el análisis de tres casos de ecosistemas industriales locales en desarrollo en el contexto italiano. Finalmente, el tercer estudio de investigación adopta una metodología de estudio de caso integrada para el análisis de un ecosistema industrial regional en desarrollo en España.

Los estudios de investigación realizados muestran que el marco estratégico de gestión de nichos proporciona ideas y fundamentos apropiados y fructíferos para la conceptualización y el análisis de los ecosistemas industriales en desarrollo. Los hallazgos sugieren que tres procesos de construcción de nichos conducen el viaje de experimentación del ecosistema industrial. Además, el contexto espacial tiene una influencia mediadora en la interacción y el funcionamiento de esos procesos. La experimentación continua con proyectos de ecología industrial es vital para mantener el impulso para el desarrollo de nichos de ecosistemas industriales. Si surge una red de nicho de ecosistema industrial amplia y profunda y si diseña e implementa herramientas de aprendizaje apropiadas, entonces ese nicho puede desestabilizar las reglas regulatorias, normativas y cognitivas de los sistemas de producción industrial existentes. Finalmente, las rutinas de producción lineal establecidas pueden experimentar un cambio hacia rutinas de producción circular, y pueden ocurrir transiciones inspiradas en la ecología industrial.

Palabras claves: Ecología industrial; ecosistemas industriales; transiciones de sostenibilidad; gestión estratégica de nicho; sistemas de producción industrial.

Sommario

Questa tesi affronta la sfida dei problemi di sostenibilità nei tradizionali sistemi di produzione industriale che operano secondo una logica "lineare" di produzione e consumo. La tesi si concentra sull'approccio all'ecologia industriale come possibile soluzione per affrontare questi problemi. La teoria dell'ecologia industriale sostiene la necessità di adottare modelli di produzione circolari per superare pratiche lineari insostenibili. Il principio generale del pensiero ecologico industriale si basa sul raggiungimento di scambi di risorse simbiotiche tra gli attori dei sistemi di produzione industriale, che possono perciò evolversi in ecosistemi industriali con un'analogia degli ecosistemi naturali. Per raggiungere questo obiettivo, le logiche di funzionamento dei sistemi industriali devono modificarsi in maniera sostanziale e questi cambiamenti sono correlati agli aspetti tecnici e sociali degli ecosistemi industriali. Ciò impone anche la necessità di riconoscere e considerare la natura dell'innovazione sistemica dell'ecologia industriale, che richiede un approccio sociotecnico nello studio degli ecosistemi industriali.

La letteratura sull'ecologia industriale fornisce casi di studio completi sugli ecosistemi industriali distribuiti in aree diverse. La maggior parte di questi casi rimane però a livello aneddotico e/o con un impatto marginale sull'ecosistema e non modifica quindi in maniera apprezzabile lo sviluppo del sistema di produzione industriale convenzionale. Le conoscenze esistenti nella letteratura sull'ecologia industriale non spiegano come le transizioni verso gli ecosistemi industriali possano avvenire seguendo i principi dell'ecologia industriale; nessuno stabilisce le basi cognitive per comprendere lo sviluppo degli ecosistemi industriali marginali. L'ecologia industriale come modello di innovazione sistemica per guidare le transizioni dei sistemi di produzione industriale non ha ricevuto sufficiente attenzione nella letteratura, né la coevoluzione degli aspetti sociali e tecnici degli ecosistemi industriali. La letteratura sull'ecologia industriale deve essere ampliata nelle basi concettuali ed empiriche, tenendo conto di questi aspetti poco esplorati.

Pertanto, questa tesi mira a far progredire la comprensione delle transizioni ispirate all'ecologia industriale inquadrando concettualmente e analizzando empiricamente lo sviluppo di ecosistemi industriali sostenibili. L'attenzione si concentra sulle due "dimensioni" più studiate degli ecosistemi industriali: locale e regionale. Questa differenziazione consente anche un approccio che fornisce le basi per la generalizzazione concettuale e una comprensione più profonda della dinamica degli ecosistemi industriali potenzialmente dispiegati attraverso diverse applicazioni dell'ecologia industriale.

Soprattutto per le ambizioni di costruzione di nuova teoria, la tesi inizialmente evidenzia come *gap* il legame mancante tra il dominio dell'ecologia industriale e il campo della transizione dello sviluppo sostenibile. La tesi affronta e interagisce la teoria della *niche strategy* sulla transizione di sostenibilità. In tal senso, l'ecologia industriale si basa su un modello di innovazione sistemica e sugli ecosistemi industriali come costruzione sociotecnica, più specificamente, come nicchie strategiche eccezionali per le transizioni dei sistemi di produzione industriale.

La tesi è costituita da tre studi di ricerca che indagano lo sviluppo degli ecosistemi industriali. Questi studi rifiniscono la teoria per gli ecosistemi industriali in transizione, prendendo i concetti di nicchia, esperimento e sperimentazione come elementi centrali dell'analisi sull'emergenza delle nicchie. I processi di creazione delle nicchie, che sono l'articolazione di aspettative e visioni, la costruzione delle reti sociali e i processi di apprendimento delineano i contorni principali

dell'eleborazione teorica generale. Inoltre, ogni studio propone un quadro concettuale diverso per l'operazionalizzazione e la valutazione empirica dello sviluppo degli ecosistemi industriali.

La tesi si basa sulla pluralizzazione metodologica, costruita attraverso l'utilizzo di diversi metodi di ricerca per i diversi studi. Il primo studio realizza un'analisi sistematica dei casi empirici di ecosistemi industriali presenti in letteratura (n = 104), reinterpretati attraverso un nuovo framework concettuale. Il secondo studio adotta una metodologia multi-caso per analizzare la transizione di tre ecosistemi industriali locali inseriti nel contesto italiano. Infine, il terzo studio adotta una metodologia basata sull'analisi di un singolo studio di caso incorporato per analizzare la transizione di un ecosistema industriale regionale in Spagna.

Gli studi condotti dimostrano come il framework per la gestione strategica di nicchia fornisca informazioni appropriate ed importanti, nonché le fondamenta per teorizzare e analizzare la transizione degli ecosistemi industriali. I risultati suggeriscono che tre processi di costruzione delle nicchie guidano il percorso di sperimentazione degli ecosistemi industriali. Inoltre, il contesto spaziale ha un'influenza mediatrice sull'interazione e sul funzionamento di questi processi. La sperimentazione continua con i progetti di ecologia industriale è vitale per mantenere lo slancio necessario ai fini dello sviluppo delle nicchie di ecosistemi industriali. Se una vasta e profonda rete di nicchie di ecosistemi industriali emerge, progettando e implementando degli strumenti di apprendimento adeguati, allora tali nicchie possono destabilizzare regolamentazioni, normative e regole cognitive dei sistemi di produzione industriale esistenti. Infine, le routine lineari di produzione consolidate possono subire uno spostamento verso routine di produzione circolari, portando ad una possibile transizione ispirata all'ecologia industriale.

Parole chiave: ecologia industriale; ecosistemi industriali; transizione sostenibile; gestione strategica di nicchia; sistemi di produzione industriale.

List of publications

This Doctoral Thesis includes three academic articles which are provided at the end in the Appendices:

I. Susur, E., Hidalgo, A., Chiaroni, D., 2019. A strategic niche management perspective on transitions to eco-industrial park development: A systematic review of case studies. *Resources, Conservation and Recycling* 140, 338-359. https://doi.org/10.1016/j.resconrec.2018.06.002

II. Susur, E., Martin-Carrillo, D., Chiaroni, D., Hidalgo, A., 2019, Unfolding eco-industrial parks through niche experimentation: Insights from three Italian cases. *Journal of Cleaner Production* 239. https://doi.org/10.1016/j.jclepro.2019.118069

III. Susur, E., Hidalgo, A., Chiaroni, D., 2019, The emergence of regional industrial ecosystem niches: A conceptual framework and a case study. *Journal of Cleaner Production* 208, 1642-1657. https://doi.org/10.1016/j.jclepro.2018.10.163

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Ebru Susur,

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Chapter 1. Introduction

This is the introduction chapter of the thesis, which aims to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems with a strategic niche management perspective. This chapter provides the research background and motivation, presents the overall research objective and following research studies, and gives the structure of the thesis.

1.1. Research background and motivation

Industrial production systems and sustainability concerns

Industrial production is a historical crucial human activity with an increasing acceleration especially since the industrial revolution when the drastic shift occurred towards intensive production, rapid growth, a particular focus in productivity, marginalised living standards, and overcapacity (Jensen, 1993). The unsustainable industrial production routines and their adverse outcomes on the surrounding society and the planet have been increasingly debated in academic and policy discourses in the last five decades since the sustainability concept was explicitly introduced in 1972 at Stockholm United Nations Conference on Sustainable Development. Since then, sustainability has been transforming into an imperative in agendas of the academicians and policy-makers. Recently, in 2015, United Nations set 17 Sustainable Development Goals (SDGs) to achieve by the year 2030 (United Nations, 2015), which call for urgent radical and systemic actions in order to fight against the economic, environmental and social problems in tandem, and to create a more equal and better quality of living standards for today's and future's generations (see Figure 1 - 1). The unsustainability problem in industrial production substantially contributes to the crucial moment of transition that the modern and advanced world is currently facing (Mazzucato & Perez, 2015). Yet, in practical terms, the sustainability concept could not find its motivated audience for the real changes due to the increasingly expanding ideas and norms around prioritising economic growth. That also results in emerging resistance from the existing actors against the radical and systemic changes in the current industrial production routines.

Figure 1 - 1: 17 Sustainable Development Goals set by the United Nations.
Source: (United Nations, 2015)

This thesis brings an inquiry on the intersection of industrial production and sustainability, perhaps an unachievable point due to the wicked nature of sustainability (Blok, et al., 2016). Although recognising the 17 SDGs by the United Nations, the thesis approaches sustainability not as a normative principle but as an analytical concept (Funfschilling, 2014) which can be operationalised, studied, understood and explained for specific contexts (Grin, et al., 2010). Moreover, the SDGs even can come to tension with each other, and some trade-offs may emerge if sustainability is blindly taken as a normative principle (Scherer, et al., 2018). What is sustainable can differ from context to context and from actor to actor considering varying interests, values, belief systems and interpretations (Garud & Gehman, 2012).

The potential analytical intersection of industrial production and sustainability can be conceptualised and analysed with a focus on individual industrial firms, collaborations and networking among industrial actors, related institutions, regulatory frameworks, business models, etc. in an industrial sector or multiple sectors, depending on the specific research interest. This thesis takes a systems perspective to have a holistic picture of industrial production and sustainability bricolage, and it focuses on sustainability transitions for more sustainable forms of industrial production at the system level without a priori general assumptions on what or how sustainable should be in a normative way.

When studying industrial production at the systems level, the boundaries can be blurred and not easy to identify. For clarity purposes, this thesis focuses on the sustainability problems in the local and regional scale industrial production systems. Although an ideal definition is not easy to formulate, at local and regional scales, industrial productions systems can be defined as geographically agglomerated and clustered industrial production firms (Lombardi, 2003; Ellison, et al., 2010; Geng & Hengxin, 2009) working under conventional production routines with linear processes (McManus & Gibbs, 2008)[1]. As the idea behind developing industrial agglomerations has been passing through different stages in time facing new academic debates, the concepts of the industrial district, industrial cluster and industrial park have been used interchangeably referring to industrial production systems in literature, specifically at the local scale (Cote & Cohen-Rosenthal, 1998; Vidova, 2010).

Implementation of local and regional scale industrial production systems is an essential part of regional economic development policies (Singhal & Kapur, 2002; Deutz & Gibbs, 2008). They are distributed all around the world, and as specific to Europe they are still seen as vital to regional economic development, and highly supported by international organisations like the United Nations Industrial Development Organisation (2012; 2014). Furthermore, mainly, the European Union gives special attention to them, to enhance innovation, research and development activities, and competitive clusters and networks (Ablonczy-Mihalyka & Keckkes, 2015). If managed properly, industrial production systems "can mobilise local assets, talent pools, leverage the history and culture of a region and become kernels of growth and innovation" (United Nations Industrial Development Organization, 2014, p. 15). Having a high potential for driving innovation, creating new markets and enhancing development, however, environmental pillars of sustainable development so far have not been paid enough attention during their development.

[1] Linear processes in traditional industrial production systems refer to approach of prevalent take-make-dispose practices or alternatively input–process– output–waste relationships of the industrial firms which go against the resource productivity (Blomsma & Brennan, 2017; Bey, 2001; Frosch & Gallapoulus, 1989). This approach is highly criticised as it perceives nature as endless resources and sees disposal of waste as an inherent component of industrial production (McManus & Gibbs, 2008).

Due to the concentration of a large number of industries in such agglomerated systems, they can pose severe environmental impacts on the surrounding society and nature, and that may end in adverse effects on the economy as well. The possible negative impacts include but not limited to: inefficient resource use, use of non-renewable energy sources, contaminated soil and lost future land use, disposal of solid wastes, local nuisances such as noise, exposure to toxic chemicals, risks from hazardous waste, marine pollution, freshwater pollution, air pollution, habitat degradation, ozone-depleting and greenhouse gases, and landscape disturbance, etc. (Singhal & Kapur, 2002). There is a need to tackle with those challenges (United Nations Industrial Development Organization, 2012) and this requires an attempt to transform our approach to industrial production, "make industry fit the environment instead of changing the environment to fit the industry" (Carr, 1998, p. 240) and realise a fundamental shift into more sustainable forms of industrial production.

Such a transition is related to and may require engagement from a broader range of actors than only the industry itself. A debate can be provoked here on the general understanding of an industrial production system, which emphasises only the agglomerated industrial organisations with a technical focus. This thesis argues that industrial production systems hold both technical and social elements at organisational and institutional levels and those elements are interdependent and intertwined through dynamics between the industrial organisations, as well as the governmental and non-governmental organisations, universities and research centres, intermediaries, etc. In parallel, those actors, together with institutions, are subject to change in their configurations, and they contribute to long-time co-evolving technical and social elements of industrial production systems in a complex form. That complexity is worth to consider to explain the resistance for changes at the systems level. Therefore, focusing only on technical elements by offering technology alternatives as solutions to the unsustainable routines is not enough to cover the social aspects. Because they are intertwined with the routines embedded in the culture, rules, lifestyles, policies and regulatory frameworks, and overall functioning economic systems, etc. Therefore, there is a need to hold a socio-technical approach when dealing with the sustainability problem of industrial production systems (see (Schot & Kanger, 2018; Kemp, et al., 1998)).

Industrial ecology and industrial ecosystems

A prominent way of realising transitions into more sustainable industrial production systems can be through resource exchanges between the system actors while changing the existing production routines based on linear processes. This argument connects the industrial production system perspective to *'industrial ecosystems'* (Adamides & Mouzakitis, 2009; Korhonen, 2001). Industrial ecosystems, both analytically and practically, function based on the synergies created through symbiotic exchanges of physical and non-physical resources between the actors (Ashton, 2008). Physical resources may include materials, water, energy, infrastructure and natural habitat (Chertow, 2000) and, on the other hand, non-physical resources may consist of information, knowledge, expertise, and management (Lombardi & Laybourn, 2012). Industrial ecosystems approach is analogous to mimicking the principles of natural ecosystems to the industrial processes (McManus & Gibbs, 2008; Frosch & Gallapoulus, 1989; Ehrenfeld, 2003) with an ambition to contribute to more sustainable forms on industrial production.

Industrial ecosystems through industrial ecology practices are relevant for positive contribution to 17 Sustainable Development Goals, as demonstrated in the recent systematic literature review

study of Sullivan et al. (2018). Yet, the ones to which they can substantially contribute are Goals 7-Affordable and Clean Energy, 9-Industry, Innovation and Infrastructure, 12-Responsible Consumption and Production, and 13-Climate Action (Sullivan, et al., 2018). The apparent industrial ecology practices for these 4 Goals are energy efficiency, innovation, closing the production cycle and impact reduction (see in Figure 1 - 2).

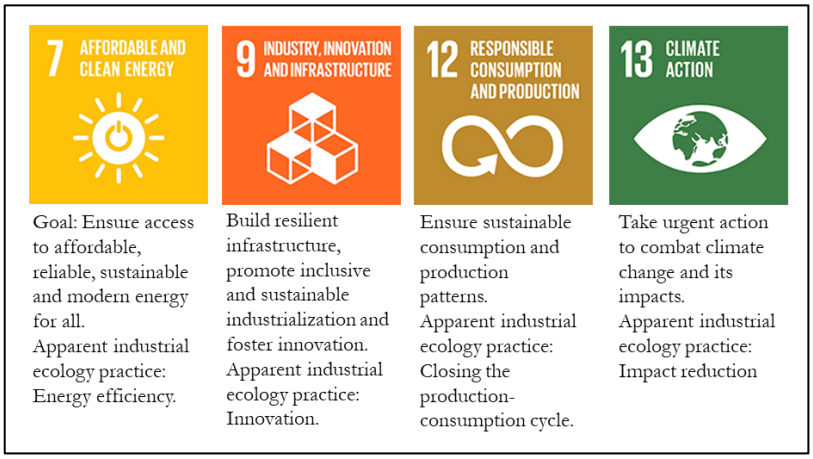

Figure 1 - 2: The Sustainable Development Goals and industrial ecosystems.
Author's elaboration based on (Sullivan, et al., 2018; United Nations, 2015).

The nature, techniques, practices, logic, forms and dynamics of such symbiotic resource exchanges have been widely investigated under '*industrial ecology*' literature in the last three decades (Erkman, 1997; Cote & Hall, 1995; Lowe & Evans, 1995; Chertow, 2000; Baas & Boons, 2004; Gibbs, et al., 2005; Chertow & Ehrenfeld, 2012; Deutz & Ioppolo, 2015; Carr, 1998; Ehrenfeld, 2004). Theoretical standpoint of industrial ecology literature argues that the problem of traditional industrial production systems is the linear industrial production routines (Frosch & Gallapoulus, 1989) and industrial ecology practices held by industrial ecosystems can bring a transition into circular industrial production routines (Chertow, 2000; Felicioa, et al., 2016; Sterr & Ott, 2004).

The geographical perspective has been central in this literature. The scholars particularly emphasise potential advantages of industrial agglomerations to adopt and develop industrial ecosystems specifically at local and regional scales (Ashton, 2008; Lowe & Evans, 1995; Lombardi & Laybourn, 2012). More specifically, the local scale industrial ecosystems, also called as eco-industrial parks (EIPs), have received more extensive attention (Carr, 1998; Ehrenfeld & Gertler, 1997). The previous studies have covered various industrial ecosystem cases distributed worldwide (Boons, et al., 2011; Baas & Boons, 2004; Ashton, 2008). The evidence shows that these cases remain fringe sustainable industrial production system experiences. However, the question of how the industrial ecology-inspired transitions into the industrial ecosystems take place remains as a problem (Gibbs, 2009; Adamides & Mouzakitis, 2009), which indeed requires a further understanding in industrial ecology literature.

Indeed, the general emphasis of industrial ecology remained only at the level of potential technical improvements in particular industrial production systems– that was also critiqued in the literature (e.g. (Gibbs, 2009; Truffer & Coenen, 2012; Smith, et al., 2010)). The potential systemic innovation nature of industrial ecology to drive for systemic transitions can be considered as one way to address that problem and also calls for the need to further elaborate on not only technical but also social aspects of the industrial ecosystems (Gibbs 2009).

Following this, industrial ecology can be considered as a systemic innovation model (Machiba, 2010; Gibbs, 2009; Adamides & Mouzakitis, 2009). Applied industrial ecology triggers innovation and accumulates into a systemic innovation model (Mirata & Emtairah, 2005; Boons, et al., 2017; Taddeo, et al., 2017; Valentine, 2016; Lombardi, et al., 2012) which can lead to fundamental technological, institutional and cultural changes at organisational and sectoral levels in industrial production systems (Adamides & Mouzakitis, 2009). However, there has not been an explicit attempt to construct a firm link between industrial ecology and innovation studies.

Sustainability transitions and strategic niche management

Along similar lines to the systemic innovations needed due to sustainability concerns, the most salient and promising research stream from innovation studies is the sustainability transitions field. In this research field, it is claimed that systemic and radical changes are in need, given the critical risks associated with ongoing sustainability challenges (Schot & Geels, 2008; Smith & Raven, 2012; Markard, et al., 2012).

Scholars in the field have studied sustainability transitions of socio-technical systems, characterised by co-evolving social and technical elements, through fundamental sustainable changes – that is, radical and systemic innovations – at individual, organisational, sectoral and societal levels through institutional, technological and cultural dimensions under influence of a broad range of actors (Truffer & Coenen, 2012; Geels, 2002; Raven, 2007; Farla, et al., 2012; Fuenfschilling & Truffer, 2014; Rip & Kemp, 1998).

Although a noticeable potential link appears between the industrial ecology and sustainability transitions research fields, sustainability transitions scholars have not paid attention to or prioritised industrial ecology literature so far. On the other hand, there are only a few studies from industrial ecology literature that have built on the sustainability transitions foundations, only at the level of borrowing some concepts (e.g. (Baas & Huisingh, 2008; Gibbs, 2009; Adamides & Mouzakitis, 2009)). There is an apparent missing bridge between these two research fields, which is timely to address.

Recognising that missing bridge, this thesis argues that the middle-range theories proposed by the sustainability transitions literature can be insightful for studying industrial ecology as a systemic innovation with a potential to bring transitions of industrial production systems. The most salient frameworks are *the multi-level perspective on socio-technical transitions* (Geels, 2002; Rip & Kemp, 1998; Geels & Schot, 2007), *strategic niche management* (Schot & Geels, 2008; Schot, et al., 1994; Kemp, et al., 1998), *technological innovation systems* (Bergek, et al., 2015; Hekkert, et al., 2007; Bergek, et al., 2008). This thesis chooses and engages with the strategic niche management framework approach. Strategic niche management framework has been prominent for analysing niche experiments as a strategy for sustainability transitions (Kemp, et al., 1998). Niche and experimentation stand as the central concepts of the theoretical model. Niches, analytically, act as incubation rooms for novelties by providing locations for networking and learning processes (Geels, 2011).

1.2. Research objective

Following the built argumentation above, this thesis highlights the potential of industrial ecology applications to bring changes at a broader systems level rather than limiting their potential to incremental technical improvements in particular industrial production systems. Industrial ecosystems may unfold through continuous implementation of industrial ecology practices and the dynamics between the broad range of actors may transform into symbiotic interactions. Then the configurations of actors and institutions may co-evolve into technical and social elements of industrial ecosystems.

Following these, this thesis argues for an elaborated understanding of the unfolding industrial ecosystems to shed some light on the potential industrial ecology-inspired transitions in the long-term. The thesis approaches industrial ecology as a systemic innovation model and leverages the industrial ecosystems as a socio-technical construct by extending its mostly-studied technical background in the literature. More specifically, the thesis considers industrial ecosystems as an analytical socio-technical construct which may represent more sustainable industrial production systems, if such an industrial ecology-inspired transition occurs in the future, but it does not suggest industrial ecosystems as the unique and ultimate solution to the sustainability problem of industrial production systems.

Therefore, the objective of this thesis is to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems. Thus, the overarching research question is:

How can unfolding industrial ecosystems be conceptualised and empirically analysed?

With an ambition to answer that research question, the thesis employs three research studies. Each research study develops a refined conceptual framework through integrating the insights from strategic niche management framework into the industrial ecology theory and applies that framework in different contexts through different research designs. The strategic niche management framework provides useful insights for studying how industrial ecosystems if conceptualised as niches can unfold. While the first two studies have a local scale industrial ecosystem focus, the third study emphasises the regional scale. In doing so, the thesis brings theoretical, methodological and empirical pluralisation for conceptualisation and analysis of industrial ecosystems.

In Research Study I, the research inquiry is on potential transitions into local industrial ecosystem development, and a conceptual framework is proposed for studying and understanding the dynamics to achieve such transitions. As the inquiry is on a broad local industrial ecosystem development model, the study analyses a comprehensive set of local industrial ecosystems cases distributed worldwide and already studied in the existing state of the, following the proposed conceptual framework. The outcome of this research study is the appended Article I.

In Research Study II, the research inquiry is on unfolding local industrial ecosystems over traditional industrial production systems. A conceptual elaboration is proposed on the journey of becoming a local industrial ecosystem. Furthermore, an empirical analysis is conducted for particular local industrial ecosystem cases in real contexts. The outcome of this research study is appended Article II.

Finally, in Research Study III, the research inquiry is on unfolding regional industrial ecosystems through local industrial ecology projects applied in industrial production systems. Local projects and their aggregated contribution to an emerging regional industrial ecosystem are first conceptualised and then analysed in a real setting. The outcome of this research study is the appended Article III.

Conceptualisation and analysis efforts in this thesis by bringing insights from strategic niche management framework attempt to reconstruct and represent the unfolding industrial ecosystems at different scales. Those efforts let this thesis bring in issues from the sustainability transitions research with different terminologies and more importantly, with alternative lines of interpretations and meanings. That enlarges the industrial ecosystem perspective and brings richness to the industrial ecology literature, in particular regarding the potential future industrial ecology-inspired transitions of industrial production systems into the industrial ecosystems. On the other hand, new empirical accounts are made available to the sustainability transitions field, which contributes to the contextual extension of the strategic niche management approach.

1.3. Structure of the thesis

This thesis includes the cover essay and three appended articles as outcomes of three research studies (see Figure 1 - 3).

The cover essay is composed of six chapters. **Chapter 1** provides the introduction which presents the research background and motivation and provides the overall research objective. **Chapter 2** provides the theoretical foundations of the industrial ecology and particularly industrial ecosystems literature. After bridging the industrial ecology to sustainability transitions field, the insights from strategic niche management framework are introduced for further conceptualisation purposes. Finally, the overall conceptual framing of the thesis, as well as the proposed specific frameworks are presented to operationalise the involved research studies. **Chapter 3** provides the overall research design covering epistemological, ontological, axiological assumptions, the methodological perspective, and the associated methods in three research studies which result in three appended articles. These first three chapters establish the grounds of the conducted three research studies which result in three scientific articles. **Chapter 4** summarises these articles outlining their purpose, methodology, findings, implications, originality/value, and contributions to the thesis. In **Chapter 5**, the results of the articles are synthesised and discussed. Finally, **Chapter 6** concludes by revisiting the overarching research objective followed by the contributions and implications of the thesis.

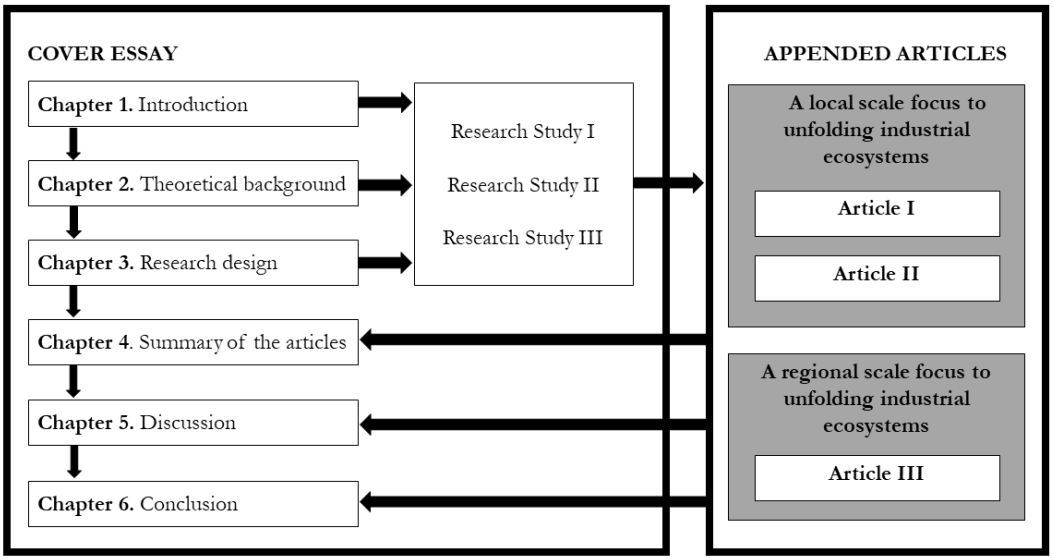

Figure 1 - 3: Structure of the thesis.

Chapter 2. Theoretical background

This chapter presents the theoretical background of the thesis in line with its interdisciplinary approach through which concepts from more than one academic literature are taken and integrated to achieve the overall research objective. More specifically, the thesis builds on and problematise the theoretical foundations of industrial ecology literature with a particular focus on the phenomenon of unfolding industrial ecosystems; brings insights from the strategic niche management, which is a middle-range theory from sustainability transitions field; and proposes an integrated conceptualisation embodying three frameworks as heuristics for the involved research studies.

2.1. Industrial ecology and industrial ecosystems

Industrial ecology has been once defined as the science of sustainability by Ehrenfeld (2004). It is a theory which argues for mimicking the principles of natural ecosystems to the industrial processes (Erkman, 1997; Graedel & Allenby, 1995; Korhonen, 2004). Initially, industrial ecology literature emphasised the symbiotic interactions among the system actors (stressing the interactions between industrial organisations) through the exchange of physical resources, including materials, water, energy, infrastructure and natural habitat (Chertow, 2000; Deutz & Gibbs, 2004). In time, the theory has been expanded by also involving the non-physical resource exchanges including information, knowledge, expertise, and management (Lombardi & Laybourn, 2012) and by considering the potential symbiotic relations between the industry and as well as the other system actors such as governmental organisations, universities, research centers, management bodies and non-governmental organisations, etc. (Baas & Boons, 2004; Boons, et al., 2011).

In industrial ecology literature, the industrial production systems incorporating industrial ecology principles are conceptualised as industrial ecosystems (Deutz & Gibbs, 2008; Frosch, 1992; Frosch & Gallapoulus, 1989; Korhonen, 2001). Industrial ecosystems thinking is about enhancing the environmental, social and economic performance of industrial production systems through efficient resource exchanges (Lowe, et al., 1995; Cote & Hall, 1995). They are mostly studied and promoted at local and regional scales (Korhonen & Snäkin, 2005; Paquin & Howard-Grenville, 2009), considering the potential advantages offered by the geographic proximity among the agglomerated industries (Chertow, 2000). The literature refers to the local scale industrial ecology as eco-industrial parks (EIPs) (Carr, 1998; Ehrenfeld & Gertler, 1997). However, industrial ecosystems can theoretically and practically operate at national scales as well (Lombardi & Laybourn, 2012).

Industrial ecosystems can be considered as next-generation industrial production systems and are mostly-studied through evolutionary ontologies. On the one hand, one approach argues that industrial ecosystems can evolve through: (i) self-organising mechanisms in a bottom-up approach, (ii) facilitated industrial ecology initiatives, or (iii) planned from scratch actions in a top-down approach (Paquin & Howard-Grenville, 2012; Chertow, 2007). On the other hand, Lambert and Boons (2002) proposed another typology for the evolutionary path of industrial ecosystems: greenfield and brownfield approach. Greenfield industrial ecosystem emergence refers to establishment of new industrial ecosystems from scratch through a top-down formulation of the requirements beforehand, whereas brownfield emergence refers to the restructuring of existing industrial production systems (Lambert and Boons 2002).

The literature argues that self-organised, facilitated, brownfield industrial ecosystems may end up with better sustainability performances (Gibbs and Deutz 2007; Chertow 2007; Gibbs, Deutz and Proctor 2005). Those approaches argues for the importance of building upon existing and potential linkages within a locality (Gibbs and Deutz 2007); using existing strengths between the system actors instead of trying to create a system from scratch (Gibbs, Deutz and Proctor 2005); and uncovering the already existing 'precursors' and 'kernels' of symbiotic interactions (Lambert and Boons 2002). Yet, they also recognise that planning still is crucial, particularly, if applied in the early stages of industrial ecosystem development and if it is combined with a facilitated model to achieve long-term goals for transitions of industrial production systems (Yu, et al., 2015).

Industrial ecosystems: A technical or a socio-technical construct?

The previous literature studied industrial ecosystems, mainly focusing on different dimensions of material resource exchanges at inter-firm level, as such approached industrial ecosystems as a technical construct. Yet, there is also number of studies which bring insights from social sciences while approaching industrial ecosystems as a socio-technical construct and focusing on the social dimensions of resource exchanges.

On the one hand, the traditional industrial ecology literature involves a wide variety of studies which focus on the technical elements – that is, more focused on realising the optimal physical resource exchange grounds between the industrial actors – of industrial ecology and industrial ecosystem development. A part of this technical-oriented research line investigates the performance assessment of different sustainability pillars of industrial ecology and as well as the success and failure factors behind the particular industrial ecosystem cases. Those cases are most of the time at local and regional scales from different countries worldwide, including but not limited to: Australia (Rosano & Schianetz, 2014; Van Beers, 2015), China (Yu, et al., 2015; Shi & Yu, 2014; Zhu, et al., 2015; Zhang, et al., 2010; Shi, et al., 2010; Geng & Hengxin, 2009), Egypt (Sakr, et al. 2011), Finland (Lehtoranta, et al. 2011), India (Singhal & Kapur, 2002), Italy (Tessitore, et al., 2015; Mannino, et al., 2015; Taddeo, et al., 2012), South Korea (Park & Behera, 2014; Jung, et al., 2013; Park, et al., 2008; Kim, 2007); Latvia (Rosa and Beloborodko 2014), Netherlands (Spekkink 2013), Puerto Rico (Chertow & Lombardi, 2005; Ashton, 2011), Thailand (Panyathanakun, et al., 2013), United Kingdom (Paquin, et al., 2014), and United States (Gibbs & Deutz, 2005; Veleva, et al., 2015; Hewes & Lyons, 2008; Martin, et al., 1998; Carr, 1998).

Another part of this line draws insights on new perspectives for realising or improving industrial ecology practices by: bringing novel methodologies (Liu, et al., 2015; Jensen, et al., 2012; Conticelli & Tondelli, 2013; Haskins, 2007); developing research and planning frameworks to promote symbiotic relationships (Roberts, 2008; Behera, et al., 2012); integrating renewable energy technologies (Wells and Zapata 2012) and green supply chains (Li, et al. 2015) into industrial ecosystem development; proposing new information and technology tools to enable industrial ecology opportunities (Sterr and Ott 2004); and generating guidelines for realising industrial ecosystem projects (Madsen, et al. 2015). Furthermore, industrial ecology networks have been studied as well with respect to their: forming process and growth patterns (Zhu and Ruth 2014); resilience and sustainability (Chopra and Khanna 2014); operational logic and architecture in order to come up with a typology (Patala, et al. 2014); and structural characteristics using social network analysis (Tang, et al., 2012).

Despite generating new knowledge and giving significant insights and implications about industrial ecosystem development, the traditional focus on technical elements emphasising the physical resource exchanges among industrial organisations resulted in a challenge for industrial ecology literature. It received critiques for falling into the trap of underestimating the overall problem as a technical one which is about how to design an optimal industrial ecosystem (Truffer and Coenen 2012) with an optimal physical resource exchange network. Indeed, industrial ecology has an unneglectable social dimension related to the symbiotic interactions among multiple actors, not only involving the industry, although it is the leading player.

On the other hand, industrial ecology literature also involves studies related to the social dimension of industrial ecology and industrial ecosystems. Those studies attempt to study industrial ecology and industrial ecosystems drawing upon social science theories, mostly through borrowing some related concepts and applying them in some industrial ecosystem cases (Spekkink 2015). Table 2 - 1 presents the previous studies from the industrial ecology literature together with related social science theory and concept(s).

Table 2 - 1: Social dimension of industrial ecology in the literature.

Publication	**Social science theory/ concept**
(Spekkink 2013)	Institutional capacity
(Boons and Spekkink 2012)	Institutional capacity
(Boons, Spekkink and Mouzakitis 2011)	Evolutionary perspective; Institutional capacity
(Paquin and Howard-Grenville 2012)	Evolutionary perspective; Social embeddedness
(Chertow & Ashton, 2009)	Social embeddedness
(Baas and Huisingh 2008)	Social embeddedness; Capabilities; Sustainable transitions
(Baas and Boons 2007)	Capabilities
(Hewes and Lyons 2008)	Trust; Social embeddedness; Regional champions
(Schiller, Penn and Basson 2014)	Ecological economics; Network perspective; Social embeddedness
(Ashton and Bain 2012)	Network perspective; Social embeddedness
(Domenech and Davies 2011)	Network perspective; Embedded networks; Trust
(Ashton, 2008)	Network perspective; Connectivity; Communication; Trust
(Deutz and Gibbs 2008)	Cluster and network theory; Economic geography
(Baas and Boons 2004)	Organisational learning; Techno-economic approach
(Costa and Ferrao 2010)	Middle-out approach
(Costa, Massard and Agarwal 2010)	Policy interventions; Social, informational, technological, economic and political factors
(Chertow and Ehrenfeld 2012)	Biological, ecological, organisational and systems theory
(Korhonen 2001)	Natural ecosystems; Roundput; Diversity; Locality and gradual change
(Wright, et al. 2009)	Ecological theory; Connectance; Diversity
(Deutz and Ioppolo 2015)	System theory; Complex adaptive systems; Policy and geographic contexts
(Ashton 2009)	Economic geography; Complex systems
(Deutz and Lyons 2008)	Economic geography
(McManus and Gibbs 2008)	Urban planning; Economic geography

Publication	Social science theory/ concept
(Chertow, Ashton and Espinosa 2008)	Agglomeration economies; Economic geography; Regional science
(Gregson, et al. 2012)	Agglomeration economies
(MacLachlan 2013)	Agglomeration economies
(Veiga and Magrini 2009)	Spatial analysis
(Bai, et al. 2014)	Spatial analysis
(Desrochers and Leppala 2010)	Spatial analysis; Geography; Economy
(Gibbs, Deutz and Proctor 2005)	Geography; Regional development
(Yu, et al., 2015)	Urban planning
(Mirata and Emtairah 2005)	Environmental innovation
(Deutz 2009)	Ecological modernisation
(Huber 2000)	Ecological modernisation
(Lambert and Boons 2002)	Learning; Sustainable development
(Adamides and Mouzakitis 2009)	Sustainability transitions; Socio-technical systems; Strategic niche management
(Gibbs 2009)	Sustainability transitions; Socio-technical systems; Niches
(Rotmans and Loorbach 2009)	Transition management; Complex systems theory
(Verguts, et al. 2016)	Organisational change; Middle-out approach; Transition management

Review of the literature shows that industrial ecology and industrial ecosystems have gained widespread attention from scholars having different backgrounds, which makes the field an interdisciplinary field. The discussions of previous studies focus on technical and social dimensions of industrial ecology, and approach industrial ecosystems as a technical construct and less frequently as a socio-technical construct.

This thesis argues that focusing on technical dimensions and narrowing industrial ecology to material exchanges between firms inside the industrial production systems is not competent enough to cover the complex phenomenon of industrial ecology. An industrial ecosystem incorporates both technical and social elements based on complex interaction dynamics among wide range of actors (Mouzakitis, Adamides and Goutsos 2003), including industrial production system management bodies (Boons, et al., 2011; Gibbs, et al., 2005), individual industrial organisations, governmental organisations, universities and research institutes (Valentino, 2015; Lowe, 2001), and regional champions (Hewes and Lyons 2008). That complexity depends on the co-evolution of social and technical elements of industrial ecosystems (Gibbs, 2009), which typically builds on a systemic and collaborative interaction between the actors and institutions (Huber 2000) to bring the systemic progress towards the goal of sustainable industrial production (Panyathanakun, et al., 2013; Machiba, 2010). That complexity again reminds a need for a holistic, systemic perspective when studying industrial ecosystems. One promising way of achieving this is by stressing the systemic innovation nature of industrial ecology, which may bring the transitions into the industrial ecosystems.

Industrial ecology and innovation studies

Industrial ecology is a promising systemic innovation approach also embedded in the model for waves of innovation covering a time frame from 1785 to 2020 (see Figure 2 - 1) to address the sustainability problems of industrial production systems (Organisation for Economic Co-operation and Development, 2009; Kloiber & Priewasser, 2014; Adamides & Mouzakitis, 2009; Gibbs, 2009; Hargroves & Smith, 2005; Machiba, 2010). Changes brought through industrial ecology practices within industrial ecosystems generally may have an incremental nature, but the accumulated economic and environmental benefits can be significant at the systems level (Doranova, et al., 2012).

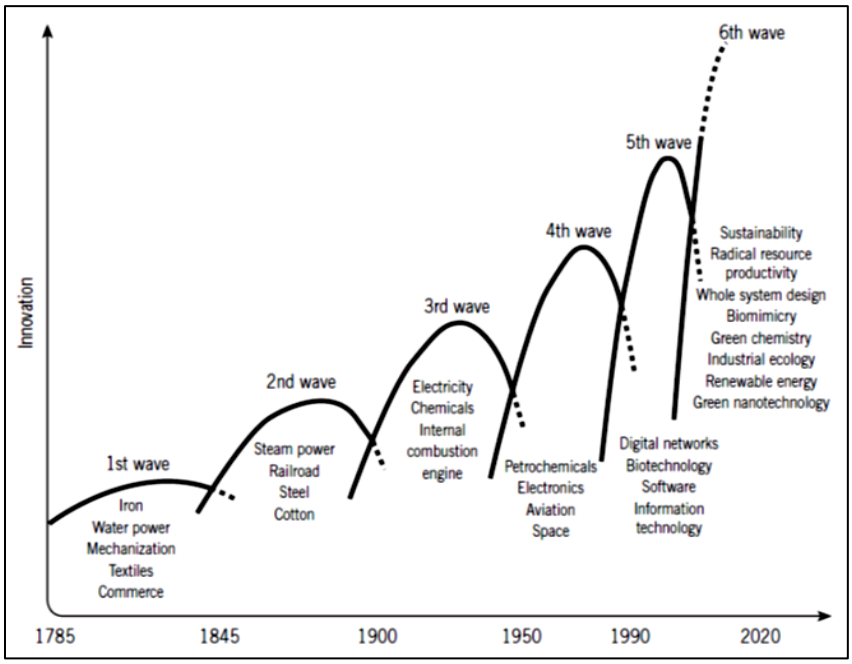

Figure 2 - 1: Waves of Innovation.
Source: (Hargroves & Smith, 2005)

On the one hand, incremental innovations are sometimes part of, or even prerequisites, for radical changes, and on the other hand, radical changes in incremental steps may let systems adjust to the new configurations realising systemic innovations (Organisation for Economic Co-operation and Development, 2010; Rotmans & Loorbach, 2009). Industrial ecology triggering systemic innovations can lead to not only technological but also organisational and institutional changes in established routines of industrial production systems. Those routine changes are dependent on reconstructing the prevailing practices of industrial and wider system actors through legitimisation and active implementation of industrial ecology practices. There is often resistance from the existing actors in the industrial production systems due to their established routines (Adamides & Mouzakitis, 2009). Continuous application of industrial ecosystems may lead to a transition from the dominant linear systems to circular systems of industrial production (Doranova, et al., 2012; Machiba, 2010; Erkman, 1997). Thereby, this thesis aims to understand industrial ecology-inspired transitions focusing on unfolding industrial ecosystems and such an inquiry requires a theoretically plural conceptualisation which may act as a heuristic to guide the research process.

The complexity of new practices in the existing systems and potential transitions have been widely addressed in innovation studies through different research lines including but not limited to, evolutionary economics (Nelson & Winter, 1982), social construction of technology (Pinch & Bijker, 1987), actor-network perspective (Callon, 1987), ecological modernisation (Mol & Spaargaren, 2007), socio-technical systems (Bijker & Law, 1992; Rip & Kemp, 1998; Geels, 2002). However, industrial ecology literature seems to overlook the potential link of industrial ecology to the innovation studies. Although some scholars from the field have argued and agreed that industrial ecology triggers innovation (Mirata & Emtairah, 2005; Boons, et al., 2017; Taddeo, et al., 2017; Valentine, 2016; Lombardi, et al., 2012; Huber, 2000; Lambert & Boons, 2002), an explicit link between industrial ecology and innovation studies has not yet been constructed and an intent on theoretical bridging to available research streams under innovation studies has not been taken.

2.2. Bridging industrial ecology to sustainability transitions research

Along similar lines to the systemic innovations needed due to sustainability concerns as in industrial ecology literature, the most salient and promising research stream from innovation studies is *sustainability transitions* with a socio-technical systems perspective. The sustainability transitions field holds a general view that systemic and radical improvements have to be realised, given the critical risks associated with ongoing environmental challenges (Geels, 2002; Schot & Geels, 2008; Smith & Raven, 2012; Markard, et al., 2012; Kemp, et al., 1998). The interest is on transitions through fundamental sustainable changes – that is, radical and systemic innovations – at individual, organisational, sectoral and societal levels through institutional, technological and cultural dimensions under the influence of a broad range of actors (Farla, et al., 2012; Truffer & Coenen, 2012).

Considering the social and technical dimensions of industrial ecosystems and the systemic innovation nature of industrial ecology, insights from sustainability transitions research, which provides promising conceptual frameworks explaining the socio-technical transition processes, offer potential explanatory grounds when studying the dynamics behind the unfolding industrial ecosystems. Both industrial ecology and sustainability transitions fields emphasise systemic innovation, sustainability, the necessity of transitions, technological change, institutional change, cultural change at organisational and sectoral levels with the integration of a broad range of actors and networks, etc. (see Figure 2 - 2). However, on the one hand, sustainability transitions scholars have not paid attention to industrial ecology literature, and, on the other hand, there are only a few studies from industrial ecology literature that considered the potential nature of industrial ecology to bring the transitions into the industrial production systems but only borrowed some concepts from the sustainability transition literature (e.g. (Gibbs, 2009; Adamides & Mouzakitis, 2009; Baas & Huisingh, 2008)). There is a missing link between these two research fields which may bring fruitful theoretical and empirical pluralisation grounds.

There are three salient analytical approaches in the sustainability transitions research context: *the multi-level perspective on socio-technical transitions* (Geels, 2002; Rip & Kemp, 1998; Smith, et al., 2010; Geels & Schot, 2007), *strategic niche management* (Schot & Geels, 2008; Schot, et al., 1994; Kemp, et al., 1998), *technological innovation systems* (Bergek, et al., 2015; Hekkert, et al., 2007; Bergek, et al., 2008). These three approaches have the similar theoretical start points drawing on founding work on evolutionary economics and social constructivist accounts of technology development

and they hold a systemic perspective focusing on the socio-technical change through new modes of production for more sustainable socio-technical systems (Markard, et al., 2012; Truffer & Coenen, 2012; Coenen & Truffer, 2012).

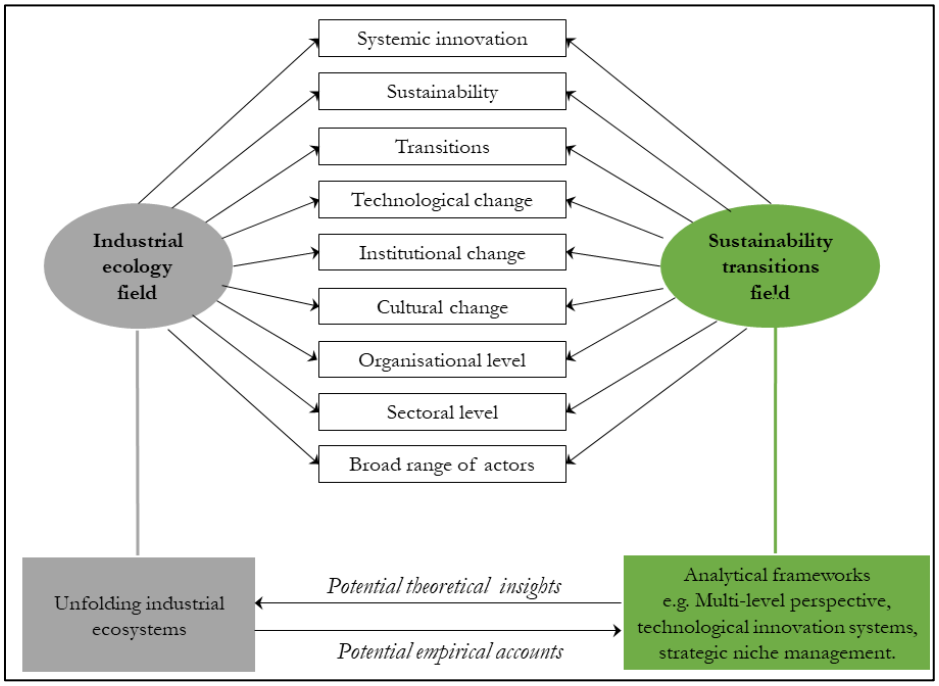

Figure 2 - 2: The potential link between industrial ecology and sustainability transitions.

The multi-level perspective proposes three analytical levels as heuristic to understand socio-technical transitions (Geels, 2005; Geels, 2002; Smith, et al., 2010; Kemp, 2009): *(i) socio-technical landscape*, which relates to material and immaterial elements at the macro-level, i.e. material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macroeconomy, demography and the natural environment; *(ii) socio-technical regime,* conceptualises the deep structure that holds the stability of the existing socio-technical systems as semi-coherent constellation of technological artefacts, infrastructures, regulations and user practices at meso-level and it is the subject to transition; and (iii) *socio-technical niches*, which are the locus of innovations at micro-level acting as incubation rooms for radical novelties and providing locations for learning processes (see Figure 2 - 3).

The strategic niche management approach analyses the local projects as niche experiments providing theoretical and practical insights on how to build and support shielded spaces for innovations (Suurs & Roelofs, 2014; Kemp, et al., 1998). The strategic niche management (SNM) studies elaborate on three internal niche-building processes that are eminent for understanding the niche development trajectories (Geels & Raven, 2006; Schot & Geels, 2008): (i) *articulation of expectations and visions;* (ii) *building of social networks*; and (iii) *learning activities*. The framework underlines the importance of continuous experimentation through local projects and focuses on the aggregation of the experiments that would lead to emergence of global level niches through internal niche processes (Weber, et al., 1999; Schot & Geels, 2008; Geels & Raven, 2006) (see Figure 2 - 4).

Finally, the ***technological innovation systems*** framework has a focus on understanding and explaining the complex emerging innovation system around a particular technology (Bergek, et

al., 2015) by analysing the system structures (actors, networks, and institutions) and functions (entrepreneurial experimentation, knowledge development and diffusion, guidance of the search, market formation, mobilization of resources, creation of legitimacy, development of external economies) (Hekkert, et al., 2007; Hekkert & Negro, 2009; Bergek, et al., 2008) (see Figure 2 - 5).

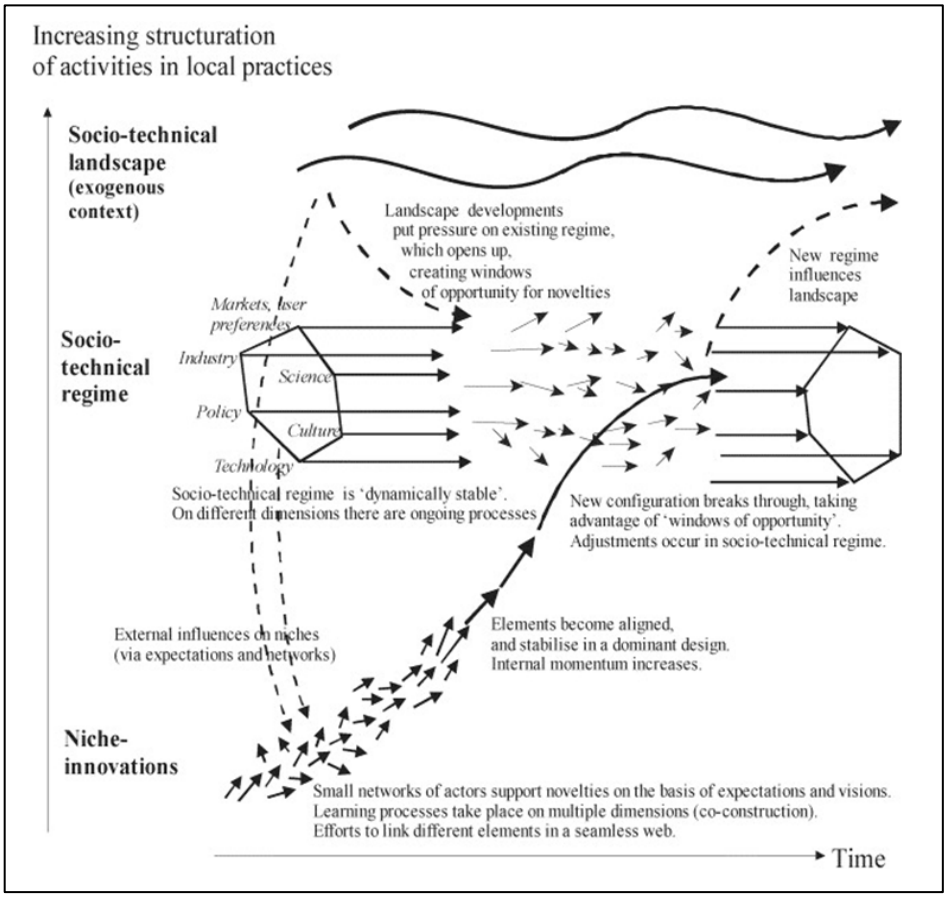

Figure 2 - 3: The multi-level perspective on socio-technical transitions.
Source: (Geels & Schot, 2007)

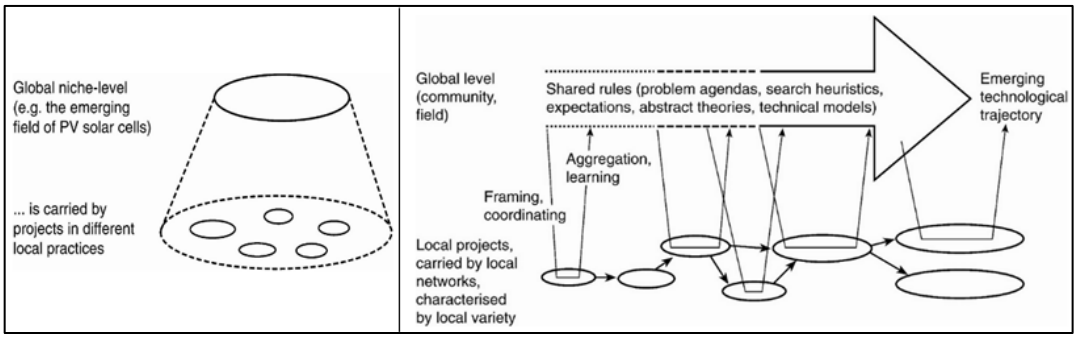

Figure 2 - 4: Local projects, global niche-level and the trajectory to emerging niches.
Source: (Geels & Raven, 2006)

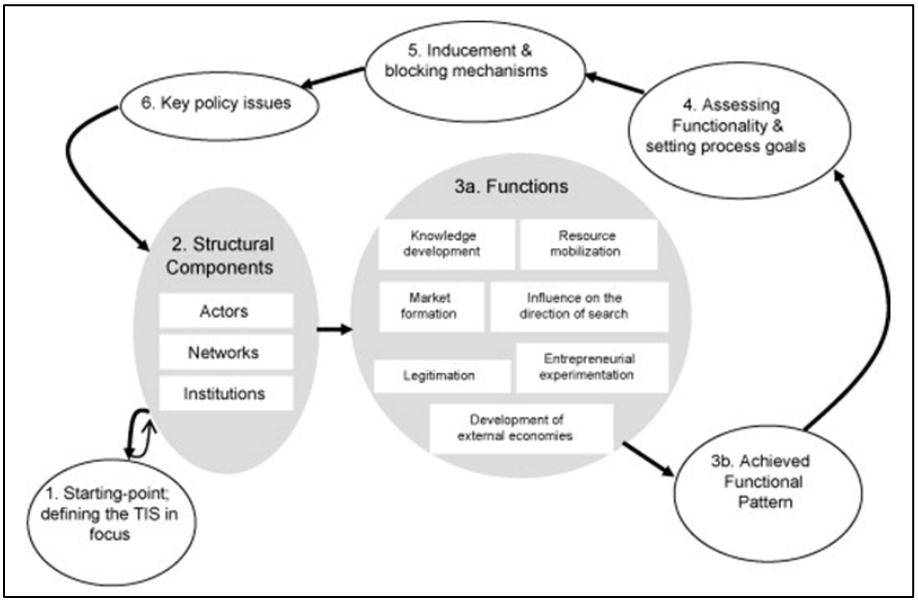

Figure 2 - 5: Technological innovation systems - scheme of analysis.
Source: (Bergek, et al., 2008)

The technological innovation systems framework and multi-level perspective do not provide the proper theoretical grounds for addressing the objective of this thesis, and the reasoning behind this is twofold. On the one hand, industrial ecology as a systemic innovation model does not refer to any particular innovative technology, and unfolding industrial ecosystems does not represent an innovation system around one specific technology. Industrial ecosystems may emerge through various incremental and radical technological, organisational and institutional innovations which accumulatively may contribute to the expected systemic transitions of the traditional industrial production systems. However, technological innovation systems framework is a technology-centred framework focusing on technology-specific factors (Markard & Truffer, 2008; Coenen & Diaz Lopez, 2010; Twomey & Gaziulusoy, 2014).

On the other hand, the multi-level perspective does not provide the proper grounds for studying unfolding industrial ecosystems as well, but for some other reasons. Firstly, a potential transition of an existing industrial production system through industrial ecology practices is supposed to end in an industrial ecosystem. Perhaps an industrial production system can be conceptualised as a socio-technical system. However, its boundaries, as well as structural and functional content are quite blurry due to its technical and social dimensions intertwined by a wide variety of embedded process and management technologies, institutional arrangements and social practices (Adamides & Mouzakitis, 2009). That is to say; an industrial production system may involve various industrial sectors agglomerated at local or regional scales. An industrial production system typically includes multiple sub-systems that function to supply the demands of different societal needs. Directly proportionally, the same applies to an industrial ecosystem which ideally operates through material and non-material resource exchanges between the industries and other system actors which are embedded in different industrial sectors with different functions in terms of the societal needs. Whereas, the multi-level perspective focuses on a system transition of the semi-coherent constellation of technological artefacts, infrastructures, regulations and user practices, which is the so-called regime of a socio-technical system of usually a sector (e.g. energy, water, transport, etc.).

Moreover, the differentiation between niche and regime as the analytical levels in the multi-level perspective does not overlap with the evolution of an industrial ecosystem. Because, the entrepreneurial or voluntary actors, which plan and implement the industrial ecology practices as novelties to the existing industrial production systems, are typically embedded in the current systems as well. They are mostly regime actors. Then, it can be argued that the industrial ecosystem niche is embedded and heterogeneously distributed in the industrial production system regime without, and perhaps unnecessary, boundaries. Therefore, a heuristic which differentiates between the niche and regime may not be suitable to understand and explain the unfolding industrial ecosystems.

Following the above arguments, this thesis engages with the strategic niche management framework because it provides appropriate grounds for organising ideas and knowledge for a research focus on unfolding industrial ecosystems for the sustainability transitions of industrial production systems in the long turn. The reasoning is twofold. Firstly, an emerged industrial ecosystem alone cannot represent the whole sustainability transition for the industrial production systems. And secondly, industrial ecosystems do not represent the main logic behind the industrial production system development, yet. The evidence shows that they remain as sustainable fringe practices at distributed geographies. The assumption behind the strategic niche management framework is that the niches act as incubation rooms for the sustainability transitions. That is a proper assumption for studying industrial ecosystems from a transitions perspective. Industrial ecosystems also can be considered as spaces that nurture the resource exchange-based interactions between the industrial production system actors, and if they can maintain the incubation for long enough in a continuous way, industrial ecology-inspired transitions may occur in future.

2.3. Insights from the strategic niche management framework

The primary purposes of the strategic niche management (SNM) framework were based in ex-ante management of sustainability-oriented innovations (Schot & Geels, 2008), and for this reason it takes the experiment and experimentation concepts central to its theoretical foundations (Borghei & Magnusson, 2018; Weber, et al., 1999). With an evolutionary perspective, the SNM studies reason that the experiments that refer to the sustainability-oriented local projects are crucial elements for building the niches (Geels & Raven, 2006), and that niches gain momentum in time through continuous experimentation and may bring the desired sustainability transitions (Geels, 2002). Niches act as the innovation incubators in which a community with shared expectations and visions emerges and provides the direction of the desired transitions (Geels & Raven, 2006). That community provides the conditions for the successful penetration of the sustainability-oriented innovations into the mainstream practices by mediating the expectations and providing the resources required for further local projects. External environment and context also shape that mediation (Van der Laak, et al., 2007; Raven & Geels, 2010).

The framework provides the grounds to analyse and understand those niche experiments (Raven, 2005), which in some cases successfully leads to emerging niches challenging the unsustainable routines and, in some cases, remain as weak and frangible practices. The SNM scholars distinguish three interdependent and interlinked niche-building processes through which the experiments can contribute to the successful development of niches: articulation of expectations

and visions, building of social networks, and learning processes (Geels & Raven, 2006; Schot & Geels, 2008; Van der Laak, et al., 2007).

- The first process, articulation of expectations and visions, is crucial for niche development because it provides the direction for further experimentation, brings attention from other actors, and creates the grounds through sharing common understandings for nurturing new experiments.
- The second process is about building social networks to facilitate interactions between different actors of the system, which include governmental and non-governmental organisations, the industry, intermediaries, universities and research centres, citizens, etc. As the networks get broader with different actor types and deeper with more commitment from the actors, this process contributes better to the emerging niches.
- Finally, learning processes form the tangible and intangible knowledge of the actors. Learning can remain at first-order learning level based on the knowledge exchange related to facts and data, or turn into the second-order level through changes in cognitive, normative and regulative frames and assumptions of the involved actors.

The SNM framework indicates that these three interacting, mutually reinforcing and co-evolving processes lead to a niche development process, which progresses at two levels concurrently (see Figure 2 - 6): the local projects level and the global niche level (Schot & Geels, 2008; Raven, 2005; Raven & Geels, 2010). The local projects level is composed of individual niche experiments conducted by local networks of actors and these projects can build on each other over time through expanding network-building and learning processes and the global niche level results from sequences and accumulation of these experiments which transcend local contexts (Geels & Raven, 2006; Smith & Raven, 2012).

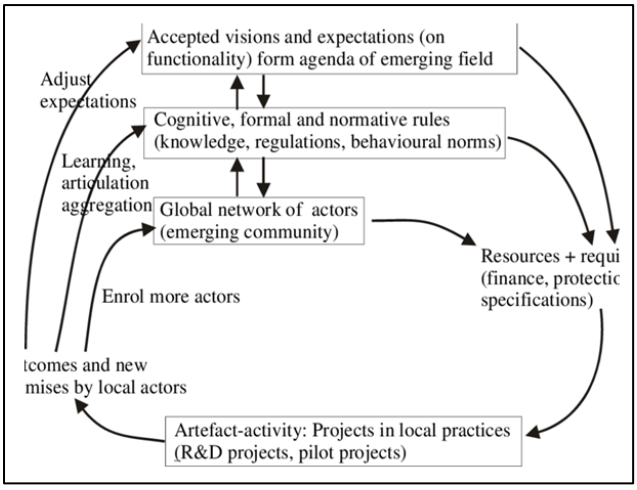

Figure 2 - 6: The niche development dynamics
Source: (Geels & Raven, 2006)

So far, SNM framework has not been applied as an ex-ante management tool for introducing new sustainable technologies and practices; instead, it has been used as ex-post conceptual framework for ex-post analysis and evaluation of cases such as biofuels (Van der Laak, et al., 2007), biomass gasification (Verbong, et al., 2010), organic food (Smith, 2006), biogas plants (Geels & Raven, 2006), sustainable transport innovations (Weber, et al., 1999) with a focus on battery-powered vehicles (Kemp, et al., 1998) and hybrid electric vehicles (Sushandoyo & Magnusson, 2014). This thesis also builds on SNM for deriving conceptual frameworks for ex-post analysis of local and regional scale industrial ecosystem cases.

2.4. Towards an integrated conceptualisation

This thesis has an overarching aim to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems. As for the analytical purposes, the thesis first offers an overall conceptualisation which integrates the industrial ecology literature and the SNM framework. Then, it derives specific frames as heuristics for the operationalisation and empirical assessment of unfolding industrial ecosystems at local and regional within three research studies (see Figure 2 - 7).

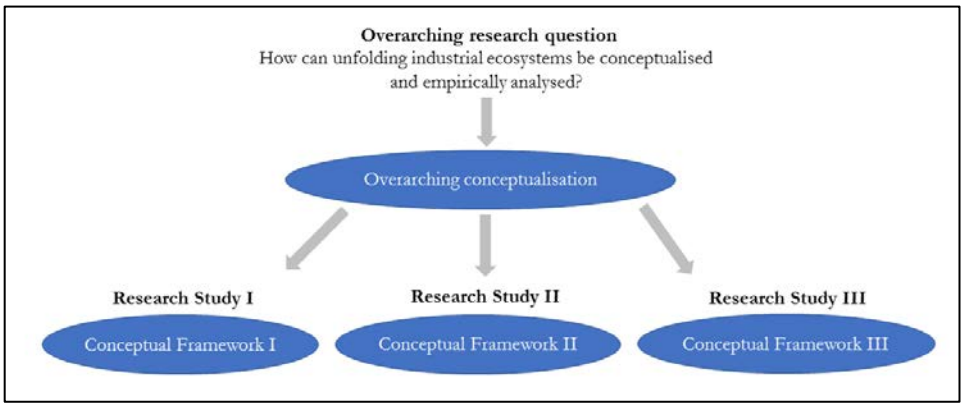

Figure 2 - 7: Conceptual approach and research studies

Overarching conceptualisation

The thesis particularly interrogates the emergence of local and regional industrial ecosystems, considering the importance of regional focus in industrial ecology literature (Boons, et al., 2011; Ashton, 2009; Deutz & Gibbs, 2008; Ristola & Mirata, 2007). Similar to the conceptual frameworks of the sustainability transitions field, the conceptualisation provided in this thesis does not claim to offer ontological descriptions of reality, but it is a heuristic (Geels, 2010; Walrave & Raven, 2016), which can guide the empirical research to understand and explain the complex dynamics of the unfolding industrial ecosystems in real settings.

The conceptualisation follows an evolutionary perspective which has been dominant in industrial ecology literature as well (Chertow & Ehrenfeld, 2012) and claims that industrial ecology principles may lead to fundamental technological, institutional and cultural changes at organisational and sectoral levels through collaboration and interaction among multiple actors and networks, and institutions in industrial production systems (Gibbs, 2009). Particular theoretical standpoints from industrial ecology and sustainability transitions fields are followed. Firstly, industrial ecology is conceptualised as a systemic innovation model, and industrial ecosystems are approached as socio-technical constructs. The overall framing mainly builds on the SNM framework and takes the niche, experiment, experimentation, and niche emergence concepts central to its approach, though through different operationalisations in each derived conceptual framework. The shared contours among the proposed frameworks are three interlinked and interdependent niche processes (Schot & Geels, 2008; Smith & Raven, 2012): *(i) articulation of expectations and visions*, *(ii) social network-building*, and *(iii) learning processes*.

Below, each niche-building process is elaborated through the integration of relevant insights from industrial ecology literature and the SNM studies.

(i) Articulation of expectations and visions:

Articulation of expectations and visions is the first niche process considered for successful niche-building in the SNM framework (Schot & Geels, 2008), which explains that when expectations and visions are specific, tangible, robust and shared by a wide variety of actors (Raven, 2005; Caniëls & Romijn, 2008; Coenen, et al., 2010), they can be coupled to address specific sustainability challenges through building more effective niches (Weber, et al., 1999).

Concepts of expectations and visions were also considered in industrial ecology literature, but not comprehensively and explicitly in central arguments of the studies. Scholars from the industrial ecology field touched on different aspects of actors' *expectations*, such as the importance of managing institutions' and community's expectations for sustainability benefits to regions (Deutz & Gibbs, 2008; Rosano & Schianetz, 2014); the role of institutional capacity in forming expectations (Boons & Spekkink, 2012); the problem of over-inflated and unrealistic expectations of developers and policymakers (Deutz & Lyons, 2008; McManus & Gibbs, 2008; Sterr & Ott, 2004); the significance of diverging expectations (Baas & Boons, 2007) and converging expectations of actors (Valentine, 2016); and evolving expectations during the construction of industrial ecology networks (Ashton & Bain, 2012).

Furthermore, the *vision* concept was also addressed in industrial ecology literature in terms of building and expanding the vision of industrial ecology (Ashton & Bain, 2012; Adamides & Mouzakitis, 2009; Korhonen, et al., 2001; Gibbs, 2008; Chertow, et al., 2008); emphasising the importance of having a shared strategic vision of sustainable development by regional actors (Baas & Boons, 2004; Spekkink, 2013; Veleva, et al., 2016; Daddi, et al., 2016; Rosano & Schianetz, 2014) and having a leader or a champion (Hewes & Lyons, 2008), or an anchor firm (Mulrow, et al., 2017) in the region to tout this vision; and also underlining the importance national level visions of countries like China and South Korea for transforming local scale industrial ecosystems into national-level industrial ecosystem networks (Yu, et al., 2015).

Yet, only a few studies have addressed the articulation of expectations and visions during the evolution of regional industrial ecosystems (e.g. (Baas & Boons, 2004; Baas & Huisingh, 2008; Boons & Spekkink, 2012)). In this vein, bringing insights from SNM further elaborates on the importance of that articulation process which can lead to a prevailing direction for the journey of sustainability transitions of industrial production systems. Such a journey may need the continuous support of robust, specific, ambitious and, at the same time, realistic visioning in line with the expectations of the regional actors.

(ii) Social network-building:

The second niche process is about network-building (Schot & Geels, 2008), which argues that if the local networks are broad, deep and heterogenous (Van der Laak, et al., 2007) – that is, inclusive to a variety of relevant actors involving industrial organisations, formal institutions, non-governmental organisations, knowledge organisations, etc. (Coenen, et al., 2010) – then a community can emerge with dedicated actors for protecting and supporting further the niche-building process (Raven & Geels, 2010).

Network-building has been a central topic in industrial ecology literature as well, while mostly referring to industrial ecology exchange networks between industrial organisations. Scholars from the industrial ecology field have looked at different aspects of network-building, such as growth patterns of resource exchange networks (Zhu and Ruth 2014); structural characteristics and the role of different actors in industrial ecology networks through social network analysis perspective (Chopra & Khanna, 2014); multiple dimensions of embeddedness in industrial

ecology networks (Ashton & Bain, 2012); social relationships between industrial organisations (Ghali, et al., 2014); the role of trust and local champions in network-building (Hewes & Lyons, 2008); and the importance of coordinating bodies to facilitate symbiotic connections between industrial organisations (Tessitore, et al., 2015). However, relatively few studies have focused on network-building covering a variety of actors, such as governmental organisations, universities and research institutes, non-governmental organisations, and local communities (e.g. (Baas & Boons, 2004; Boons, et al., 2011)), rather than only focusing on industrial organisations in the inter-firm resource exchange networks.

Incorporating the SNM approach, the conceptualisation here holds a broader network perspective, covering relevant system actors (governmental and non-governmental organisations, knowledge organisations (research centres and universities), local champions, managing/coordinating bodies, entrepreneurs, local community, etc.) that participate in the planning and implementation of industrial ecosystems. The thesis proposes that an industrial ecosystem can unfold incorporating a network of actors as an emerging community. That requires a social network-building process which is broad, deep and heterogeneous enough to involve multiple actors and to mobilise their available resources. Such an emerging community then can protect the on-going niche-building process and bring support in terms of requirements for continuous application of industrial ecology practices.

(iii) Learning processes:

The final niche-building process is related to *learning* (Schot & Geels, 2008). The learning concept has found widespread attention in industrial ecology literature. Indeed, the essential argument of the domain is related to learning from an analogy with nature and its ecosystems (Frosch & Gallapoulus, 1989). Not surprisingly, the industrial ecology literature gave considerable attention to collective learning by the industrial organisations (MacLachlan, 2013; Grant, et al., 2010) and as well as by all relevant regional actors (Baas & Boons, 2004; Roberts, 2004; Veleva, et al., 2016; Lambert & Boons, 2002) through means of communication events (trainings, seminars, conferences, workshops, etc.), media (television, radio, internet, newspapers, magazines, etc.), and information communication technologies (information and knowledge sharing and management platforms).

Building on and extending those studies, the conceptualisation here emphasises collective learning to create a shared culture, which can be defined as shared cognitive, formal and normative rules. Those rules refer to common knowledge, required regulations and converging behavioural patterns of the network actors (Geels & Raven, 2006; Geels, 2004). Learning activities are not only expected to trigger first-order learning through which actors can identify a problem and correct it without changing the underlying rules but also – and even more importantly – they are supposed to facilitate second-order learning through real implementations (Boon, et al., 2014). An industrial ecosystem culture may emerge through changes in the underlying rules governing mainstream behaviour (Mirata & Emtairah, 2005; Argyris, 1997; Schot & Geels, 2008). The second-order learning can be enforced by developing tacit knowledge (Ghali, et al., 2014) by continuous experimentation with industrial ecology practices and exchange of the experiences (Boons, et al., 2017) through effective interactions (Baas, 2011). Moreover, the existence of local/regional champions (Hewes & Lyons, 2008; Qu, et al., 2015) and coordinating bodies (Domenech & Davies, 2011; Boons & Spekkink, 2012) may trigger second-order learning as well.

Conceptual Framework I

This framework with evolutionary perspective conceptualises local industrial ecosystem cases as niche experiments which are expected to steer transitions to the local industrial ecosystem development, and traditional industrial production system development is subject to sustainability transitions. Local industrial ecosystem development is stressed more like a trend that is expected to excel traditional industrial production system development, rather than focusing on evolution of industrial ecology in some specific local industrial ecosystem experiments, as mostly done in the industrial ecology literature (e.g. (Chertow & Ehrenfeld, 2012; Paquin & Howard-Grenville, 2012; Baas & Boons, 2004; Domenech & Davies, 2011).

Three "interrelated and mutually reinforcing" niche-building processes (Caniëls & Romijn, 2008, p. 248), which are *the articulation of expectations and visions*, *social network-building* and *learning activities*, are proposed as the main contours of the analytical approach while explaining and further understanding the dynamics behind the greenfield and brownfield local industrial ecosystem niche experiments, and also the continuation of traditional industrial production system development due to embedded routines of mainstream actors (see Figure 2 - 8). Such an understanding can provide clues on how to achieve sustainability transitions into local industrial ecosystem development.

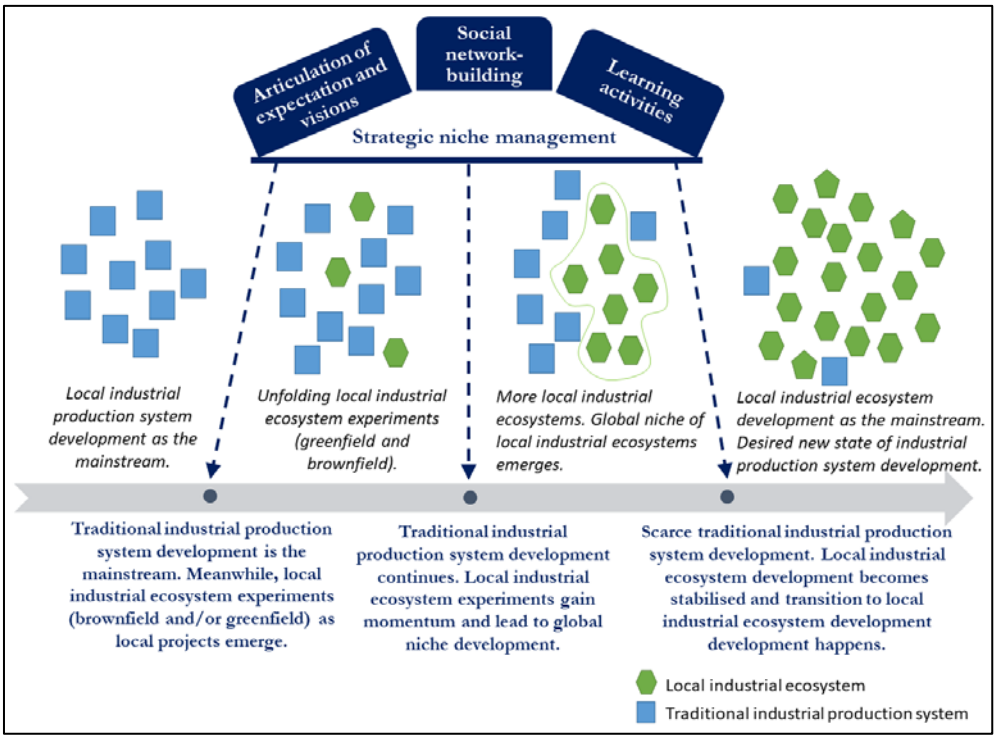

Figure 2 - 8: Conceptual Framework I.
Source: Author' elaboration based on Geels (2011), Schot and Geels (2008), Geels and Raven (2006), Chertow and Ehrenfeld (2012), Lambert and Boons (2002), and Gibbs (2009).

Building on SNM foundations (Schot & Geels, 2008; Caniëls & Romijn, 2008; Geels, 2011), the framework proposes that proper combination and interaction between three internal niche-building processes can lead, firstly, to development of greenfield and brownfield local industrial ecosystem experiments; secondly, to global niche of local industrial ecosystems where there are still traditional industrial production systems, but greenfield and brownfield development gains more momentum; and, finally, to transitions into local industrial ecosystem development where local industrial ecosystems excel industrial production systems and local industrial ecosystem

development becomes the mainstream. Global niche in this framework can be thought as accumulations of local industrial ecosystem experiments and involves an emerging network that has similar or common concerns, problem agendas, expectations, visions, interests, etc. (Schot & Geels, 2008; Geels & Raven, 2006). Conceptual Framework I is derived to guide the analysis of Research Study I, which resulted in Article I.

Conceptual Framework II

This framework aims to guide the analysis to understand and explain how local industrial ecosystems can unfold over the traditional industrial production system through industrial ecology practices. It takes the *experimentation* concept central to its analytical approach. The journey to becoming a local industrial ecosystem is conceptualised as niche experimentation and local industrial ecosystems as niches. The framework focuses on the experimentation as a journey that involves the planning and implementation of various industrial ecology practices within the industrial production systems. It argues that the continuous experimentation may, in time, replace the existing individual-performance-oriented routines of the industrial production systems and local industrial ecosystems can unfold as niches following the industrial ecology-inspired collective-benefit-oriented routines.

To understand how a local industrial ecosystem unfolds, the framework proposes to follow three internal niche-building processes of SNM (Schot & Geels, 2008; Weber, et al., 1999), which are *the articulation of expectations and visions*, *social network-building* and *learning activities*, while analysing the local industrial ecosystem experimentation journey (see Figure 2 - 9). The argument is that the experimentation of industrial ecology practices may lead to an unfolding local industrial ecosystem through those niche-building processes. The emerging community that would provide support for further industrial ecology practices is key to the conceptualisation and is not limited to the network of the involved industrial organisations in the system. The emerging community involves all relevant actors that have an impact on other actors in the making of the unfolding local industrial ecosystem.

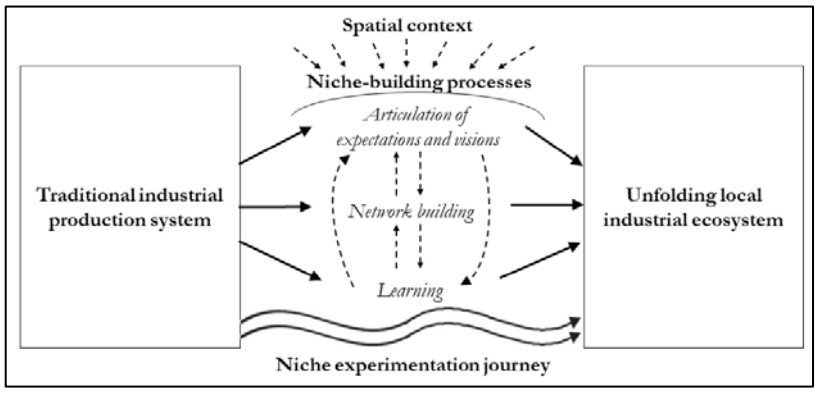

Figure 2 - 9: Conceptual Framework II.

Finally, the framework also considers the *spatial context.* The attributes of the spatial context which may include the policies and regulations of central and regional governments, regional culture, available markets, industrial structures, already-existing networks, etc. can have crucial mediating influences and may further support or hinder the incubation of industrial ecology practices throughout the experimentation. Conceptual Framework II is derived to guide the analysis of Research Study II, which resulted in Article II.

Conceptual Framework III

This conceptual framework emphasises the emergence of industrial ecosystems, considering the importance of the regional focus in industrial ecology literature (Boons, et al., 2011; Ashton, 2009; Deutz & Gibbs, 2008; Ristola & Mirata, 2007). The framework is developed to guide the analysis to understand and explain regional industrial ecosystem development by focusing on the interaction of two heuristic and analytical levels – that is, the *local industrial ecology experiments level* and the *regional industrial ecosystems niche level* – linked through three analytical niche-building processes as suggested by the SNM framework. The developed framework provides grounds for a structured and diversified analysis of individual industrial ecology projects and their aggregating contribution to the emergence dynamics of regional industrial ecosystems (see Figure 2 - 10).

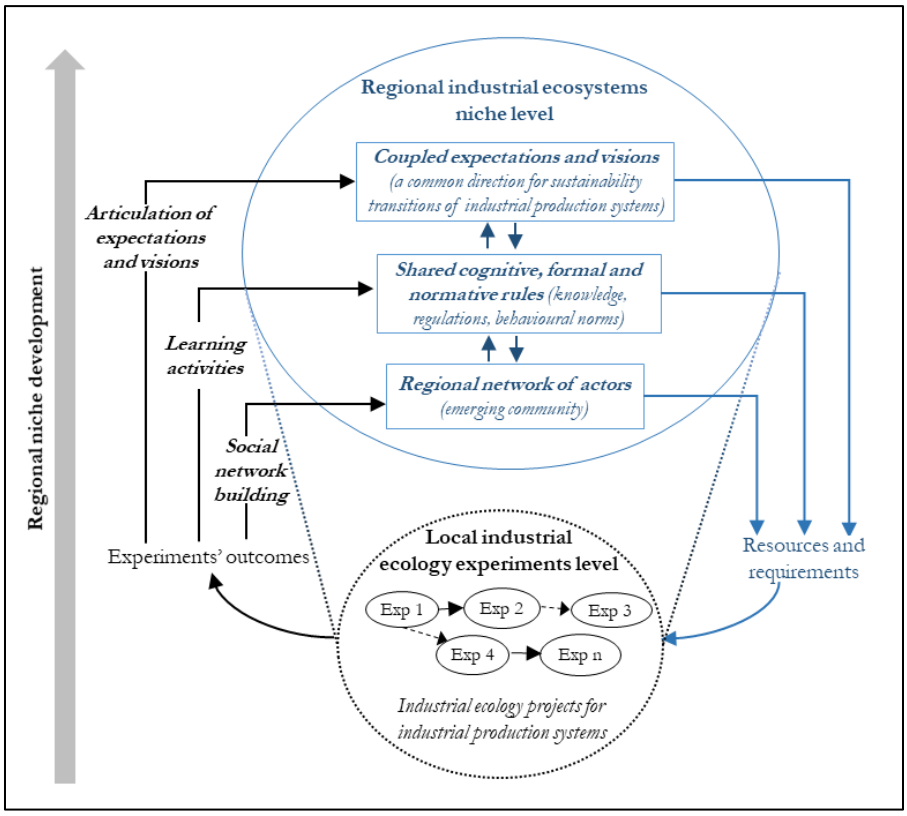

Figure 2 - 10: Conceptual Framework III.

Source: Authors' own elaboration based on (Geels & Raven, 2006), (Schot & Geels, 2008), (Baas & Boons, 2004), and (Raven & Geels, 2010).

The first level is the *local industrial ecology experiments level*, which is composed of individual local industrial ecology projects. At this level, industrial ecology projects are conceptualised as niche experiments. An industrial ecology project can be in the form of research, task, mission, network formation action, etc. that may be completed or on-going, but holding an objective of supporting sustainability transitions of industrial production systems in the specific geography under focus. The industrial ecology literature provides a rich set of case studies on various industrial ecology projects, among the most studied of which are Kalundborg (Valentine, 2016), Kwinana (Giurco, et al., 2011), Tianjin (Yu, et al., 2014), Dalian (Geng, et al., 2008), Ulsan (Behera, et al., 2012) and Devens (Veleva, et al., 2015). The conceptualisation approach here has a broader focus than most of those studies and intends to involve multiple projects from the same region. Such an approach is prominent in the SNM studies but has received scant attention in the industrial ecology literature. More significantly, the proposed framework stresses the need to analyse the

interlinkages between multiple projects (that is, in forms of either direct support or influence) and the potential aggregation of those projects for building regional industrial ecosystems, which is the emerging niche level as explained in the second heuristic level of the conceptual framework.

The second level is the *regional industrial ecosystems niche level* following the underpinnings of the SNM studies which addresses the differentiation between the local projects level and the global niche level (Raven, 2005; Schot & Geels, 2008; Geels & Raven, 2006). Here, a regional industrial ecosystem at the niche level is conceptualised as a *regional network of actors* representing an emerging community that can overcome the lock-in to the linear industrial production routines through establishing shared cognitive, regulatory, and normative rules coupled with shared expectations and visions of its wide variety of actors.

While conceptualising the links between two heuristic levels, the framework proposes that individual local industrial ecology experiments at the first level can build on each other and gradually add up to a regional industrial ecosystems niche level over time. For this gradual process, it distinguishes three interacting and interdependent niche-building processes drawing on the SNM framework: *the articulation of expectations and visions*, *social network-building* and *learning activities*.

The proper combination of these three processes can lead to the emergence of a regional industrial ecosystem niche that involves a network of actors holding coupled expectations and visions through shared cognitive, formal and normative rules. This niche then can provide support and protection measures in terms of the *resources and requirements* – tax regime, environmental regulations, policy programmes, financing incentives, etc. – needed to plan and implement new industrial ecology experiments in the region. Thus, the framework proposes a continuous feedback mechanism between two heuristic levels of analysis that may lead to continuity and stability for the regional industrial ecosystem development. If this feedback cycle sustains for long enough, a culture change may occur, and the industrial production systems in the region may employ closed industrial production routines, and finally experience sustainability transitions into industrial ecosystems.

Conceptual Framework III is derived to guide the analysis of Research Study III, which resulted in Article III.

Chapter 3. Research design

This chapter presents the reflections on the underlying research design of this thesis with a particular focus on the philosophical assumptions (the conception of reality – that is, ontology; the broader philosophy of knowledge – that is, epistemology; and the role of the values – that is, axiology); methodology as the overall process of carrying out the research; the methods related to gathering, analysis and interpretation of data and insights; and finally, the methodological considerations.

3.1. Philosophical assumptions

This thesis' intent to contribute to the theoretical domains of industrial ecology and SNM brings the need to reflect on the philosophical underpinning of the research (Berthon, et al., 2002), which can be thought as the motivational driver of the overall research process while employing specific theories. The philosophy behind the research design brings questions on the nature of the reality, what reality is – that is, *ontology*, the sources of knowledge, how we know about the world – that is, *epistemology*, and the role of values, – that is, *axiology*. Those questions relate the thesis to its methodological choices used to discover new knowledge.

Related to the overall aim of the thesis which is to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems, research inquiry is related to the intertwined technical and social elements of industrial ecosystems which also require an understanding of complex contextual factors. Such phenomena may need to be operationalised and studied by a reflexive research design rather than a rigid structural approach such as in positivist research (Black 2006). In this respect, *interpretivism* paradigm has a short mental distance to the thesis considering the research aim and question, which are not addressed to establish the truths but instead to offer some understanding and explanation about different scale industrial ecosystems unfolding at different contexts.

This thesis approaches industrial ecology as a systemic innovation model which requires engagement from multiple actors (not limited to the industry) through different interactions (not limited to physical resource exchanges) which may vary from context to context. Thus, the reality, as we know it in one particular context, maybe relative (Hudson and Ozanne 1988) and may change in a different context. This thesis holds this underlying ontological assumption. Additionally, the knowledge offered by this thesis is constructed based on the constructed reality behind the studied unfolding industrial ecosystems and the author cannot separate herself from that knowledge. The author also acts as a social constructor, together with the subjects and objects involved in the construction of the overall research process. Therefore, the research studies included in this thesis build on interpretation as the primary tool for knowledge construction. Each research study lies in a particular investigative context (the when, where, and from whom/what data and insight gathering) and an interpretive context (the when, where, and whom of data and insight interpretation) (Berthon, et al., 2002). It is worth to note that the interpretation is open to re-interpretation in different contexts. That is the underpinning of the epistemological assumption of this thesis. Finally, as for the axiology, it is assumed that the values of the author, as well as the interpretations, are embedded in all research steps beginning from the problematisation to the analysis and discussion. The reflected and embedded values in this thesis are rather intellectual than technical with "an awareness of the various interpretive dimensions" at different research steps (Alvesson & Skoldberg, 2009, p. 318).

Reflexivity: Levels of interpretation

Perhaps the most exciting part of interpretivism is its progressive nature this is expressed in Ravn's (1991, p. 97) words as: "*the reality is not fixed or given; you partake in its creation and must ensure that reality does not rigidify. Hence, keep the options open and the alternatives fresh, and grant others the freedom you would want - while being considerate of them."* However, one needs to consider the crux of social constructivism and also think of the limits of such a liberal paradigm. On the one side, one needs to face the question of what constructs social constructor. Therein lies the problem of the interpretivist research, which may represent a quasi-vicious cycle. To avoid that problem (as much as possible), some reflexive elements can be useful when designing the study, such as consideration of different levels of interpretation following Alvesson and Skoldberg (2009), which may bring a relatively higher degree of structuration to the interpretivist grounds. This consideration also bridges to the other side where one needs to be aware of "what is not capable of saying" (p. 269) during the interpretivist research process and this can be achieved by recognising the philosophical assumption that the research evidence is constructed, interpreted and written through different interpretation levels.

Therefore, this thesis does not argue, for instance, for a formal generalisation of the results, but instead provide conceptual frameworks and implications for researchers in terms of generalisability in an analytical nature while recognising that the results and discussion of the studies ground in different levels of interpretations. Those levels interrelate with varying kinds of linguistic, empirical and theoretical elements while interacting with the sources of insights and data; analysing and discussing them; and finally reporting the overall research when one faces the problem of language's limited ability to reflect the explored reality (Alvesson & Karreman, 2000).

3.2. Methodological perspective

In line with the overall aim and philosophical underpinning of this thesis, the research design has a *qualitative* nature which enables studying "things in their natural settings" (Denzin & Lincoln, 2005, p. 3) and let the author's "construction of what is explored become more visible" (Alvesson & Skoldberg, 2009, p. 7) by offering interpretative possibilities. This thesis is a single research project with three embedded research studies which employ different methods. Therefore, this thesis is a multiple method research project.

Research Study I follows a case survey through a systematic literature review (SLR). Research Study II and Research Study III, although both employ a case study method, they differ from each other in terms of their designs. The former holds a multiple case study design and the latter a single embedded case study design. Moreover, three research studies differ from each other in terms of their investigative and interpretive contexts. Those together enable a methodological triangulation which eases a better understanding of a particular phenomenon with the help of different methods (Yin, 2014) in different contextual levels (Berthon, et al., 2002). That also increases the research validity in classical terms (Creswell & Clark, 2007), and trustworthiness and transferability in more reflexive terms (Guba & Lincoln, 1994). The overview of three research studies are presented in Table 3 - 1 covering the related research methods and outcome scientific articles.

Table 3 - 1: Overview of the research design.

Research study	Research method	Appended article
I	Case survey through a systematic literature review (Systematic literature review + case survey)	I
II	Case study (Multiple case study)	II
III	Case study (Single embedded case study)	III

The role of theory: Ways of understanding

The thesis employs an *abductive approach* concerning the role of theory in research design following Alvesson and Skoldberg (2009). Abductive approach holds some characteristics of both induction and deduction, but also adds some new specific elements to overcome the limitations of *inductive approach* such as the assumption of the general validity of observations concluded from some cases, and *deductive approach* such as lack of underlying patterns and tendencies. Abduction, alternating between induction and deduction, for this thesis refers to analysing, synthesising and interpreting the empirical data and insights and integrating them with the previous theory, however, from a novel conceptual perspective.

It is worth to note that this thesis is not a favour of any abstract framework claimed to offer 'a privileged understanding' of the research object. In other words, recognising the trick "which is to control theories (interpretive possibilities), without letting them control you" (p. 274) is critical. Included research studies aim at a better understanding of industrial ecology-inspired transitions through investigation rather than establishing the truths. Therefore, they do not employ "the theory as a mechanical application on single cases", but instead they refine and use the SNM framework "as a source of inspiration for the discovery of patterns that bring understanding" (p. 4) on the unfolding industrial ecosystems. Insights from SNM are integrated into theoretical foundations of industrial ecology to offer a novel conceptualisation.

Moreover, the SNM framework, as the primary source of theoretical inspiration of this thesis, has theoretical start points drawing on founding work on evolutionary economics and social constructivist accounts of science technology studies (Schot & Geels, 2008). Its social constructivism grounded ontologies are due to its focus on transition studies with sustainability at the core, "an ambiguous and contested concept" (Geels, 2010, p. 500) that makes it open to different interpretations by different actors. Thus, the chosen theoretical perspective fits well into the philosophical assumptions of this thesis, which in turn brings convenience for conceptual refinement.

The theory-driven approach in this thesis is not to test, verify or expand the SNM framework. Instead, it should be seen as an endeavour to link industrial ecology to innovation studies and to bring in issues from sustainability transitions field into the industrial ecology literature The proposed conceptual frameworks advance the richness of the industrial ecology field through using different concepts (niche experiments, niche-building, articulation of expectations and visions, first-order and second-order learning, emerging community, etc.) and, more importantly, making different lines of interpretations. Once again, the thesis does not claim to provide ontological descriptions of reality; instead, it proposes heuristics that can guide the research to understand and explain the complex dynamics of unfolding industrial ecosystems in real settings. Finally, the employed research studies also illustrate the merits of the proposed frameworks and also contribute to the SNM theory by providing new empirical accounts of application. The overall methodological perspective is shown below in Figure 3 - 1.

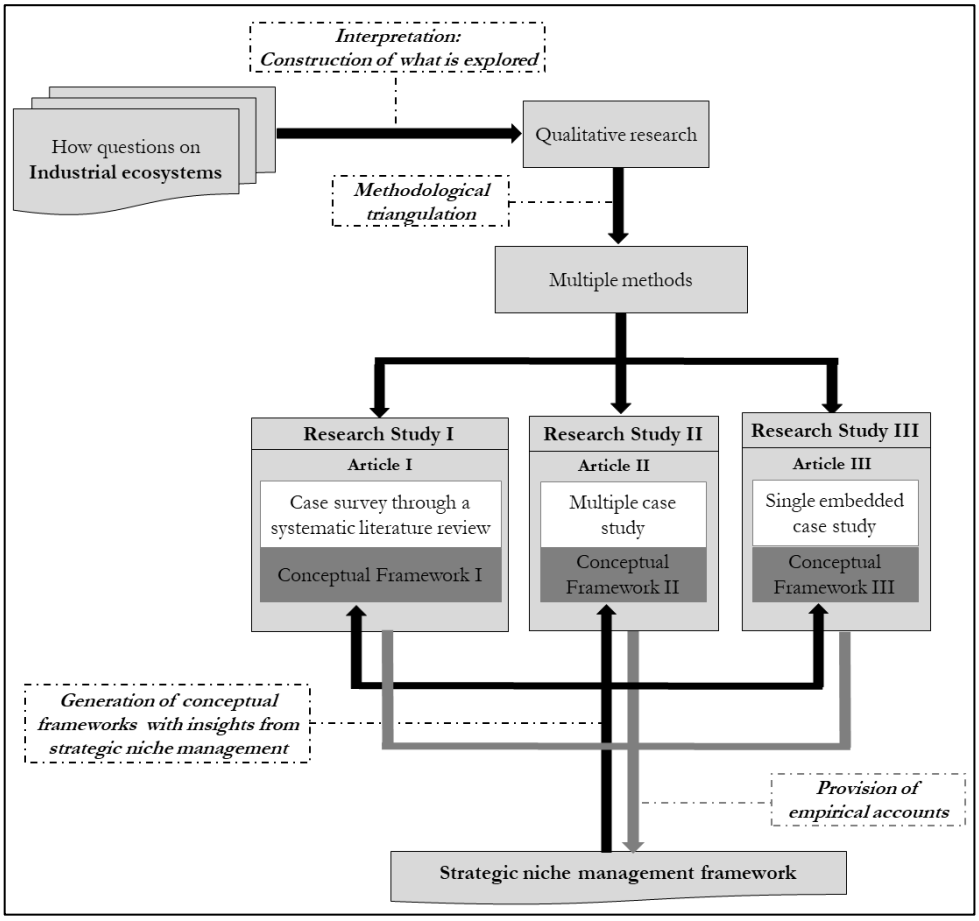

Figure 3 - 1: Methodological perspective of the thesis.

3.3. Case survey through a systematic literature review

Research Study I follows a case survey method (Lucas, 1974) through a systematic literature review (SLR) (Fischl, et al., 2014; Petticrew & Roberts, 2006; Tranfield, et al., 2003) in order to gain a familiarity with a wide range of literature that may bring intellectual flexibility and creativity (Alvesson & Skoldberg, 2009) while providing valuable knowledge to elaborate on how transitions into local industrial ecosystem development can be achieved. More specifically, the study extracts the local industrial ecosystem cases available in the existing state of the art through an SLR and re-interpret them with a different theoretical perspective, which is Conceptual Framework I as presented in Chapter 2.4.

Case survey method enables a rich set of case materials (Kivimaa, et al., 2017; Newig & Fritsch, 2009) which were previously generated for different research objectives under different research designs with varying perspectives of research. The proper synthesis of such case material requires a smart bricolage especially considering the "risk of bias in summarising" (Kivimaa, et al., 2017, p. 20) the previous studies (Petticrew & Roberts, 2006). Therefore, enough time and commitment were present in this research study for the literature synthesis, so that it has been possible to benefit from the advantage of having numerous case studies which would not be probable through direct insight gathering from the primary sources.

The SLR method, instead of a traditional or narrative literature review is more convenient to identify and extract the cases from the literature in a systematic way. The definition of SLR is given by Fink (1998, p. 3) as "a systematic, explicit and reproducible design for identifying, evaluating and interpreting the existing body of recorded documents". Following a case survey through an SLR, the study achieved to gather and re-interpret the earlier interpretations of local industrial ecosystem cases in a new interpretative context through Conceptual framework I. In that way, various case studies (n=104) were brought together under a common theoretical perspective.

For the sake of thoroughness and rigour, the study followed six steps as illustrated in the following Figure 3 - 2 to use the existing knowledge effectively: (i) keyword identification[2], (ii) literature search, (iii) filtering to include relevant publications, (iv) further filtering through title and abstract review, (v) literature analysis, and (vi) literature synthesis. In the last step, the unit of analysis was the local industrial ecosystem case(s) in the selected articles out of the literature search step, rather than the full articles. The final local industrial ecosystem list was composed of 104 cases from 24 countries studied in 66 articles. The global distribution of the cases included in the literature synthesis is given in Figure 3 - 3.

[2] As already explained in Chapter 1 and Chapter 2 of the cover essay, local scale industrial ecosystems are referred as eco-industrial parks (EIP) in the industrial ecology literature. Although 'eco-industrial park (EIP)' terminology is used in the appended articles, the cover essay sticks to the 'local industrial ecosystem' terminology in order to keep the overall coherence. The EIP concept refers to industrial production systems which have a focus on environmental and social pillars of sustainability through 'industrial ecology', and 'industrial symbiosis'. Therefore, three keywords are selected for literature search step of SLR: 'eco-industrial' and its parent concepts 'industrial ecology' and 'industrial symbiosis'. In the keyword selection, industrial symbiosis is also included because it is commonly used in industrial ecology literature. Industrial symbiosis is a practical form of industrial ecology which refers to inter-firm resource exchanges (Chertow, 2000; Chertow, 2007; Felicioa, et al., 2016) to employ closed industrial production loops holding circular industrial production routines (Sterr & Ott, 2004). Industrial symbiosis aims to benefit from the advantages of industrial agglomerations in industrial production systems contributing to the unfolding industrial ecosystems (Ashton, 2008; Lowe & Evans, 1995). In traditional terms, industrial symbiosis can be defined as industrial ecology at inter-firm level (Chertow, 2000).

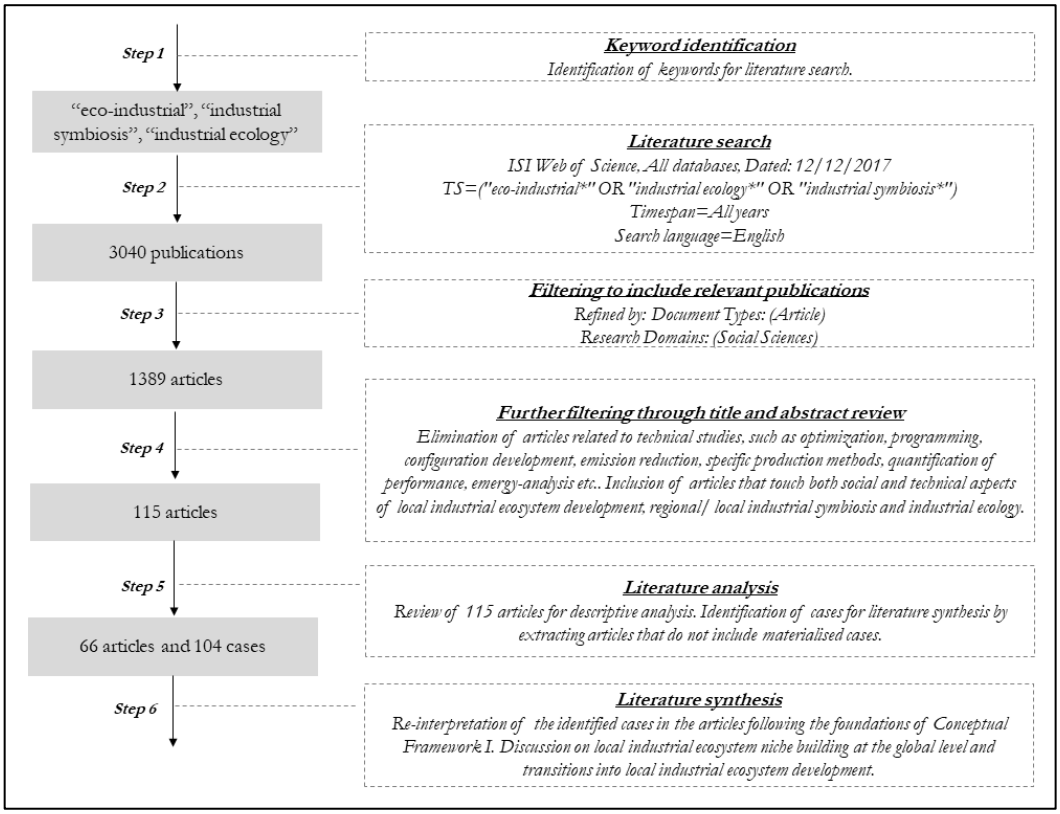

Figure 3 - 2: Case survey method through a systematic literature review in six steps.

Figure 3 - 3: Global distribution of synthesised local industrial ecosystem cases.

3.4. Case study

The main reason behind choosing case study as the second method is that it provides proper ground for constructing context-dependent knowledge (Flyvbjerg 2006) which very much relates to the essence of this thesis which looks for knowledge to further the understanding of industrial ecology-inspired transitions through a scale rendered conceptualisation and analysis of unfolding industrial ecosystems. Such a focus brings a complexity which can be better 'handled' by a modest way of reflexive interpretation (Alvesson and Skoldberg 2009) where the focus is not "to summarise and generalise" cases but instead creating "narratives in their entirety" (Flyvbjerg, 2006, p. 241).

The thesis includes two different case study designs incorporated in Research Study II and Research Study III to generate knowledge on how local and regional industrial ecosystems unfold respectively. Research Study II is a multiple case study focusing on how three local industrial ecosystems have been unfolding in Emilia Romagna and Tuscany regions from Italy, whereas, Research Study III is a single embedded case study focusing how various local industrial ecology projects have been contributing to an unfolding regional industrial ecosystem in Catalonia region from Spain. As such, the overall design of case studies adds both the scale and space variants to the thesis by focusing on two different scales of industrial ecosystems in different empirical contexts.

Two case study designs have some common elements as well. The data and insights gathering for both case studies – that is, the data constructing level – incorporated observations to create images of the empirical phenomenon and also low degree preliminary interpretations. Both case studies planned and followed two different sources of empirical material. On the one hand, secondary data and insights (including comprehensive sector reports from industry associations and government, and scientific articles on industrial development in Italy and Spain) have been the primary sources to trace the development of the industrial production systems in the Emilia Romagna, Tuscany and Catalonia regions. Those secondary sources provided insights on the policy, regulation, technology, actor structure, financial investments, consumer behaviour, etc. about industrial production routines in the contexts under focus. The secondary sources were selected considering their origin and scope (Hox & Boeije, 2005), trustworthiness and relevance to the research objective of the case studies. On the other hand, semi-structured interviews were conducted with the relevant actors related to the unfolding industrial ecosystems in these three regions. All conversations were recorded and treated through a qualitative data coding procedure. It is important to note that, at the data constructing level, the gathered empirical material was not regarded as 'raw' "but as a construction of empirical conditions" (Alvesson and Skoldberg 2009, 283), which were reflected through the interpretations of the interviewees and the secondary sources' authors.

The gathered data and insights for both case study designs in Research Study II and Research Study III were then subject to content analysis, which followed a reflexive interpretation. The significant determinants of the reflexive interpretation have been the gained pre-understanding of a broad range of local industrial ecosystem cases grounded in Research Study I together with the proposed conceptual frameworks (see Chapter 2.4). Following Conceptual Framework II and Conceptual Framework III improved the explanatory power of the case studies (Dubois & Gadde, 2002), which in turn illustrated the merits of the conceptualisations when applied to real settings. Figure 3 - 4 presents the employed case studies. Next, detailed explanations of each case study are given.

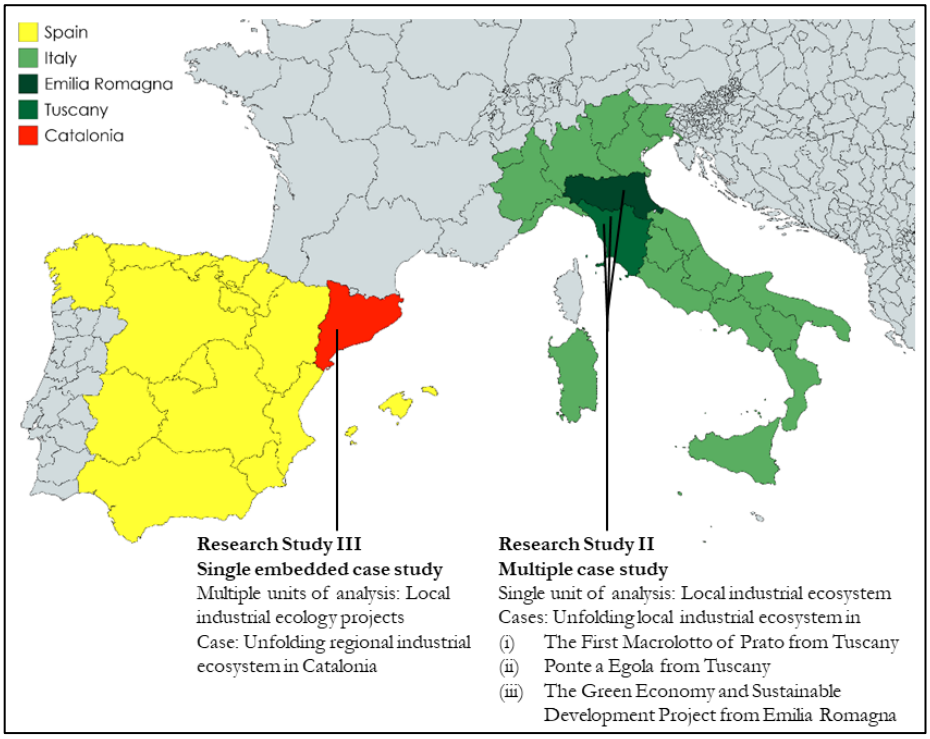

Figure 3 - 4: Case study method in different designs and empirical contexts.

Research Study II: Multiple case study

Multiple cases can provide stronger grounds as it enables cross-analysis and comparison, as well as a more reflexive interpretation through the discussions (Yin, 2014; Alvesson & Skoldberg, 2009; Eisenhardt & Graebner, 2007). Therefore, Research Study II employs a multiple case study methodology to understand and explain how local industrial ecosystems can unfold while following the theoretical foundations of Conceptual Framework II.

Italy has been chosen as the empirical context as it has advanced geography in terms of local industrial ecosystem development (Taddeo, et al., 2012; Daddi, et al., 2016; Taddeo, et al., 2017) and it can provide appropriate grounds for conducting an insightful case study considering the research question of this research study. The landscape provided by the European Union, which has been encouraging the Member States to increase the environmental performance of its territories, has nurtured the Italian context to boost the transitions into more sustainable and eco-compatible spaces.

Along these lines, the Ecologically Equipped Productive Areas (EEPAs) was the first initiative introduced by the Italian Government in 1998 (Tessitore, et al., 2015), and the first concrete attempt in Italy to search for a new industrial production model through the application of industrial ecology principles on the local industrial ecosystem development model (Daddi, et al., 2015). Although the EEPAs initiative was introduced by the central government, it did not accumulate into a national guideline, and each Italian region has disciplined its implementation considering its specific regulatory, geographic, industrial, technical and socio-economic characteristics. Nine out of 20 Italian regions have indicated an intention to experiment with the Italian version of the local industrial ecosystems development through the EEPA certification. Of these, five regions (Emilia-Romagna, Liguria, Marche, Piedmont and Tuscany) have started the regional implementation, and the other four regions (Abruzzo, Apulia, Calabria, and Sardinia) have been developing related policies and strategies (Taddeo, 2016). The initiatives other than

EEPAs also have influenced the Italian industrial ecosystem development journey. In particular, the Eco-Management and Audit Scheme (EMAS) has been contributing to the involvement of industrial clusters in the district level since 1993. The EMAS Cluster Certificate by the Italian National EMAS Competent Body has been a special recognition for the clusters that implement local industrial ecosystem management models (Daddi, et al., 2016).

As for the design of this research study, a structured case study methodology has been followed through three main steps. The first step was about reviewing the secondary data and insights collected through the desk search to obtain an understanding of the general background for local industrial ecosystem development in Italy. Then identified Italian local industrial ecosystem experiences were screened by conducting brief semi-structured interviews and analysing the collected secondary data and insights. That screening was steered by criteria including the existence of the management body in the local industrial ecosystem and its size and age, as well as willingness to collaborate for the research study. At the end of this step, three cases were selected which emerged in Tuscany and Emilia Romagna regions of Italy: (i) The First Macrolotto of Prato from Tuscany, (ii) Ponte a Egola from Tuscany, and (iii) The Green Economy and Sustainable Development Project from Emilia Romagna. Considering the approaches to the local industrial ecosystem development, both Emilia Romagna and Tuscany regions aim to increase the environmental performance of their territories while maximising the economic benefits. Moreover, both regions have introduced the related regulations and resolutions into the force relatively close to each other, compared with others.

In the second step, semi-structured interviews (n=7 in total) were conducted with the senior representatives of the cases and gathered secondary data involved programme reports, policy statements, company data, and relevant publications, etc. Initially, the design of the semi-structured interviews was elaborated. The interviews included two question sections. The first of these sections was designed following the contours of Conceptual Framework II, asking about the niche-building processes, also including the background of the experimentation of the industrial ecology practices. This section remained the same for all conducted interviews. The second section included specific questions for each case based on the already-outlined overview of its context as a result of the initial screening and case selection step. Such an interview design enabled in-depth questions based on a more solid background and appreciated by the interviewees as an indication of the researcher's interest in their cases.

For the First of Macrolotto of Prato, interviews (n=2) were conducted with senior members of Confindustria Toscana Nord, which has been in charge of the environmental management. For Ponte a Egola, interviews (n=3) were conducted with senior representatives of Tannery Consortium of Ponte a Egola, the entity that has been in charge of the environmental management since the settlement of the industrial production system. Finally, for the Green Economy Project, interviews (n=2) were conducted with the senior representative of ASTER, which has been the entity in charge of technical coordination of the experiment as a part of the consortium for the innovation and technological transfer in the Emilia-Romagna region. The interviews not only served as the primary data and insight source but also ended in reliable secondary evidence provided by the interviewees, which enforced the data triangulation. The interviews lasted between 45 and 65 minutes. All conversations were recorded after obtaining the consent of the interviewees. The data and insight gathering was completed from February to July 2018.

In the third step of the case study method, the semi-structured interviews were transcribed and coded. The analysis followed the theoretical foundations of Conceptual Framework II, focusing on the coupling of visions and expectations, the social network-building, the learning processes and spatial context behind the local industrial ecosystem experimentation. For each case, the unit of analysis and level of analysis were the local industrial ecosystem and the niche experimentation journey, respectively. The methodological choice to conduct a multiple case study provided suitable grounds to theoretically replicate the instrumental application of the proposed conceptual framework in more than one setting (Yin, 2014). That also enabled aggregation and cross-discussion of the insights from three experimentation journeys. The empirical study led to an insightful discussion and conclusion through comprehensive interpretations and relevant implications on how local industrial ecosystems can unfold.

Research Study III: Single embedded case study

A single embedded case study methodology with multiple units of analysis (Yin, 2014) is employed in Research Study III to empirically assess how local industrial ecology projects can contribute to the unfolding regional industrial ecosystems for sustainability transitions of industrial production systems. While designing, analysing and interpreting this case study, Conceptual Framework III was followed.

The empirical setting of the case study was chosen as Catalonia region from Spain, which has not been a focus for related research studies despite its diverse and rich industrial production culture and routines embedded in a long industrial tradition. The region was one the early adopters of British industrialisation model in the nineteenth century. The manufacturing has been a leading employing sector in Catalonia; for example, it employed 21 per cent of the total Catalan workforce in 1860, 47 per cent in 1930, and 18.4 per cent in 2014, despite the general de-industrialisation trend and global crisis (Domenech & Ramos, 2016). In the region, the development of agglomerated industries first came to the scene through the regional policies of the 1960s. Since then, the agglomerated industrial production system model has been the most salient form of developing industrial areas and the economic reality of the region, especially since the 1980s (Incasòl, 2007). Industrial activity, in general, represents almost 20 per cent of GDP. There are more than 40 local scale industrial production systems, including nearly 9000 industrial establishments, generating a turnover of more than 45 billion Euros, contributing to an estimated 10 per cent of the region's GDP (Hernández, et al., 2005). Meanwhile, the region has been active in sustainability-oriented initiatives because its rapid industrial development has surpassed the available land for further development. The intensity and diversity in geographically agglomerated industries have provided a proper ground for potential exchange synergies between industrial actors, which may create industrial ecosystems in the region.

As for the design of this research study, an embedded case study design has been chosen. The case study focused on multiple units of analysis which were various industrial ecology projects with a level of analysis of the unfolding regional industrial ecosystem niche. After a review of the literature, internet and research reports, eight industrial ecology projects were selected, which have addressed sustainability problems of industrial production systems in the region through their objectives and activities. The selected set of projects covered a period of 18-years, from 1999 to 2017. Temporal distribution of initiatives, together with their names, start and end years, is illustrated in Figure 3 - 5 below.

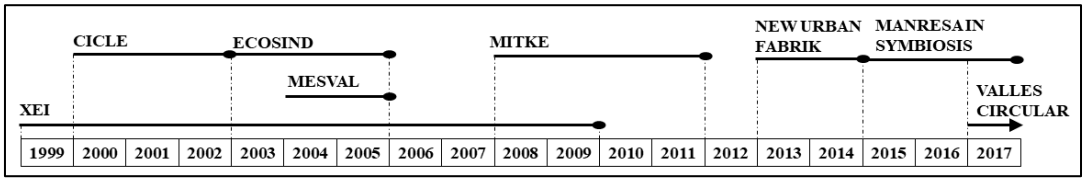

Figure 3 - 5: Temporal distribution of industrial ecology projects.

After identifying these eight projects, semi-structured interviewees were conducted, and available secondary data from the interviewees and online sources were gathered to develop an integrated set of interpretations (Yin, 2014). Firstly, secondary data and insights related to industrial ecosystem development in Catalonia were used as a source of evidence to trace the related industrial development in the region. Collected secondary evidence included comprehensive reports from governmental organisations, interim and final reports of selected local projects, press releases, presentations, posters, articles, news and blogs published in the mass media or community newspapers. Secondly, semi-structured interviews (n=8 in total) were conducted with the relevant actors involved in the selected industrial ecology projects. The interviews were completed from May to October 2017.

The interviews started with key informants who were involved in the management of the projects. More key interviewees were identified using the snowball technique (Lincoln & Guba, 1985; Heckathorn, 2002) for other selected projects as well. All selected interviewees had been involved in the design and implementation of the selected projects with critical roles, such as manager, coordinator, expert, and principal architect, etc. Thus, they were able to provide the proper background, design, implementation and follow-up situation of the projects. The interviews lasted between 35 and 90 minutes. All conversations were recorded after obtaining the consent of the interviewees. Follow-up enquiries were employed by e-mail or telephone, and further secondary evidence was collected from the interviewees as well for the sake of triangulation.

Regarding the design of semi-structured interviews, a priori framing of the underlying interview questions (Creswell, 2009) was outlined encompassing the underpinning elements of Conceptual Framework III. The questions were formulated to examine: (i) the background of the interviewee; (ii) the industrial production routines in the region; (iii) the related project; and finally (iv) the region in regard to other similar initiatives and other relevant actors based on the experience and the knowledge of the interviewee.

Finally, the gathered data and insights were analysed through codes and categories, and then interpreted focusing on the relationship among them through explanation building. The analytic technique of *'explanation building'*, which is a type of pattern matching (Yin, 2014), has been particularly useful to observe the patterns and interpret the relationship among the codes and categories to explain how each local industrial ecology project and its outcomes influenced three internal niche processes and how these together contributed to the unfolding regional industrial ecosystem niche for sustainability transitions of industrial production systems in Catalonia.

3.5. Methodological considerations

This thesis, with its qualitative nature, incorporates three different research studies with different research designs which hold strong interpretative characteristics as a result of the underlying philosophical assumptions. That calls for some considerations on the research rigour, yet with more reflexive terms. In this vein, the thesis stands closer to the 'trustworthiness' approach (Guba & Lincoln, 1994), and deals with research rigour concerns in terms of *credibility*, *transferability*, *dependability*, and *confirmability* which appreciate the reflexive research grounds, rather than traditional focus on *internal validity*, *external validity*, *reliability* and *objectivity*, respectively.

Considering the ***credibility*** concerns, firstly, a well-established integration of conceptual approach to the empirical perspective has been ensured. That is to say, the central concepts of the conceptual framing were followed in the design of the empirical studies. The methods employed in this thesis incorporated the proper "operational measures for the concepts being studied" (Yin, 2014, p. 72), primarily through the design of data and insight gathering, i.e. literature search strings, semi-structured interview designs. Moreover, following Lincoln and Guba (1985), a prolonged engagement between the author and evidence sources has been established to have a priori understanding of the involved industrial ecosystem cases (in Article I, Article II and Article III) and this particular constructed the initial trust grounds between the author and the interviewees especially when employing the case study method (Article II and Article III). Notably, while using the case survey method (Article I), the author was aware that the proper synthesis of such amount of case material (n=104 cases) would require a smart bricolage ability, especially considering the "risk of bias in summarising" (Kivimaa, et al., 2017, p. 20) the studies that she had not conducted (Petticrew & Roberts, 2006). Therefore, enough time and commitment have been devoted to the literature synthesis step to benefit from the advantage of having numerous case studies, which would not have been possible through direct insight and data gathering from the primary sources. Also, methodological triangulation through incorporating different research methods increased the credibility of the overall research. More specifically, using various sources (primary and secondary evidence), involving multiple interviews from multiple organisations, and so analysing multiple unfolding industrial ecosystems have substantially contributed to the credibility of the employed case studies (Yin, 2014; Creswell & Clark, 2007; Denzin & Lincoln, 2005).

Giving a specific focus on the design and implementation of the semi-structured interviews (Article II and Article III), the questions were tailored in a language that would be understandable by the interviewees (Meyer & Ward, 2014) and the interviewees were selected in a way that all of them had had critical roles in and extensive knowledge about the cases (Article II) and industrial ecology projects (Article III). Moreover, interviewees were also permitted to explain beyond the answers to the drafted questions to gather more insights without concrete, and perhaps unnecessary, constraints. It is also crucial to recognise that the interviews alternated between retrospective and prospective reflections of interviewees (Schultze & Avital, 2011). More specifically, most of the interviewees firstly shared their past experiences and ideas – that is, retrospective reflections (Eisenhardt & Graebner, 2007). There were also prospective reflections from those interviewees evolved during the interviews when they started envisioning ideal conditions for industrial ecosystem development based on their past. It is also worth pointing out that the author was aware of the potential recall bias, which may be due to retrospective distortion (Miles, 1979). To avoid this potential bias, the semi-structured interview questions had been shared with the interviewees in advance, and during the meetings, enough time was given to them to reflect and think before answering (Hassan, 2005). Furthermore, using secondary

evidence considering triangulation also enabled the grounds to scrutinise reflections and insights of the interviewees through multiple sources of evidence, again, to allay the potential recall bias concerns (Gioia, et al., 2010).

The thesis stands at a fair distance to the traditional understanding of external validity, which is related to generalisability of the research results, and instead aims to address the issue of ***transferability***. The research involved in this thesis seeks to advance the understanding of industrial ecology-inspired transitions by conceptually framing and empirically analysing the unfolding industrial ecosystems building on the data and insights from the selected empirical cases. Each unfolding industrial ecosystem journey may carry particular characteristics due to its specific context-dependent features, varying constellation of involved actors, their past experiences and also the future expectations (Garud & Gehman, 2012). The thesis does not aim to construct ontological realities which can apply to all past, present and future industrial ecosystem cases. The intent here is to generate knowledge which can "enter into the collective process of knowledge accumulation in a given field or in a society" agreeing with Flyvbjerg (2006, p. 227).

Therefore, the thesis does not argue for the formal generalisation of the results but instead provide conceptual frameworks and some implications for researchers while recognising that the results of the studies have been formulated through different levels of interpretations. Expectantly, the involved research studies in this thesis can influence other researchers to design their studies in a similar manner using similar perspectives and considering similar dimensions. The proposed conceptual frameworks can be used for different units of analysis in different empirical settings. If generalisability has to be mentioned, then this thesis does not offer a generalisability in a statistical nature but instead an analytical nature (Yin, 2014).

Concerning the ***dependability*** dimension, the above-explained credible nature of the involved research studies substantially contributes to the dependability of the thesis as well (Lincoln & Guba, 1985). Even so, each conducted research study has been archived appropriately to provide a comprehensive understanding of the employed methods incorporating the operational details of the research design (Shenton, 2004). A potential future researcher can repeat the research with the same techniques, with the same interviewees, with the same secondary evidence. However, the researcher not necessarily will be able to obtain the same results due to the changing nature of the industrial ecosystem phenomena and also the changing nature of the investigative and interpretative contexts (Fidel, 1993; Marshall & Rossman, 2015).

Finally considering the ***confirmability***, the thesis recognises the impossibility of 'researcher perspective free' research agreeing with Guba and Lincoln (1994), and also given its *interpretivist* assumptions. In the embedded research studies, the analyses and discussions are strongly related to the author's interpretations of the interpretations of data and insight sources. Still the overall research design contributes to achieving confirmability as: a detailed methodological description was given for each research study; the results and discussions of each research study were examined by all co-authors of the related outcome article; data and insights were triangulated with multiple primary and secondary sources, and finally the results and discussions of case studies were reviewed by the interviewees as well.

Chapter 4. Summary of the appended articles

This chapter summarises the included three articles in the thesis. The articles are the outcomes of three research studies which are conducted to address the overall research objective. They examine different scale industrial ecosystems which unfold in different contexts following the proposed conceptual frameworks. The outline which illustrates how each article is related to the relevant research study and how they provide the discussion and conclusion concerning the overall research question of the thesis are given in Figure 4 - 1 below. Then, summaries are provided for each article focusing on its purpose, methodology, findings, research implications, originality/value, and finally the contributions to the thesis.

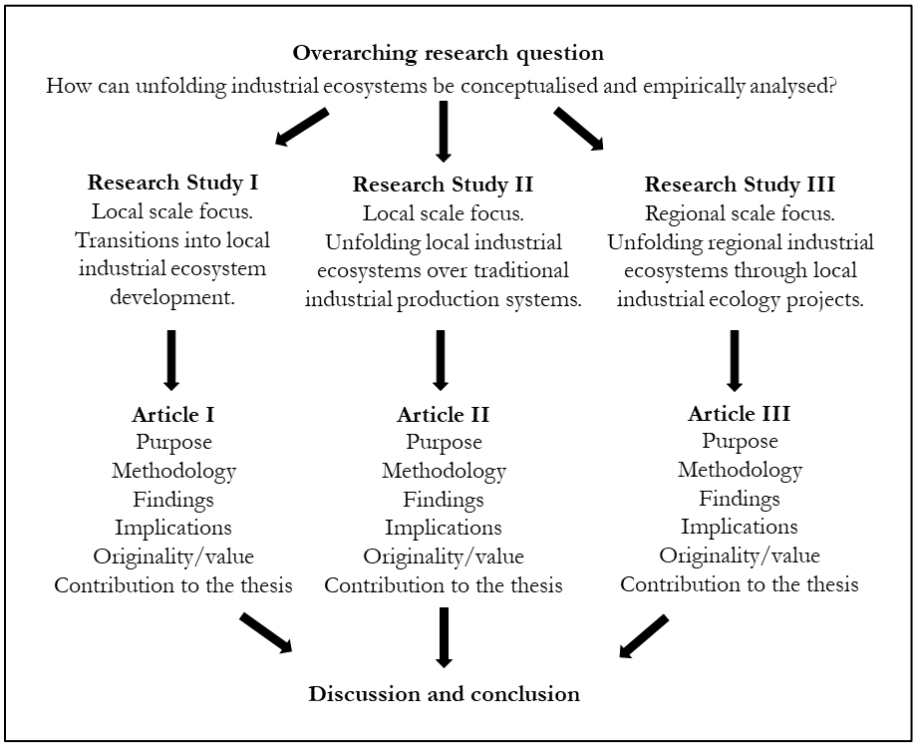

Figure 4 - 1: Appended articles and their link to the thesis structure.

4.1. Article I

Purpose: The purpose of this article is both to understand and shed some light on how a transition from local industrial production systems[3] development into local industrial ecosystem[4] development can be achieved through lessons from the local industrial ecosystem cases in the existing state of the art and to establish a research agenda that would elaborate on sustainability transitions into local industrial ecosystem development.

Methodological perspective: The skeleton of the methodological approach behind the article is based on its conceptual framing and the selected method. As for the conceptual approach, this article brings insights from sustainability transitions research stream and mainly builds on the SNM framework, in which transitionary sustainable practices are approached as niche experiments. By proposing a novel conceptual framework (Conceptual Framework I), local industrial ecosystem cases are conceptualised as strategic niche experiments that are expected to steer transitions to local industrial ecosystem development, and mainstream local industrial production system development is subject to sustainability transitions. As for the employed method, an SLR involving a case survey is conducted. The SLR starts with a literature search, where the crucial element is to choose the database(s) and the keyword(s). Then, in the literature analysis step, selected studies are descriptively analysed in terms of various aspects related to journals, publication years, and geographical focus of studies. The local industrial ecosystem cases that are included in the literature synthesis step are also identified in this step. The final list is composed of 104 cases from 24 countries studied in 66 articles. Finally, each case is re-interpreted following the backbones of the proposed conceptual framework. Moreover, the literature synthesis step also formulates policy and research implications.

Findings: The results of the literature analysis indicate that research on local industrial ecosystems in social sciences domain stands still like a new line and maybe enriched within interdisciplinary studies operationalised in concepts from different social science theories. This enrichment would further extend our understanding of if and how transitions to local industrial ecosystems development can be achieved. Moreover, articles with a multi-country focus provide experience and knowledge from and across different contexts, which arguably creates a more fruitful learning ground for the readers. The results of the literature synthesis are presented in line with the core concepts suggested by the conceptual framework. The article also discusses the development of local experiments and local industrial ecosystem niche formation at different geographies. For each analytical level, policy implications and research implications are also suggested.

[3] As previously explained, local scale industrial production systems can be referred as industrial parks in the industrial ecology literature. Although 'industrial park (IP)' terminology is used in the Article I, the cover essay sticks to the 'industrial production systems' terminology in order to keep the overall coherence

[4] As previously explained, local scale industrial ecosystems are referred as eco-industrial parks in the industrial ecology literature. Although 'eco-industrial park (EIP' terminology is used in the appended articles, the cover essay sticks to the 'local industrial ecosystem' terminology in order to keep the overall coherence.

Implications: On the one hand, at the policy level, the findings imply that an effective combination of a top-down and bottom-up approach stressing more brownfield local industrial ecosystem projects would be more suitable. Moreover, the network perspective in local industrial ecosystem development should be widened, aiming at a combination of industries and external actors such as governmental organisations, research institutes, universities, informal institutes like industrial associations and NGOs. Furthermore, learning activities and processes require an explicit focus in industrial ecology applications. If first-order learning can be achieved continuously via capacity-building measures for actors, it can accumulate into second-order learning. In that vein, cross-fertilisation across different examples from different places is crucial for experiments to learn from each other. Finally, the article suggests that the isolated experiments can be further developed into niches by interconnecting or expanding them beyond the local level utilising effective policy mechanisms.

On the other hand, some research implications are also proposed forming a research agenda. Evolving expectations and visions for local industrial ecosystem development covering a wide variety of related actors require an explicit focus on the industrial ecology literature. A broader view for transitions into local industrial ecosystem development has not been explicitly examined as well. Structures of more extensive networks, which involves not only industrial actors but also external institutions, and the interaction among them remain underexplored. Considering that, an understanding of the potential correlation between the visioning and emerging industrial ecosystem network characteristics can be useful. Learning transfer from one experiment to other experiments, although it is considered essential for local industrial ecosystem development, received scant attention and requires further investigation. The existing literature misses alternative conceptual frameworks for examining industrial ecosystem transitions. To address this gap, it would be fruitful for industrial ecology research to bring in insights from sustainability transitions literature.

Originality/value: This article proposes a conceptual framework with an evolutionary perspective drawing on industrial ecology literature and the SNM framework. As such, it connects two streams of research that have not been closely associated in the past. The selected methodology is also novel in terms involving a case survey within an SLR. Moreover, to the best of the authors' knowledge, no literature reviews have been conducted to date to understand how sustainability transitions into local industrial ecosystem development can be achieved or to extract the local industrial ecosystem cases studied in the literature. This article, doing so, contributes to the cross-fertilisation across globally distributed cases while also adding to the critical mass in leveraging global industrial ecosystem development. Drawing lessons from past and present local industrial ecosystems bring insights for future local industrial ecosystem transitions.

Contribution to the thesis: This article is the outcome of the Research Study I. It contributes to the understanding of potential sustainability transitions into local industrial ecosystem development based on the experience from the past and present local industrial ecosystems studied in the industrial ecology literature. It provides a rich set of insights on how local industrial ecosystem development can unfold by synthesising 104 cases distributed to 24 countries worldwide. It also contributes to the conceptual framing of the thesis by proposing Conceptual Framework I, bridging between the industrial ecology and sustainability transitions fields.

4.2. Article II

Purpose: This article aims to understand and explain how local industrial ecosystems can unfold over the traditional industrial production systems.

Methodological perspective: The methodological approach is twofold. Conceptually, the article refines the SNM framework under its local industrial ecosystem-focused inquiry and conceptualises the journey to becoming a local industrial ecosystem as niche experimentation and local industrial ecosystems as niches. Then three niche-building processes are proposed as the main dynamics of the niche experimentation journey: (i) the articulation of expectations and visions, (ii) building of networks, and (iii) learning processes, considering the mediating effect of the spatial context (Conceptual Framework II). Empirically, a qualitative multiple case study is employed. The article studies three local industrial ecosystem cases from Italy, an advanced country in terms of industrial ecosystem development and focuses on the regions of Tuscany and Emilia Romagna. Following semi-structured interviews and the documentation analysis, a multiple case study goes beyond a data-driven empirical analysis as the article strengthens its theorisation and power of interpretation by analytically building on the SNM framework. As an outcome of the empirical analysis guided by the initial conceptual framing, an overall framework is derived and presented that illustrates the unfolding local industrial ecosystems through niche experimentation.

Findings: The results of the analyses indicate that the continuous experimentation of the local industrial ecosystem practices within a broad actor-network, through learning processes, leads to shared expectations and visions regarding economic gains and also the environmental benefits of the industrial ecology practices, which enable the local industrial ecosystems to unfold. Still, there is no single rigid model that explains the unfolding local industrial ecosystems, because the continuously interacting and interdependent niche-building processes assemble the niche experimentation journey, which is also shaped by the spatial context.

Implications: The article provides action-, policy- and research-oriented implications. On the one hand, the learning offered through the results and discussion may serve for the regional policy-makers and practitioners for further local industrial ecosystem experimentation in the Emilia-Romagna and Tuscany regions. Moreover, the derived framework may be used as an ex-ante management tool for future local industrial ecosystem experimentation elsewhere. The article suggests that the potential for an industrial production system to transform into a local industrial ecosystem calls for specific niche formation policies. Particular importance can be given to the network-building process targeting various regional actors (not only focusing on the industry), which will couple their expectations and visions through learning mechanisms disseminating the knowledge on the industrial ecology practices.

Moreover, continuous experimentation will not only lead to an increased number of local industrial ecosystems in specific regions but may also bring a shift in traditional industrial production routines through the industrial ecology philosophy on a broader scale. On the other hand, considering the research implications, the case study provided in this article can be extended to different local industrial ecosystem cases to understand their emergence and to further test the plausibility of the overall framing for the analysis and explanation on how local industrial ecosystem unfold at different spatial contexts. Moreover, further research could study in detail the interdependency of the niche processes and their impact on each other during the experimentation.

Originality/value: A few earlier studies borrowed from or instrumentally used concepts from the analytical frameworks proposed by sustainability transitions research for analysing different scale industrial ecology implementations. The present article differs from those previous attempts in several ways through its original approach on the conceptual framing and methodological design. Considering its theoretical approach, firstly, it further illustrates the usefulness of the SNM framework for framing the local industrial ecosystem development-related studies within the industrial ecology domain. Secondly, it systematically strengthens the link between the industrial ecology literature and sustainability transitions field. Thirdly, the suggested conceptual framing differs from above-mentioned previous studies because it focuses on how local industrial ecosystems unfold through the niche-building processes, taking the niche experimentation central to the conceptualisation. The article also brings the spatial context as the mediating factor for niche experimentation. The internal niche-building processes under the influence of spatial context guide the interpretations in terms of understanding how local industrial ecosystems can unfold by observing the experimentation journeys in specific settings. In terms of the methodological approach, the article seeks first and foremost to answer a novel research question. Secondly, it distinguishes between the conceptual framing and empirical methodology for the research inquiry. Initially, it frames the research study analytically while refining and operationalising SNM. That enables formulation of the constructs of the study based on the concepts from the SNM framework. Finally, the empirical methodology allows the authors to bring a rich set of new insights from two regions in Italy, an experienced country in that field.

Contribution to the thesis: This article is the outcome of Research Study II. The article contributes to the understanding of how local industrial ecosystems unfolds over traditional industrial production systems through the niche-building processes under the influence of spatial context. It provides empirical insights from three local industrial ecosystem cases from two Italian regions focusing on their journeys to become a local industrial ecosystem as niche experimentation. It enriches the theoretical bridging between the industrial ecology and sustainability transitions fields and expands the boundaries of the industrial ecology field by advancing the knowledge generation. This also contributes to the conceptual framing of the thesis by proposing Conceptual Framework II.

4.3. Article III

Purpose: The objective of this article is to understand how local industrial ecology projects[5] can contribute to the emergence of regional industrial ecosystems for sustainability transitions of industrial production systems.

Methodological perspective: The methodological approach is twofold. On the one hand, the article offers a conceptual framework that integrates industrial ecology literature and SNM framework (Conceptual Framework III). The framework provides a theoretical foundation for analysing the individual industrial ecology projects and their aggregated contribution to the emergence of regional industrial ecosystems. Analytically, it conceptualises two different heuristic levels -the local industrial ecology experiments level and the regional industrial ecosystems niche level- which are interlinked through three niche-building processes: the articulation of expectations and visions, social network-building, and learning activities. The conceptualisation aims to generate a heuristic that can guide the analysis of the intricately evolving dynamics of unfolding regional industrial ecosystems in real settings. On the other hand, the merits of this conceptualisation are represented through a single embedded case study with multiple units of analysis in an empirical context - a highly industrialised and rarely explored region, the Autonomous Region of Catalonia in Spain. Eight industrial ecology projects that evolved during 18 years are identified, analysed and synthesised.

Findings: The empirical study demonstrates how a set of local industrial ecology experiments can be analysed to understand the emergence of a regional industrial ecosystem using the proposed conceptual framework. The results show that continuously cultivated and interlinked industrial ecology projects from the region gradually add up to an emerging regional industrial ecosystems niche. However, it is not yet accurate to speak of a broad emerged community with articulated expectations and visions and shared cognitive, formal and normative rules. In this vein, continuity of local experiments is crucial for reasons: to keep the momentum going, as also proposed by the SNM studies; to involve more industrial actors in the regional network; to develop real symbiotic exchanges for supporting further second-order learning outcomes; to create deeper linkages between the experiments; and to inform more actors in the region about what has been achieved so far and the necessary future steps. If the emerging regional network provides support and protection for new experiments, which will continuously contribute to niche-building processes, a culture change then can reveal towards industrial ecology-inspired sustainability transitions.

Implications: Considering action- and policy-oriented implications, the developed conceptual framework in this article can be extended as a prescriptive management tool for regional actors from Catalonia, as well as other regions holding an interest in initiating or sustaining industrial ecology experiments or in developing industrial ecosystems. If new experiments are designed from the beginning by using the proposed framework as a management tool, then their contribution to regional industrial ecosystems niche can be potentially stronger. Moreover, this article, contributing to a better understanding of regional industrial ecosystems, may be influential on the decisions and actions of industrial organisations of all sizes, governmental and non-governmental organisations, entrepreneurs, knowledge organisations, managing/

[5] As previously explained, industrial symbiosis is a practical form of industrial ecology and any industrial symbiosis practice is an industrial ecology practice. The cover essay sticks to 'industrial ecology' terminology in order to keep the overall coherence.

coordinating bodies, etc. The article also offers further research avenues. The conceptual framework can be further tailored and used as an ex-post analytical framework for analysing other regional industrial ecosystem empirical cases. Moreover, future industrial ecology studies can seek to focus on the transitions of industrial production systems. Such a focus may require analysis of multi-regime dynamics which indeed needs to be expanded as other sustainability transitions scholars have also recommended (e.g. (Schot & Kanger, 2018; Raven, 2007)).

Originality/value: The article offers a novel conceptual framework which provides the analytical grounds for an empirical assessment of the contribution of a set of local industrial ecology projects to the emergence of regional industrial ecosystems. Operationalisation of the conceptual framework in a real setting also enables a new case study perspective for industrial ecology literature, which did not provide an explicit methodological focus on a broad set of industrial ecology projects as separate units of analysis from the same region for assessing the emergence dynamics of regional industrial ecosystems. The article also provides new empirical evidence from an underexplored context, Catalonia, in the literature.

Contribution to the thesis: This article is the outcome of the Research Study III. It provides the interpretive explanations for understanding the individual industrial ecology experiments, the interplay between them, and their aggregating contribution to the unfolding regional industrial ecosystems through an empirical study. The included empirical study not only contributes to the overall research aim of the thesis but also serves to further explore the plausibility of the conceptual framing with a particular regional focus (Conceptual Framework III).

Chapter 5. Discussion

This chapter presents the synthesis of the findings of the appended articles by offering new insights on unfolding industrial ecosystems. The discussion firstly focuses on the local scale and then the regional scale industrial ecosystems while following the contours of the proposed conceptualisation. Finally, a blended frame is provided to further understanding the industrial ecology-inspired transitions.

5.1. Unfolding local industrial ecosystems

The inquiry on conceptualisation and analysis of unfolding local industrial ecosystems have been addressed in Research Study I and Research Study II, which resulted in Article I and Article II, respectively. The former employed a case survey through an SLR. It conceptualised local industrial ecosystem development as a general trend and synthesised the already studied 104 cases from 24 countries by following the Conceptual framework I. Whereas the latter study, first offered a conceptualisation and then an analysis on particular unfolding local industrial ecosystems over traditional industrial production systems following a multiple case study methodology (three cases from Italy) operationalised with the Conceptual Framework II. Below the discussion on unfolding local industrial ecosystems is provided through a synthesis of the results from both articles.

Articulation of expectations and visions

The results of Article I and Article II showed that the *expectations and visions* of local industrial ecosystem development are strongly shaped by the motivations of the involved actors. The actors usually hold different interests, and their expectations can vary, even within the same geography. On the one hand, the motivation for the industrial players are almost always economical, and whenever the industrial ecology project does not seem economically feasible, the industry is usually not interested. Industrial organisations do not tend to prioritise the social and environmental potential of industrial ecology practices. Besides, industrial actors that do not have any related experience and are not equipped with enough background knowledge related to industrial ecology (Park, et al., 2016) are not willing to initiate such experiments. Rarely, industrial actors can take the lead in starting industrial ecology practices, and even in that case, they mostly collaborate with local and regional governmental organisations. However, routines can change, and experimentation can play a crucial role in that. For instance, the studied Italian cases in Article II implied that during the local industrial ecosystem experimentation, the motivation among the industrial actors has been shifting from individual-performance-oriented focus considering only economic sustainability towards collective-benefit-oriented collaboration with other system actors. On the other hand, expectations of governmental organisations, especially considering the planned experiments, are mostly positive and mainly motivated by the global landscape pressure on sustainable development, concerns related to sustaining the active presence of country's industry in the international market, and the environmental pollution and resource scarcity problems at the regional or national levels.

Expectations of actors from industrial ecology practices are highly interlinked with the general vision of local industrial ecosystem development in the related geography. That vision relates to mainly three evolution models proposed by the industrial ecology: (i) planned, (ii) facilitated, and (iii) self-organised local industrial ecosystems. In the literature, some leading scholars argue for importance of building upon existing and potential linkages within a locality (Gibbs and Deutz 2007), using existing strengths (Gibbs, et al., 2005), identifying and uncovering existing collaborative culture (Lambert & Boons, 2002; Chertow, 2007), and so they promote self-organised and facilitated models in this respect. However, the results show that planning can be useful particularly when it takes place in the early stages of the experimentation, and also if it is combined with a facilitated model to achieve long-term goals for industrial ecosystem transitions (see also (Yu, et al., 2015)).

Indeed, a top-down approach leading to planned local industrial ecosystems has been prevalent in various cases from North America, South America, Asia and Australia. Especially in USA and China, local industrial ecosystem development has been strongly guided by the government (Yu, et al., 2015; Gibbs & Deutz, 2005; Chertow, 2007). The results of Article I also indicated some cases from these geographies on which top-down planning was combined with a bottom-up approach and those cases turned out to be facilitated models. That approach combining top-down and facilitated models have led to a higher number of local industrial ecosystem cases when compared to all other countries (see Figure 3 - 3).

In Europe, on the other hand, there is a diversity in local industrial ecosystem development visions. Still, the self-organising and facilitation mechanisms for brownfield experiments have been more prevalent than planning trends for greenfield experiments. Bottom-up self-organised development as a result of voluntary co-operation has been the primary trend at various European local industrial ecosystem experiments. The initial triggering factors behind these experiments were mainly related to sustainability-related concerns of industries and facilitation mechanisms were introduced later by governmental and private intermediary organisations. For some other cases, however, bottom-up involvement has emerged later, leading to a facilitation model, although industrial ecology mechanisms initially had been introduced in a top-down fashion. This also has been observed in the Italian cases, which were analysed in-depth in Article II.

Moreover, the regional and national vision also play crucial roles in the protection of local industrial ecosystem experiments, considering the supporting potential regulatory and financial frameworks. Protection measures, such as tax regimes, environmental regulations, national policy programmes, financing incentives, and so on, condition and trigger, or in some cases even hinder local industrial ecosystem development, and decisions related to them can be political and often can be influenced by the power parties at the national level (Weber, et al., 1999). In this regard, the integration of top-down planning into local industrial ecosystem development appeared to be critical in the involved cases in Article I and Article II.

Followingly, a broader long-term vision for local industrial ecosystem transitions only appears in countries where a top-down approach with national-level goals has been followed, such as China, South Korea, Italy, and Thailand through brownfield projects, and the USA, mostly through greenfield projects. However, the local industrial ecosystem experiments which followed a narrower vision built by expectations of particular local/regional actors mostly remained at the local level by either developing greenfield cases from scratch or leading the transition of a specific industrial production system through brownfield experimentation.

Finally, the results also showed that brownfield vision using existing linkages and strengths within an industrial production system has generally been more fruitful than the greenfield vision (see also (Chertow & Ehrenfeld, 2012)). More successful local industrial ecosystem experiments have been the ones that actively engaged in facilitation mechanisms to keep the viability at even later stages of the experimentation. Facilitation mechanisms generally combine top-down, and bottom-up approaches and that combination provides the appropriate grounds for interactions between the system actors to build industrial ecosystem networks. For instance, the coordination/management activities offered by public, or public-private organisations in facilitated models, can be specifically helpful for learning processes to have aligned expectations and visions among the system actors.

Social-network-building

Regarding the *network-building*, the results of Article I and Article II indicated that industrial ecosystems development requires a consideration of a broader constellation of actors including not only the industry but as well as other organisations such as governmental bodies, regional and local development agencies, universities and research centres, local communities, non-governmental organisations representing the community interests, etc., in order to involve multiple views in a more democratic way and engage resources from different actors. However, the network perspective in the majority of industrial ecology literature mostly covers the industrial actors involved in resource exchange networks. The analysis of included local industrial ecosystem experiments in Article I depicted that a broader industrial ecosystem network can condition the resource exchanges between the industrial actors and constructs (particularly non-material) resource exchanges between other actors as well. Then, the results suggested considering the resource exchange network based on industry interactions as a part of the broader industrial ecosystem network.

The results implied that some actors might have relatively more critical roles than others in the experiments. Among these, the coordinating body (Chertow & Ehrenfeld, 2012), which sometimes also referred as the management body (Tessitore, et al., 2015), together with local/regional champions (Chertow, 2007; Roberts, 2004; Heeres, et al., 2004) seem to be the most noticeable ones when their potential industrial ecology facilitating power is considered. On the one hand, the coordinating body can be a private company, an industry association, a public or a public-private authority (Caniëls & Romijn, 2008) depending primarily on the expectations and visions for the local industrial ecosystem development in the concerned geography. For instance, in China (Yu, et al., 2015), South Korea (Behera, et al., 2012; Park, et al., 2008) and Italy (Tessitore, et al., 2015), where there is a national-level vision planned in a top-down manner, coordinating bodies are established and represented by public authorities. The coordinating body in some other experiments, which hold a combination of top-down and bottom-up vision, demonstrates a mixed structure with representation from the industry, government and academia, and appreciates and communicates a broader range of articulated views. The local/regional champions, on the other hand, can facilitate a more realistic but still ambitious goal setting, and also a broader and deeper network-building, which is also in line with the arguments from the SNM framework (Caniëls & Romijn, 2008). These actors can strengthen bottom-up activities to gather all relevant actors for fostering social connections and developing trust in the built networks.

Moreover, the governmental organisations' role can also be fundamental in enabling and boosting the experimentation, primarily through establishing relevant regulatory and financial incentivising mechanisms. For example, the Italian Government recognises the local industrial ecosystem development as a strategic regional development model and reasons that local industrial ecosystems shall not only serve for better environmental performances but also foster job creations and contribute to the regional economic development. Such an approach also nurtures the involvement of the regional and local authorities as well as the local industries in the experimentation, as also shown in Article II.

Learning processes

Finally, *learning*, as argued in the SNM literature, has a crucial role in sustaining the experimentation of single cases or a set of demonstration cases (Schot & Geels, 2008). An in-depth look into learning activities embedded in the evolution paths of industrial ecosystems has been necessary in both Article I and Article II to analyse and synthesise the local industrial ecosystem cases.

The results showed that the depth and breadth of learning processes are related to the characteristics of emerging local industrial ecosystem development networks. The results showed that the communication and dissemination events as capacity-building measures, organised by intermediary facilitating actors such as coordinating/management bodies, local/regional champions, environmental agencies, or governmental organisations, can provide appropriate mediums for, particularly first-order learning among the actors. Information systems technologies can also be essential tools to facilitate the exchange of information and materials. Then, repetition and accumulation of first-order learning over time can lead to a rethinking of assumptions and changes in production routines (that is, the second-order learning), through which not only technological issues but also social, managerial and organisational dimensions required for symbiotic exchanges can be addressed.

The analysed indicated that when the industrial ecosystem networks are broad, and they connect various experiments, as in countries like China and Italy, where there is a national scale vision on industrial ecosystem development, the second-order learning seems to be more likely. One reason for this is the "structured repeated visioning" (Schot & Geels, 2008, p. 541) through various experiments under the protection of the same umbrella programmes, such as the National Demonstration Eco-Industrial Park Program and the National Demonstration Circular Economy Zone Program in China (Zhang, et al., 2010) and Ecologically Equipped Productive Areas and Eco-Management and Audit Scheme in Italy (Daddi, et al., 2015). Another reason is related to the higher number of experiments, which were initiated and protected by these programmes through concurrent experimentation, and aggregation of learning outcomes from these experiments. For instance, Chinese governmental organisations have, since the beginning of the 21st century, been accumulating knowledge through monitoring the results from different experiments and have been facilitating learning for actors of traditional industrial production systems by disseminating this knowledge with them through publications and media, as well as some useful capacity-building events such as seminars, forums, workshops, trainings, business meetings, etc., as well as dissemination through media.

Another interesting finding has indicated the importance of transfer of experiences and lessons from one experiment to other spaces to construct cross-fertilisation across experiments (see also (Weber, et al., 1999; Caniëls & Romijn, 2008)). In that respect, the *Kalundborg* local industrial ecosystem case stands as the most influential experiment (Branson, 2016; Chertow, et al., 2008;

Deutz & Gibbs, 2008) and serves as a benchmark learning reference point for the development of various other experiments distributed over broad geographies (Gibbs, et al., 2005; Park, et al., 2008; Adamides & Mouzakitis, 2009). In that respect, the results from both Article I and Article II suggested that international collaborations can be crucial to learn from experiments abroad, and intermediary organisations can act as local industrial ecosystem development influencers across Europe or even at the global level to facilitate the knowledge transfer and co-creation.

Interacting and interdependent niche-building processes

The results of Article I and Article II showed that the above-explained three niche-building processes for local industrial ecosystem experiments are in constant interaction and interdependent on one another, as also previously argued by Schot and Geels (2008). Each niche process has an essential influence on the other two during the experimentation journeys. That interdependence makes it difficult to analyse and understand their development dynamics separately, which reinforces the need to consider the niche-building processes under their dynamic interactions, as also reasoned by Elmustapha et al. (2018).

The evolution of the analysed local industrial ecosystem experiments stands as an adaptive and continuous experimentation journey during which the visions and expectations of the industrial ecosystem community converge through learning processes, which at the same time have an impact on the size of the emerging networks. Although at the beginning of the experiments a relatively narrow local industrial ecosystem network may exist, mainly aiming to involve the located industries in the industrial production systems, in time during the experimentation, new actors like governmental organisations, knowledge organisations, non-governmental organisations, different intermediaries can be involved as well. And perhaps even more importantly, more industrial actors can get attracted to the potential symbiotic exchanges over time.

Network adaptation not only implies the continuous entry of new actors to the networks, but also that some others can leave, and interactions between the actors can change in time. Therefore, the local industrial ecosystem networks, as a reflection of changes in visions and expectations, evolve and vary in time in terms of the actors involved and the relational dynamics among them. The results also indicated that industrial organisations usually show resistance to the industrial ecosystem practices, especially in the beginning of the experimentation, due to the lack of knowledge on the potential benefits of industrial ecology to their businesses. The studied local industrial ecosystem experiments in Article I and Article II showed that when the industrial ecosystem networks are broad where the intermediary organisations (particularly coordinating/management bodies and local/regional heroes) are deeply engaged and play fundamental roles, together with the knowledge and governmental organisations, the entry of the industry to the networks can be smoother and more effective as the industrial ecosystem evolves in time. The enlightened visions about local industrial ecosystem development can alert local actors to the importance of looking beyond the local and individual interests and being more open-minded to new interactions.

The results illustrated that the industrial actors are more likely to integrate the industrial ecology-inspired visions to their expectations in successful experimentation journeys steered by the presence of intermediary, governmental and knowledge organisations. In more details, the presence of intermediary organisations can facilitate interactions among the existing and as well as potential future network members, and create awareness and learning about industrial ecology

practices among them (see also (Daddi, et al., 2015; Hewes & Lyons, 2008)). Moreover, the presence of knowledge organisations like universities and research centres in the networks can provide particular learning tools for the dissemination of knowledge and a theory-based vision for testing in the field. They can advance the identification of possible synergies among actors and contribute to the involvement of more actors to the networks. Finally, governmental organisations' role can be crucial in terms of facilitating the entry of the industry to the local industrial ecosystem networks. Once the governmental organisations understand whether and how the industrial ecology practices, when followed in local industrial ecosystem development pattern, can add to the regional economies, then they take more concrete actions and design appropriate incentivising mechanisms to the industry. Those three actors can facilitate the changes in the industry's assumptions about sustainability and consciousness about the potential economic and ecological benefits from local industrial ecosystem networks.

The influence of the spatial context

The results of Article I and Article II indicated that the spatial context mediates the niche-building processes of the analysed local industrial ecosystem experiments. The niche-building processes are dependent on the realities of both the different industrial production systems and the context surrounding them (see also Coenen et al. (2012) for further reading on the spatial variants). Therefore the analyses have not claimed for a rigid model on how the local industrial ecosystems unfold.

Firstly, the results depicted that the structure of the industrial production systems may affect the unfolding local industrial ecosystems in varying ways. On the one hand, as Article I suggested, the network diversity may enhance the symbiotic interactions between the actors. Considering the industrial networks that are centred on one or a few major industries, the absence of variety may "hinder learning and critical reflection about an experiment" (Weber, et al., 1999, p. 39). Heterogeneity in terms of sectoral and size differences inside the industrial production system can facilitate observing, analysing and learning from the facts and data mainly related to the technical dimensions of industrial ecology, especially considering the first-order learning. On the other hand, as Article II suggested, relatively more homogenous industrial production systems composed of small and medium-sized enterprises can be more likely to develop industrial ecology practices. Similar size and sector industries may share similar concerns in terms of resilience strategies to the changing socio-economic environment, which can also contribute to the (further) construction of participatory and collaborative culture in the regions. The unfolding local industrial ecosystem in Tuscany represents an example of this. It is one of the most advanced Italian regions in terms of the local industrial ecosystem development and the areas in that territory show the characteristics of homogeneity and companies of small dimension. However, agreeing with the results of Article I, the lack of heterogeneity have restricted the type of potential symbiotic exchanges in the region and made the system more limited to particular synergies, such as recycling and recovery consortiums, a collective coordinating body, or shared infrastructure, as also indicated by Daddi et al. (2015) while discussing the Italian approach in general.

Secondly, narrowing the focus more into the surrounding context, in the countries where there are no national guidelines for local industrial ecosystem development, different regions can take specific approaches, as shown in the cases from Article II. In Italy, the local industrial ecosystem experimentation has been under the strong influence of the specific regional characteristics. Regional governments' pressures, incentives or implementation strategies on the national scale

programmes shape both the planning and implementation of the experiments. Moreover, in geographies where, the government plays an initiator role (as in China, South Korea, Thailand, Italy, the USA or Canada), or a facilitator role (as in Denmark, Australia, the Netherlands or Sweden) for the local industrial ecosystem development, the experiments gain legitimacy and stability relatively in a smoother way resulting from the proper support and protection. Furthermore, receiving support from the international landscape can also be beneficial for on-going experimentation. In China, for instance, governments and industries have further participated in local industrial ecosystem development efforts through financial support from international development agencies like the United Nations Environmental Program, the Asian Development Bank, and the Canadian International Development Agency (Geng, et al., 2007). These international support mechanisms have also been present in the European experiments through the funding mechanisms from the European Union.

Therefore, the characteristics of the existing industrial production systems, as well as the active role of the governmental organisations and the presence of proper support and protection mechanisms at regional, national, international and even global scales, if considered as spatial context attributes, can mediate the niche-building processes of the unfolding local industrial ecosystems in varying ways at different spaces.

5.2. Unfolding regional industrial ecosystems

The inquiry on conceptualisation and analysis of unfolding regional ecosystems has been addressed in Research Study III, which resulted in Article III. The proposed Conceptual Framework III provided an analytical foundation for analysing the individual industrial ecology projects and their aggregated contribution to the emergence of regional industrial ecosystems through three analytical niche-building processes. The analysis followed a single embedded case study methodology (one regional case, Catalonia from Spain, with multiple units of analysis) drawing upon the proposed framework. Below the discussion on an unfolding regional industrial ecosystem is provided following the findings from Article III.

Local industrial ecology experiments

In the selected region, Catalonia, industrial ecology concept first attracted the academic debate through the end 1990s. The academicians built the first bricks on the regional industrial ecosystem niche emergence. They initiated the first few industrial ecology experiments in collaboration with related governmental organisations, and those experiments introduced the initial momentum for various others. The empirical analysis in Article III covered a selected set of eight experiments from the region, which in common have addressed sustainability-related issues of industrial production systems through industrial ecology practices, distributed over 18 years starting from 1999 and coming up till 2017.

The local experiments level in Catalonia showed characteristics of both top-down and bottom-up industrial ecosystem development, in both approaches aiming to establish connections between particularly the knowledge and governmental organisations, as well as and industry. Indeed, those connections have been resulting in fruitful interactions that led to considerable linkages, both in direct support or inter-facilitation manner, between various experiments. Those interlinkages showed clues of an emerging regional industrial ecosystem niche Catalonia. Those findings indicated that interconnected experimentation by different actors could be critical for

an emerging industrial ecosystem that can overcome the mainstream rules of the traditional industrial production systems.

Experiments' influence on niche-building processes

The results of Article III indicated that each analysed industrial ecology experiment has substantially contributed to three conceptually proposed regional niche-building processes.

To start with the ***articulation of expectations and visions***, the regional actors did not hold a shared view on what industrial ecology meant at the beginning of the industrial ecosystem experimentation journey, yet, they had positive and high-level expectations on network-building through a knowledge exchange platform, a thematic network, as named by the network founders. That thematic network facilitated to uncover the potential of industrial ecology in the region. However, recognising that potential was not enough for application of the new and relatively radical industrial ecology practices. Notably, the industry did not hold positive expectations and standpoint in the beginning, mainly due to trust issues. Even introducing the international best practices to the regional context was not very helpful. Although the experimentation was on-going, real symbiotic resource exchanges, particularly in between industrial actors, were still missing in the region. Therefore, in time, the experiments' nature has evolved towards aiming in practical applications of industrial ecology within the existing industrial production systems.

In the meantime, introducing a regional waste recovery strategy, despite limiting the potential of industrial ecology to the waste management sector, was useful to create positive and high-level expectations for brownfield experimentation by retrofitting existing industrial production systems and transforming them into sustainable spaces. However, there was still a lack of consciousness of industrial ecology among the actors. There were, as expectedly, different actors with different interests in the industrial production system or with different priorities in terms of dedicating the available resources. For instance, a change in the power party at the regional administration level even led to the failure of one particular industrial ecology experiment. Indeed, as Truffer and Coenen (2012, p. 12) stated, "sustainability transitions are by their very nature political projects" and transition processes might change based on the change (in the interests of) specific power actors.

Finally, the findings also indicate that there has been a recent overall vision shift in the region. The circular economy, as a bigger umbrella concept for industrial ecology, has become a promising and more popular policy tool for regional industrial development. This may be due to its clear emphasis on 'economy' although the core emphasis is on the resource scarcity same as industrial ecology. In the region, there have been positive and high-level expectations for promoting the circular economy to become a reference benchmark territory that will also serve as a branding instrument. Industrial ecology is now covered in a circular economy vision concerning the creation of a public-private collaboration ecosystem in which the different organisations may act as agents of change.

The other niche-building process, ***social network-building,*** perhaps has been the most noticeable activity in all analysed experiments. Since the beginning of the industrial ecosystem experimentation, the active involvement of the actors from knowledge organisations was particularly useful in terms of bringing the international know-how and best practices to Catalonia, as well as facilitating new entries to the emerging industrial ecosystem community. In general, network-building activities were not limited only to the regional actors but also achieved

creating connections at the cross-national level. The experiments coordinated by international consortiums were particularly successful in that.

The results indicate that most of the industrial ecology experiments were related to planning and strategy-making, and they established fruitful links between knowledge, governmental and non-governmental organisations. However, there has been minimal involvement from the industry, and therefore real symbiotic exchanges between the industrial actors were not easy to achieve. In this respect, applied industrial ecology-oriented experiments were crucial, and they facilitated the active involvement of the industry in the emerging community. Those experiments ended in some pilot symbiotic resource exchanges, but trust issue was emerging as the main difficulty, and it was challenging to convince industrial actors to share information. The case study shows that working individually with particular industries showing them special care to identify potential synergies can be particularly useful in motivating the industry to participate in the emerging industrial ecosystem network.

Considering the need for continuous experimentation, another important network-building activity emerges as lobbying, and advocacy for industrial ecology, especially with the governmental organisations. Effective communication with key policy actors can be particularly helpful for bringing protection and support to start, implement and follow-up the industrial ecology experiments. Intermediary actors can play an essential role in such activities. Same actors' continuous active involvement in different experiments can help them become the critical intermediary nodes building on the already established relationships.

Finally, the last internal niche-building process, ***learning***, has also been distinguished in the outcomes from all analysed industrial ecology experiments, except one which was interrupted due to change in power actors, as also previously mentioned. Starting with the initial thematic network experiment and continuing with other analysed experiments, knowledge communication events, including but not limited to meetings, workshops, forums, conferences, and seminars, were vital for knowledge exchange within the emerging network, explicitly considering the first-order learning. Remarkably, actors from knowledge organisations acted as knowledge bridges between the region and the international industrial ecology community. Moreover, the actors from governmental organisations who directly involved in these learning events, although mostly having limited technical responsibilities in their home organisations, acted as learning facilitators for other public actors, who had more political and competitive power to initiate new experiments.

The results show that some experiments cultivated some other upcoming ones. The actors involved in an experiment later took more active roles in initiating other experiments. That stands as a practical outcome example of second-order learning in terms of involved actors' changing visions and agency against the problematic industrial production routines from the sustainability perspective (see also (Schot & Geels, 2008)). Yet, considering the second-order learning in terms of applying the gained knowledge was not that successful for the involved industrial organisations. There have been only a few success cases in terms of applied industrial ecology through the industry's involvement in symbiotic exchanges. Although there have been continuous efforts within different experiments for providing knowledge, building regional awareness and establishing the industrial ecology culture within the industrial production systems, there was limited interest from the Catalan industry. One reasoning behind, as the results suggest, can be missing successfully applied and visible industrial ecology exemplary cases in the region.

Regional industrial ecosystem niche

The discussion here builds on the results of the analysis of local industrial ecology experiments from a region, their influence on regional industrial ecosystem niche-building processes, the aggregation of these processes into an unfolding regional industrial ecosystem.

The findings of Article III indicate a regional endogenous and gradual steering for an unfolding regional industrial ecosystem embodying a collective representation (see also (Weber, et al., 1999)). A regional network of actors has been emerging in the selected region, Catalonia, involving various regional actors: regional and local governmental organisations, knowledge organisations (universities), intermediary organisations (such as regional development agencies), private consultancy companies, and industry. The involved actors and their interactions have been varying in each analysed experiment, and it is still early to mention about shared expectations and visions among them. A standard contour among the experiments can be pictured around networking-building, and continuously cultivated experiments have been interacting in different ways within the emerging regional network. The results show that the experiments have either directly supported or influenced each other's objectives and outcomes through learning processes. Learning from the experiments have conveyed expectations and visions to regional actors, who then turned out to be niche actors for the upcoming experiments in the region.

A crucial shortcoming of most experiments has been as the minimal involvement of the industry. Cognitive and normative frames of industrial actors have not been genuinely aligned into industrial ecosystem principles. Moreover, real changes have not been observed over the formal rules such as tax regime, environmental regulations, or market mechanisms that could also facilitate changes in cognitive and normative frames. Niche experiments have not yet totally fitted into the existing industrial production routines and have mostly provided first-order learning outcomes for the industry. Therefore, although the results give important implications for an unfolding regional industrial ecosystem, they still do not demonstrate a transition case. For an industrial ecosystem transition to occur, there is a need to change the production routines; and this can be widely achieved by second-order learning through real industrial ecology applications, as also suggested by the SNM studies (Schot & Geels, 2008; Boon, et al., 2014). A demonstrative set of real fruitful resource exchanges in a region can be particularly supportive in that sense. Moreover, the active presence of intermediary organisations involving local/regional champions or coordinating bodies may have been helpful, also in line with previous empirical findings from industrial ecology literature (Hewes & Lyons, 2008; Domenech & Davies, 2011), but the case study has not identified any in the region.

Overall, the results of Article III suggest that the outcomes of continuously cultivated local experiments in Catalonia have crucially contributed to three internal niche-building processes of the unfolding regional industrial ecosystem. However, there is still a way to go. While social network-building processes have led to a promising emerging community, the involvement of the Catalan industry is still limited in industrial ecosystem networks. The second-order learning is still missing, especially for industrial actors. The results point to the required conditions that would better encourage the industry to participate in real industrial ecology applications. The region still misses a broader regional network, including a more profound presence of the industry, with more second-order learning outcomes.

The influence of the spatial context

Finally, the results also suggested that the spatial context also matters. The spatial context can mediate the success of the niche-building processes for an emerging regional industrial ecosystem. For instance, in case of Catalonia, the region has been constructing its industrial production routines through a long industrial tradition, as Catalonia was one of the early adopters of British industrialisation model in the 19th century. Industrial activity, in general, represents almost 20 per cent of gross domestic product in the region. The development of industrial production systems in agglomerated forms substantially contributed to the economic reality of the region, especially since the 1980s (Incasòl, 2007).

Not surprisingly, rapid industrial development has surpassed the available land for further development, and the regional actors started taking actions in sustainability-oriented initiatives. The intensity and diversity in agglomerated industries have provided the proper grounds for considering industrial ecology as a potential response to address the growing sustainability problems by triggering the resource exchanges between the regional actors. Among many other active actors, Government of Catalonia has recently taken varying actions towards industrial ecosystem development together with its major economic and environmental agencies, including ACCIÓ, Waste Agency of Catalonia, Water Agency of Catalonia and Catalan Institute of Energy. In those actions, especially considering the more recent ones, the circular economy concept once again emerges and covers the industrial ecology understanding in the region.

For example, in 2015, Catalonia became a member of Circular Economy 100, which is a large scale innovation programme initiated by Ellen MacArthur Foundation to enable circular economy practices through capacity building, knowledge sharing, networking and collaboration among network members. Furthermore, the approval of the Strategy for Smart Specialization of Catalonia in February 2014 and development of General Waste and Resource Management and Prevention Programme 2013- 2020 with a circular economy approach stand as important formal milestones which may serve for the promotion of more industrial ecology projects. Therefore, the region provides the appropriate supportive context particularly at the policy level, yet, it still misses to take concrete actions to bring change into the formal rules such as tax regime, environmental regulations, or market mechanisms. Those changes, once realised, can also facilitate changes in cognitive and normative frames required for industrial ecology-inspired industrial production systems.

5.3. An overall frame for unfolding industrial ecosystems

This thesis first conceptualised and then analysed unfolding industrial ecosystems at local and regional scales to advance the understanding of industrial ecology-inspired transitions of industrial production systems. Based on the above-synthesised results, this section proposes a blended frame of unfolding industrial ecosystems, because such a heuristic can be particularly useful to analyse and understand those fringe industrial ecology applications and so to inform the industrial ecology-inspired transitions.

The results showed that industrial ecology could be conceptualised as a systemic innovation model and industrial ecosystems as socio-technical constructs. More specifically, unfolding industrial ecosystems analytically act as prominent strategic niches for transitions of industrial production systems through the symbiotic resource exchanges between not only the industrial actors (as traditionally addressed in industrial ecology literature) but as well as other system actors

including particularly governmental, knowledge and intermediary organisations. Involved research studies built refined conceptualisations bridging the industrial ecology theory to sustainability transitions research, particularly by bringing insights from the SNM framework. The research studies showed that the SNM framework provides relevant and fruitful insights for the conceptualisation of unfolding industrial ecosystems and the derived conceptualisations enabled an overall coherent frame for understanding industrial ecology-inspired transitions.

Taking the niche, experiment, experimentation concepts central to the overall analytical framing of niche emergence, the synthesis of the research studies indicated that three niche-building processes steer the industrial ecosystem experimentation journey: the articulation of expectations and visions, social network-building and learning processes. The spatial context has a mediating influence on the interaction and functioning of those processes. A broad range of actors involved in the experimentation can accumulate into an emerging niche community which may include the governmental organisations, intermediary organisations (e.g. coordinating/ management bodies, local/ regional heroes), knowledge organisations (e.g. universities and research centres), non-governmental organisations, and obviously, industrial actors in the production systems.

The research studies showed that the industrial ecosystems niches at local and regional scales may emerge if the broad industrial ecosystem niche network designs and implements different learning tools that contribute to the evolving expectations and visions, which would diverge from individual-performance-oriented focus towards collective-benefit-oriented collaboration focus in time (see generally other SNM studies on other novelties, e.g. (Schot & Geels, 2008; Van der Laak, et al., 2007)).

When dealing with the regional scale industrial ecosystems, particular industrial ecology projects can be analytically approached as local scale experiments that can accumulatively contribute to the emerging regional industrial ecosystem niche through, again, the niche-building processes (see also (Raven & Geels, 2010)). The emerging regional niche community if continuously supports and implements the industrial ecology practices, the experimentation would get momentum, and regional industrial ecosystem niche can get stronger to destabilise the existing regulatory, normative and cognitive frames embedded in the traditional industrial production systems.

Finally, with regards to the mediating influence of the spatial context (see also (Coenen & Truffer, 2012)), the industrial composition related to the size and sector of the companies, as well as (existing) collaborative culture and trust, the regulatory and financial support from the governmental organisations at different scales, etc. affect the effectiveness of the niche-building processes and may foster a relatively smoother industrial ecology-inspired transitions by conditioning the unfolding local and regional industrial ecosystems.

Chapter 6. Conclusion

This chapter concludes the cover essay by articulating the main argument of the thesis and how it addresses the overarching research objective; by presenting the theoretical, methodological and contextual contributions; and finally, by offering research-, action-, and policy-oriented implications.

This thesis contributed to addressing the challenge of sustainability problems in traditional industrial production systems which work under linear production routines. It focused on the industrial ecology approach as one prominent way of addressing those problems. Industrial ecology theory stresses the importance of resource exchanges between the system actors to change the usual production routines of industrial production systems based on linear processes. However, the mainstream industrial ecology studies seem to underestimate the overall problem as a technical one which can be solved by a design of an optimal industrial ecosystem with an optimal physical resource exchange network. In that regard, this thesis argued for the need to consider both social and technical aspects of industrial ecology, because, focusing only on technical solutions is not enough to cover the social elements of industrial production systems which hold regulatory, normative and cognitive rules constructed through the complex interactions between the social and the technical dimensions. The problematisation of how industrial ecology theory deals with the sustainability problem of transitional industrial production systems is necessary at the first-hand before assuming the potential solutions.

Given these lines, this thesis mainly focused on unfolding industrial ecosystems to further the understanding of potential industrial ecology-inspired transitions. With an ambition to advance that understanding, it conceptualised and empirically analysed unfolding industrial ecosystems at local and regional scales. To that end, the conducted research offered a socio-technical system approach, particularly building on the SNM framework as the main theoretical inspiration. Industrial ecology has been approached as a systemic innovation model, and industrial ecosystems have been leveraged as a socio-technical construct, more specifically, as prominent niches for socio-technical system transitions of industrial production systems.

The thesis embodied three research studies with inquiries on unfolding industrial ecosystems differentiating at local and regional scales. This differentiation enabled a scale rendered approach which provided the grounds for conceptual pluralisation and a deeper understanding of the dynamics of unfolding industrial ecosystems through different scale applications of industrial ecology. Thereby, the thesis proposed a refined conceptualisation through three different frameworks on unfolding industrial ecosystems, while taking the niche, experiment, and experimentation concepts as central to its analytical design on niche emergence. The niche-building processes, which are the articulation of expectations and visions, social network-building, and learning processes, have been among the shared contours of the proposed conceptual frameworks for these research studies.

The first research study focused on the potential industrial ecology-inspired transitions of industrial production system development into local industrial ecosystem development. A conceptual framework was proposed for studying and understanding the dynamics to achieve such transitions. As the inquiry has been about a broad local industrial ecosystem development model, an extensive set of worldwide distributed local industrial ecosystems cases, studied in the existing state of the art (n=104 cases), have been under analysis following the proposed

conceptual framework. That contributed to the re-interpretation of already analysed and discussed local industrial ecosystem cases. That, on the one hand, allowed a thorough deduction resulting in impactful policy- and research-oriented implications, and on the other hand, resulted in learning outcomes on how local industrial ecosystem development has remained at the level of local projects in some geographies and evolved into the niche level in others. The outcome of this research study is the appended Article I.

The second research study stressed the unfolding local industrial ecosystems over traditional industrial production systems. A conceptual elaboration has been done on the experimentation journey of becoming a local industrial ecosystem. An empirical analysis was conducted for particular brownfield local industrial ecosystems in a real context (n=3 cases from Italy) building on the proposed conceptual framework. The empirical findings revealed, on the one hand, how the local industrial ecosystems unfold depends on the interacting and interdependent niche-building processes during the experimentation, and on the other hand, how the spatial context influences the niche-building processes. The outcome of this research study is appended Article II.

Finally, the last research study looked into an unfolding regional industrial ecosystem, particularly by considering the applied local industrial ecology projects in industrial production systems in a region. Local projects and their aggregated contribution to an emerging regional industrial ecosystem were first conceptualised and then analysed in a real setting (n=1 regional case from Spain). The theoretically guided empirical analysis depicted a detailed picture of how a regional industrial ecosystem unfolds through the continuous experimentation by local industrial ecology projects, outcomes of which accumulate through three niche-building processes. The outcome of this research study is the appended Article III.

The employed research studies implied that industrial ecosystem transitions are not easy to realise. Industrial ecology applications require substantial changes in existing frames of industrial production systems. Existing actors in the systems tend to resist changes in their regulatory, normative and cognitive rules and that brings lock-ins in the current routines. The employed empirical analyses indicated that industrial ecology-inspired transitions could not have gained internal momentum rapidly and easily at various geographies. Instead, industrial ecosystems stayed at local isolated experiments level, like most of the strategic niche experiments (Schot & Geels, 2008), and often did not lead to a niche formation at a broader scale, and therefore, could not replace the traditional industrial production system development trend and could not lead to a transition.

However, continuous experimentation is crucial to keep the momentum going, as also suggested by the SNM studies (Raven, 2005; Schot & Geels, 2008) to involve more actors in the emerging industrial ecosystem niche networks; to develop more symbiotic exchanges for second-order learning of the industry; to create deeper linkages between industrial ecology experiments at local, regional, national and even international scales; and to inform more actors in the region about what has been achieved so far and the necessary future steps. Intermediary organisations involving actors such as local/regional coordinating/management bodies or heroes can be particularly helpful for the maintenance of that momentum. If emerging niche networks provide support and protection for new experiments, which will continuously contribute to the niche-building processes, changes in the rules of industrial production systems can be realised to achieve industrial ecology-inspired transitions.

6.1. Contributions

This thesis has provided substantial contributions for three different research dimensions as suggested by Berthon et al. (2002): the theory, method and context. The contributions are discussed as follows.

Theoretical contributions

This thesis contributed to the scientific discourse on industrial-ecology transitions by focusing on industrial ecosystems as a response to the sustainability problems of the regional and local industrial production systems. The conducted research studies proposed new ways of conceptualisation which offer new ways of understanding and explaining unfolding industrial ecosystems over traditional industrial production systems.

On the one hand, research on industrial ecosystems in industrial ecology literature approaches industrial ecosystems mostly as a technical construct by formulates a technical engineering problem to be solved by design or implementation of an industrial ecosystem through optimisation, efficiency increase, energy evaluation, flow analysis, or waste management, etc. On the other hand, a relatively narrower part of the industrial ecology literature has considered the social dimensions of industrial ecosystems development. However, a focus on both social and technical aspects of industrial ecosystems, as well as the potential of industrial ecology to bring the transitions into industrial ecosystems, have not been sufficiently addressed in the literature. Positioning here, this thesis argued for the value of leveraging industrial ecosystems as a socio-technical construct, approaching industrial ecology as a systemic innovation model, and as such, it indicated an under-explored conceptual link between the industrial ecology and the innovation studies.

In this vein, the thesis introduced sustainability transitions research field, which is founded in innovation studies literature, and suggests that insights from that field can be particularly useful for studying industrial ecosystems. Sustainability transitions research addresses the socio-technical transitions phenomena toward sustainability, and it provides middle-range theories and uses them as heuristics for understanding and explaining the expected transitions. The SNM framework is one of the salient heuristics. It was initially developed for ex-ante management, but then mainly used for the ex-post analysis of novelties which may bring the desired sustainability transitions into the socio-technical systems.

Bridging between the industrial ecology and innovation studies, this thesis offered a socio-technical system approach, particularly building on the SNM framework as a basis for studying industrial ecosystems. The main aim was to increase the understanding of industrial ecology-inspired transitions by elaborating on the relevance of niche emergence conceptualisation. In this respect, industrial ecosystems have been conceptualised as niches which can drive for sustainability transitions of industrial production systems. As for the overall conceptual framing, the thesis followed the foundations of the SNM framework and proposed three internal niche-building processes: the articulation of expectations and visions, network-building, and learning processes. The scale dimension also entered to the conceptualisation through differentiation between local and regional industrial ecosystem niches.

Such a focus enabled the theoretical advancement of insights for, mainly, industrial ecosystems approach and, also partly, the SNM framework. On the one hand, the conceptualisation of industrial ecosystems as niches facilitated the operationalisation and assessment of unfolding industrial ecosystems by focusing on the niche-building processes employed by an emerging niche community which is composed of a broad range of actors, not only emphasising the importance of industrial actors as traditionally done in the industrial ecology literature. Moreover, the mediating influence of the spatial context not only enriched the conceptualisation but also brought further explanatory power to the cases. The conceptualisation proposed by the thesis enabled various elaborated pictures of unfolding industrial ecosystems at different scales, including: how a transition into local industrial ecosystem development may be achieved; how the accumulation of local industrial ecosystems may contribute to emergence of a global industrial ecosystem; how local industrial ecosystems emerge over the traditional industrial production systems; and how local industrial ecology projects may contribute to unfolding regional industrial ecosystems.

On the other hand, it also brought new empirical accounts to the SNM literature. The framework had not been thoroughly followed for analysis and understanding of industrial ecosystem transitions before. The traditional approach of the SNM applications in empirical contexts has generally focused on particular innovations in particular socio-technical systems. However, industrial ecology as a systemic innovation model may include and nurture the various type of innovations which may accumulatively lead to fundamental technological, institutional and cultural changes at organisational and sectoral levels in industrial production systems.

Methodological contributions

The thesis also provided some particular methodological insights. To begin with, it involved three interdependent and interacting research studies which ended in three scientific articles. That already enabled a methodological triangulation through a combination of different methods including SLR, case survey and case study with different designs.

In Research Study I, the combination of case survey and SLR has been followed for extracting the local industrial ecosystems cases from the literature systematically. The study resulted in having a rich set of evidence (104 cases distributed worldwide). This would not have been possible by direct insight and data gathering from the primary sources. Re-analysis and re-interpretation of those cases from a novel conceptual approach (Conceptual Framework I), also developed within this research study, provided valuable knowledge to reflect on how transitions into local industrial ecosystem development can be achieved.

In Research Study II and Research Study III, the case study method was employed with different designs. Research Study II followed a multiple case study method on three local industrial ecosystems as separate units of analysis and analysed the experimentation journeys of those through the proposed conceptual framing (Conceptual Framework II). Research Study III showed an application example of a single embedded case study method with multiple units of analysis in a single regional industrial ecosystem case. Various industrial ecology practices were conceptualised at the level of the local experiments and analysed in terms of their contribution to the emerging regional industrial ecosystem level (Conceptual Framework III). These two research studies showed an example of how conceptual pluralisation and refinement drawing upon the same theoretical framework, which is SNM in those cases, can answer different research inquiries and how the research designs change depending on the changing conceptual frameworks.

To sum up, the conceptualisation derived in each research study guided the analyses of theoretical concepts, including niche, experimentation, expectations and visions, network-building, learning, local – regional - global niche differentiation, etc. and showed how those concepts can be empirically assessed through a concrete operationalisation in industrial ecosystems domain by properly chosen qualitative methods.

Contextual contributions

Three research studies involved in this thesis provided contextual contributions at both investigative and interpretive levels[6].

For Research Study I, the data and insights on 104 local industrial ecosystem cases were gathered from the existing state of the art through a literature search covering a time span of all years in Web of Science database. Those cases from all around the world provided fertile grounds for a re-interpretation from a different theoretical perspective. The data of this research study was not objective itself but constructed by other scholars, but the re-interpretation was contextually novel as collected cases were re-assessed through the proposed conceptual framework. The results of the study offered a sound learning opportunity on how industrial production system development can experience a transition into local industrial ecosystem development at different scales.

For Research Study II, the data and insights were gathered through semi-structured interviews with the relevant actors of the selected three local industrial ecosystem cases in Emilia-Romagna and Tuscany regions of Italy. Moreover, a desk analysis with guidance support from the interviewees was run to bring secondary evidence to the investigative context. The derived conceptual framework has been applied for the interpretation of the cases to answer how local industrial ecosystems unfold over traditional industrial production systems. The results of the study brought a rich set of new insights from two regions in Italy which is an experienced country in the field of industrial ecology.

Finally, for Research Study III, which was a single embedded case study, data and insights were gathered through semi-structured interviews with the relevant actors of eight different industrial ecology projects, distributed over 18 years, in Catalonia region of Spain. Secondary sources have also been as evidence to trace the related industrial development in Catalonia. The aggregated contribution of industrial ecology projects into an unfolding regional industrial ecosystem was discussed following the proposed conceptual framework. The study generated new understandings through new empirical evidence from a region, which has not been studied in the industrial ecology literature before. Moreover, empirical research enabled the illustration of theoretical linkages between the concepts of the proposed framework in a real setting. The results of the study may guide the analysis of other relevant contexts in future studies with the same or a further-refined conceptual approach.

[6] See generally (Berthon, et al., 2002) for further reading on contextual contributions. Investigative level is related to the when, where, and from whom/what data is collected. Interpretive level is related to the when, where, and whom of data interpretation.

6.2. Implications

Mainly for the knowledge transfer purposes, the research-, action-, and policy-oriented implications based on the findings of the involved research studies are given as follows considering potentially high research impact that this thesis can bring about.

Research-oriented implications

The thesis offers a set of potential research lined mainly for the industrial ecology domain. To start with, evolving expectations and visions for industrial ecosystem development covering a wide variety of related actors and their motivations requires an explicit focus of the industrial ecology literature. Further building on that, a broader vision for industrial ecosystem transitions (at different scales) has not been explicitly explored as well.

Furthermore, the industrial ecology scholars seem to underexplored the structures of broader networks for industrial ecosystem development, which involves not only the industry but also actors such as governmental organisations, knowledge organisations (e.g. university and research institutes), intermediary organisations (e.g. coordinating/management bodies, industry associations, local/regional heroes), non-governmental organisations, etc., and the interaction among them. Another focus for further research would be through an elaboration on the potential qualitative relation between the industrial ecosystem development visions (through top-down, bottom-up, and mixed approaches) and network-building characteristics related to involved actors and their interactions.

The existing research also misses exploring the different aspects of the learning concept further. Learning processes which drive for or result from industrial ecosystem experiments require further consideration in the field. Also, the transfer of learning from one industrial ecosystem case to other potential spaces of potential experimentation has received scant attention.

Finally, the empirical insights from the research studies, especially from Research Study III, have shown that in some contexts, the circular economy frame has been emerging to cover the industrial ecology approach as well. This indicates a need to consider the circular economy concept when studying industrial ecology in future research.

This thesis has been the first attempt to bridge between industrial ecology and sustainability transitions research fields explicitly. Therefore the results indicated a rich set of future research inquiries for both fields. The results showed that industrial ecology research could fruitfully benefit from the insights of different conceptual framings in the sustainability transitions research. And this also can enable the provision of new empirical accounts to the sustainability transitions research. More specifically, the research studies provided in this thesis can be extended for different industrial ecosystem cases to test the plausibility of the proposed conceptual frameworks further. Further research can put more explicit emphasis on the interdependency of the niche-building processes and their impact on each other during the industrial ecosystem experimentation journeys.

Finally, as the initial argumentation and as well as the results of the research studies implied, the sustainability transitions are strongly context-dependent. The cognitive, normative and regulatory rules in the industrial production systems are not easy to change. That reminds the necessity to bring a sharper focus on the institutions and institutional context which can be studied through insights from institutional theory in the future industrial ecology research.

Action- and policy-oriented implications

This thesis included analyses of unfolding industrial ecosystems at different scales - that is, over one hundred local industrial ecosystem cases distributed worldwide, three local industrial ecosystem cases from Italy, and an emerging regional industrial ecosystem case incorporating eight different industrial ecology projects from Spain. Those analyses provided useful insights for further industrial ecosystem experimentation in different contexts and hopefully for future industrial ecology-inspired transitions. The learning offered by the thesis can penetrate the argumentation of policy-makers and managers that are the potential decision-makers expectantly having an interest in industrial ecology as a way to address the sustainability problems of traditional linear industrial production routines, which is timely.

To begin with, it is essential to recognise that there are not universally correct implications and that decision-makers embedded in different environments need to consider the context-specific constraints before implementing any suggestion given out of the research studies. Considering that, the thesis has formulated the implications in a way that they can offer enough flexibility to be tailored and further detailed, considering the potentially different contexts in which different decision-makers can follow them.

The implications provided here should be seen as a practical way of bringing systemic change in particularly regulatory but as well as normative and cognitive rules in both the involved contexts in this thesis and as well as in different settings at different spaces. The primary audience of these implications is the policy-makers at local, regional, national, and even international and global levels. Besides, the managers, including the coordinating/management bodies of the unfolding industrial ecosystems, as well as the decision-makers at individual organisations (e.g. knowledge organisations, non-governmental organisations and more importantly the industrial organisations) stand also as a powerfully relevant audience. Indeed, those actors need to take consistent actions and derive supportive shielding policy mechanisms in a collective approach to achieve the industrial ecology-inspired transitions in industrial production systems. Therefore, this section provides the implications common to all type of relevant organisations aiming at the decision-makers, not necessarily by differentiating between the action and policy levels.

The first and foremost implication of the thesis would be suggesting the decision-makers to consider and follow the proposed conceptual frameworks in this thesis as prescriptive ex-ante management tools for future industrial ecosystem experimentation journeys. The results of the research studies showed that the potential for an industrial production system to transform into an industrial ecosystem or to construct a new industrial ecosystem experiment call for specific niche formation policies. More specifically, if new industrial ecosystem experiments (brownfield or greenfield) can be managed considering the interdependent and interacting internal niche-building processes under the mediating influence of the spatial context, then their contribution to the unfolding industrial ecosystems can be stronger, as also suggested by the SNM studies for other niche experiments (Weber, et al., 1999; Raven, 2006; Schot & Geels, 2008). Particular importance can be given to the network-building process targeting various regional actors (not only focusing on the industry but involving governmental and non-governmental organisations, entrepreneurs, universities and research institutes, local champions, managing/coordinating bodies, the local community, etc.). Such an approach can facilitate the coupling of expectations and visions of a broad range of related actors. Moreover, networking-building can be more efficient if guided by a local/regional coordinating body that ensures all actors communicate effectively, and if it is supported by local champions that facilitate interaction and trust development among network actors.

Considering the potentially required visions related to industrial ecosystem development, the findings suggested that the top-down planning strengthened with facilitating mechanisms with a stronger focus on brownfield industrial ecosystem experiments can provide more promising conditions for building specific expectations with specific motivations among the potential actors of an industrial ecosystem. Thus, an effective combination of a top-down and facilitation approach stressing more brownfield projects through providing support and shielding mechanisms would be suitable for the evolution of the long-term vision required for industrial ecology-inspired transitions.

In line with these, the research studies also implied that the learning activities and processes require an explicit focus when planning or implementing an industrial ecosystem experiment. Learning mechanisms disseminating the knowledge on the industrial ecology practices are essential to sustain the impact of the experimentation and so of its results. If first-order learning can be achieved continuously via capacity-building measures for the involved actors, it can accumulate into the second-order learning, which facilitates the viability of a local/regional industrial ecosystem experiment and also the emergence of positive expectations and visions for industrial ecosystem development at broader geographies.

Additionally, the findings indicated that the cross-fertilisation across different industrial ecosystem experiments is also crucial so that the involved actors can learn from each other. Moreover, isolated experiments can be further aggregated into global industrial ecosystem level through intermediary policies and actions. On that point, intermediary organisations such as coordinating/management bodies together with the governmental organisations can play a crucial role. The expansion beyond the local level can be achieved through employing effective policy mechanisms whereby collective visions can be formulated by the intermediary organisations through network management by enabling inter-learning from different experiments.

Finally, continuous experimentation of the industrial ecology practices among the traditional industrial production systems is critical and this will not only lead to an increased number of local/regional industrial ecosystems in the regions but can also bring a shift in traditional production routines towards circular production routines through the industrial ecology philosophy in a broader scale. To achieve that, perhaps the most challenging task for the decision-makers would be establishing and maintaining the motivation from the industrial organisations to get involved in the experimentation. Considering this, the new supportive and shielding mechanisms (e.g. public policy, legal systems, market forces, incentives, tax regulations, deregulation, etc.) that will be introduced to the regulatory rules of the contexts can be particularly helpful to change the established norms and cognition of the managers existent in the industrial production systems. If such mechanisms can even be co-created with the intermediary organisations and if also the intermediary organisations can effectively involve the industry and other actors in the change process, then the engagement from the industry would be more profound and broader in the unfolding industrial ecosystem experiments.

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A strategic niche management perspective on transitions to eco-industrial park development: A systematic review of case studies

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ABSTRACT

In recent decades, industrial park (IP) development has been an important practice for regional economic development for various geographies. Eco-industrial park (EIP) development, on the other hand, has been proposed as an alternative, considering environmental problems raised from the high number of agglomerated industries in IPs. Although there are some quite progressive EIP experiences that are globally distributed, IP development remains the mainstream industrial agglomeration model and has not yet experienced a transition into EIP development. The purpose of this article is both to understand and shed some light on how such a transition can be achieved through lessons from the EIP cases in the existing state of the art and to establish a research agenda that would elaborate on sustainability transitions into EIP development. To achieve these aims, a systematic literature review involving a case survey is conducted. A theoretical framework with an evolutionary perspective is developed drawing on EIP literature and strategic niche management (SNM) framework from sustainability transitions research. This connects two streams of research that have not been closely associated in the past. While synthesising 104 EIP cases from 24 countries, three analytical processes of SNM are considered: (i) articulation of expectations and visions, (ii) building of social networks, and (iii) learning activities. This article also discusses the development of local EIP experiments and EIP niche formation at different geographies. Based on this synthesis, policy implications are suggested and research implications are provided, stressing critical and interesting issues that have not yet had an explicit focus in the literature. This article enables cross-fertilisation across globally distributed EIP cases while adding to the critical mass in leveraging EIP development.

1. Introduction

The importance of agglomerated industries has been reflected in the development of industrial parks (IPs), which have experienced global popularity especially since the last quarter of the 19th century, when English economist Alfred Marshall coined the concept of industrial districts (1890/1920). Meanwhile, discourse on industrial agglomerations was widened to "capture the knowledge aspect" (Nuur, 2016) of development bringing innovation to the scene, which led to the phenomenon of *industrial clusters* (Porter, 1990) being used interchangeably with industrial districts. Then, as the idea behind developing industrial agglomerations has passed through different stages, faced new academic debates, and changed over time, the concepts of industrial district, industrial cluster, and industrial park have been used interchangeably (Côté and Cohen-Rosenthal, 1998; Vidova, 2010). In the present article we have chosen to focus on *industrial parks* as their development as a new system approach started relatively recently, in early 1970s (Kumar, 2005; Tylecote, 1995; Geng et al., 2008), and our focus is on the sustainability problematique of IP development and possibilities for next-generation IPs.

1.1. IP development and its problematique

IPs can be defined as systems of industrial actors within one location (Geng and Hengxin, 2009), based on a philosophy of obtaining advantages of potential common resources and services (Vidova, 2010; Fernández and Ruiz, 2009), such as infrastructure, transportation, management, recreational facilities, etc. IP development is "perceived as an integral part of regional development strategies of many countries worldwide" (Singhal and Kapur, 2002) and it has a crucial role in national and regional economic strategies (Fernández and Ruiz, 2009; UNIDO, 2012, 2014; Vidova, 2010; Liu and Côté, 2017). Naturally, IP

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development has been a mainstream feature of global industrial production systems. The number of IPs worldwide was between 12,000 and 20,000, according to data from 2001 provided in a report for UNEP (Francis and Erkman, 2001), approximately 3000 of which are in China (Liu and Côté, 2017).

While it has been claimed that IPs have the potential to function well in terms of efficiency, effectiveness, outcomes, etc. in order to drive for innovation, create new markets, mobilise local assets, and leverage the history and culture of a region while enhancing local development (Vidova, 2010; Ablonczy-Mihalyka and Keckkes, 2015; UNIDO, 2014; Fan et al., 2017), the environmental pillar of sustainable development has been missed out during their development, which has created pressure on the environment and as such relatedly on the society. Along with increasing awareness of sustainability concerns, negative environmental impacts from a concentration of large number of industries in IPs (Shi et al., 2010; Liu et al., 2017; Geng et al., 2008; Bai et al., 2014; Fernández and Ruiz, 2009; Côté and Liu, 2016; UNIDO, 2012; Gómez et al., 2018) have started to be discussed seriously. There would appear to be a need to integrate the economic, ecological, and social dimensions of IP development and transform these local scale industrial production systems considering regional, national, and even global ecological limitations (Wheeler, 2009).

In view of this, EIPs have been proposed as alternative IPs (Zhu et al., 2015; Wang et al., 2010) implementing "industrial ecology principles into existent and newly built industrial parks" (Farel et al., 2016) to address the sustainability–related problems (Gibbs et al., 2005; Cote and Hall, 1995; Erkman, 1997; Ehrenfeld, 2004) benefiting from the agglomerated nature of IPs (Bai et al., 2014).

1.2. EIP development

Industrial ecology, which Ehrenfeld (2004) once defined as "the science of sustainability", has been studied both as a policy tool and an academic theory (Daddi et al., 2016) with a motivation to provoke systemic transitions and to reduce environmental impacts by mimicking the principles of natural ecosystems (Erkman, 1997) to the industrial processes (Deutz and Gibbs, 2008; Panyathanakun et al., 2013). Development of EIPs has emerged as an inter-firm level application of industrial ecology, which was also referred as *industrial symbiosis* (Chertow, 2000). The initial philosophy behind industrial symbiosis was mutualistic interaction of different industries in a system for exchange of materials – water, energy, by-products, infrastructure, and natural habitat – resulting in economic, social, and environmental benefits (Lowe et al., 1995; Cote and Hall, 1995; Cossentino et al., 1996; USPCSD, 1996; Chertow, 1999, 2000). In time, industrial symbiosis has also been approached considering its social aspects revealing the importance of intangible resource exchanges (information, knowledge, and expertise), which has also facilitated the material resource exchanges (Gibbs, 2009; Lombardi and Laybourn, 2012).

Industrial symbiosis can benefit the advantages of agglomerations, which may ease the potential resource exchanges between industries (Chertow et al., 2008) and makes EIPs ideal next-generation sustainable IPs (Geng et al., 2008). EIP development can be followed both by designing/constructing new EIPs (that is, greenfield projects) and also by transforming existing IPs into EIPs (that is, brownfield projects) (Lambert and Boons, 2002). In the literature, the evolution of greenfield and brownfield EIP experiments has been addressed mainly by proposing three different models: (i) planned symbiosis (the build-and-recruit top-down model) (Chertow, 2007; Gibbs and Deutz, 2007); (ii) self-organising symbiosis (the bottom-up model) (Chertow, 2007; Chertow and Ehrenfeld, 2012); and (iii) facilitated symbiosis (facilitation by organisations and individuals) (Paquin and Howard-Grenville, 2012; Hewes and Lyons, 2008), which is a mixture of the top-down and bottom-up models.

EIP development has received global attention (Tiu and Cruz, 2017), especially after learning about the success of Kalundborg Symbiosis, which can be claimed to be the most influential EIP case for academia, policy-makers, and practitioners (Chertow, 2007; Branson, 2016). As expected, not all EIP cases are as influential and well-resulted as Kalundborg due to various reasons related to variety of involved actors and complex dynamics among them. Nevertheless, EIP development is a prevalent research topic in industrial ecology (Zhang et al., 2013; Yune et al., 2016). Both success and failure cases have been analysed in order to understand and extend the theory behind them, as well as for policy-making reasons.

1.3. Sustainability transitions to EIP development

Despite learnings based on extended research on various EIP cases, many regions continue to develop IPs (Geng and Côté, 2002; Côté and Liu, 2016) based on traditional ways of thinking that do not prioritise collective benefit through collaboration between industries for material and non-material exchanges, and instead favour the individual benefits of each firm (Lowe, 1997) concerning only individual performances.

In other words, EIP development has not substituted traditional IP development and IP development is still seen as strategic tool for local and regional development despite its sustainability problematique. Indeed, EIPs remain fringe sustainable practices and there are limited EIP initiatives distributed over different geographies, whereas IP development is still the mainstream logic. Apparently, there is resistance to potential transitions and this resistance stems from routines embedded in these industrial production systems. Therein lies the crux of the matter; how can EIP development become mainstream and how can such a transition from IP development into EIP development be achieved?

There are no concrete answers to those questions. In this vein, the EIP literature provides rich case studies that mostly focus on transitions of particular IPs into EIPs (Yu et al., 2014b; Shi and Yu, 2014; Mathews and Tan, 2011; Shi et al., 2010). However, there is a missing global systemic vision on a wider question of transitions into EIP development. Holding such a vision, we claim that the resistance can be overcome by correct interpretation of implications based on the understanding of development processes of existing EIP examples. Drawing lessons from past and present EIP examples would bring insights for future transitions into EIP development and these insights could be further elaborated through future research. Systematic literature review stands as a promising method for such an ambition especially considering the various EIP cases studied in EIP literature.

Therefore, the purposes of this article are (1) to understand and shed some light on how transitions into EIP development can be achieved through lessons from the EIP cases that have been studied in the existing state of the art; and (2) to establish a research agenda that would elaborate on sustainability transitions into EIP development.

In this review article, in order to understand better the EIP cases and also enrich the EIP literature with new insights, we intend to build a theoretical framework drawing upon a theoretical perspective called strategic niche management (SNM) (Kemp et al., 1998; Schot and Geels, 2008). SNM comes from another recently developed research stream, known as sustainability transitions (ST). In ST, scholars have developed middle-range theories and analytical frameworks (Geels, 2007) to study systemic sustainability transitions that hold a co-evolutionary view of society and technology with insights from evolutionary economics, sociology of technology, and history of technology and innovation studies (Geels, 2012; Markard and Truffer, 2008; Geels, 2010). The ST studies explore, describe and explain occurred, happening, or future potential transitions through co-evolution and interdependence of various system structures such as institutions, science, culture, technology, regulations, etc. (Geels, 2004; Coenen and Diaz Lopez, 2010; Smith et al., 2010; Truffer and Coenen, 2012).

Although both the EIP and ST literatures emphasise sustainability, systemic perspective, necessity of transitions, technological change, institutional change, broad range of actors and networks, etc., they

have not often been brought together; furthermore, EIPs, industrial ecology, and industrial symbiosis have not been often studied thoroughly drawing upon analytical frameworks provided by the ST field. Nevertheless, there are still some relevant EIP-related studies. Adamides and Mouzakitis (2009), Gibbs (2009) and Shi and Yu (2014) have drawn upon SNM, albeit partially. Adamides and Mouzakitis (2009) operationalised EIPs as strategic niches in industrial productions systems and analysed three well-known EIP initiatives to provide policy-level implications. Similarly, Gibbs (2009) approached EIPs as niches and provided generic analysis on the potential use of transition literature and particularly SNM framework for industrial ecology and industrial symbiosis research. Moreover, Shi and Yu (2014) borrowed concepts from ST and SNM studies and referred to EIPs as strategic niches. However, none of these studies have detailed analytical processes of SNM for the analysis of EIP development.

The remainder of this article is structured as follows. Section 2 presents the research objectives and research questions. It is followed by Section 3, which explains the theoretical framework combining SNM perspective with EIP development. In Section 4 the methodology is detailed and justified. That section also details how literature search was conducted, showing all search steps together with inclusion and exclusion criteria, as well as results of literature analysis, which covers meta-analysis of the selected articles focusing on their distribution over journals, years, and geography; this is presented to strengthen the background understanding of upcoming literature synthesis. Then, in Section 5, the literature synthesis is elaborated through re-interpretation of the EIP cases from the existing literature drawing upon the theoretical framework in order to take lessons to understand how IP development can experience a transition into EIP development. This section provides policy implications for sustainability transitions into EIP development and research implications for a future research agenda on EIP development. Finally Section 6 offers conclusions and a combined list of policy and research implications.

2. Research objectives

The industrial ecology literature has studied various EIP development initiatives from all around the world. Considering the rich EIP case studies available in the literature, we aim to learn from these cases how IP development can experience a transition into EIP development. A systematic literature review represents a proper method to do this by its facilitating capability to provide an overview of existing knowledge (Fischl et al., 2014; Tranfield et al., 2003).

There have already been some related literature review studies in the EIP literature. Therein, the researchers reviewed the literature with respect to identification and classification of industrial symbiosis indicators (Felicio et al., 2016); analysis of optimisation mechanisms for the design of EIPs (Boix et al., 2015); identification of different forms of eco-industrial networks that have the potential to advance environmental sustainability (Patala et al., 2014); analysis of the role of governmental policy in facilitating the development of industrial symbiosis (Jiao and Boons, 2014); analysis of the evolution of the industrial symbiosis research field and its embedding in industrial ecology through bibliometric and network analysis (Yu et al., 2014a); exploration of the methodological issues faced in the application of life cycle analysis to the various research questions arising from industrial symbiosis studies (Mattila et al., 2012); development of a theoretical framework for understanding the industrial symbiosis dynamics through which regional industrial systems change their connectiveness in an attempt to reduce their ecological impact (Boons et al., 2011); and development of EIPs as concrete realisations of the industrial symbiosis concept through a taxonomy of different material exchange types (Chertow, 2000).

To the best of our knowledge, no literature reviews have been conducted to date to understand how sustainability transitions into EIP development can be achieved. Elaborating such knowledge could reveal the ways in which EIP development processes can be influenced in desired transition directions rather than keeping them as frangible practices. Following that, our objective in this review article is twofold: (i) to understand and shed light on how transitions into EIP development can be achieved through lessons from the EIP cases that have been studied in the existing state of the art; and (ii) to establish a research agenda that would elaborate on sustainability transitions into EIP development. Following these objectives, the two following research questions are formulated:

Research question 1: What can be learnt from the existing state of the art on how transitions from IP development into EIP development can be achieved?
Research question 2: Which topics related to sustainability transitions into EIP development lack further investigation and offer opportunities for future research?

3. Theoretical framework

This article brings insights from ST research stream and particularly builds on the SNM framework, in which transitionary sustainable practices are approached as niche experiments. The SNM framework provides the grounds to analyse and understand niche experiments (Raven, 2005), which in some cases successfully challenge the unsustainable routines and in some cases remain as weak and frangible practices. In this article, EIP cases are conceptualised as strategic niche experiments that are expected to steer transitions to EIP development, and mainstream IP development can be thought as the logic of the existing industrial production systems, which is subject to sustainability transitions. When investigating the literature to answer the research questions, three “interrelated and mutually reinforcing” (Caniëls and Romijn, 2008) processes of the SNM approach are considered. These processes are (Schot and Geels, 2008; Raven, 2005; Weber et al., 1999):

(i) *articulation of expectations and visions*, which provides the grounds of interaction and gives direction to learning processes and lead to niche protection;
(ii) *building of social networks*, which creates mediums for interaction between related actors and facilitates learning; and
(iii) *learning activities*, which actually sustains the impact of niche experiments and changes the routines related to the socio-technical system subject to transition.

Considering three internal processes of SNM can be valuable while explaining and further understanding the development of greenfield and brownfield EIP niche experiments, and also the continuation of IP development due to embedded routines of mainstream actors. Such an understanding can provide clues on how to achieve sustainability transitions of IP development.

Fig. 1 provides an analytical illustration of the research conceptualisation of this article. This framework, with an evolutionary perspective, follows some theoretical standpoints that have emerged from both the ST and EIP literatures. In providing this framework, we connect two streams of research that have not been nurtured from each other very often.

In the EIP literature, EIP development has been mostly studied by scholars from industrial ecology, industrial symbiosis and regional science, drawing upon biological and ecological systems theory (Allenby and Cooper, 1994; Chertow and Ehrenfeld, 2012; Wright et al., 2009), having mostly an evolutionary perspective (Chertow and Ehrenfeld, 2012) and claiming that industrial ecology principles may lead to fundamental systemic transitions in technologies, industries and social life (Doranova et al., 2012; Machiba, 2010) through collaboration and interaction among multiple actors and networks in interaction with institutions (Gibbs, 2009).

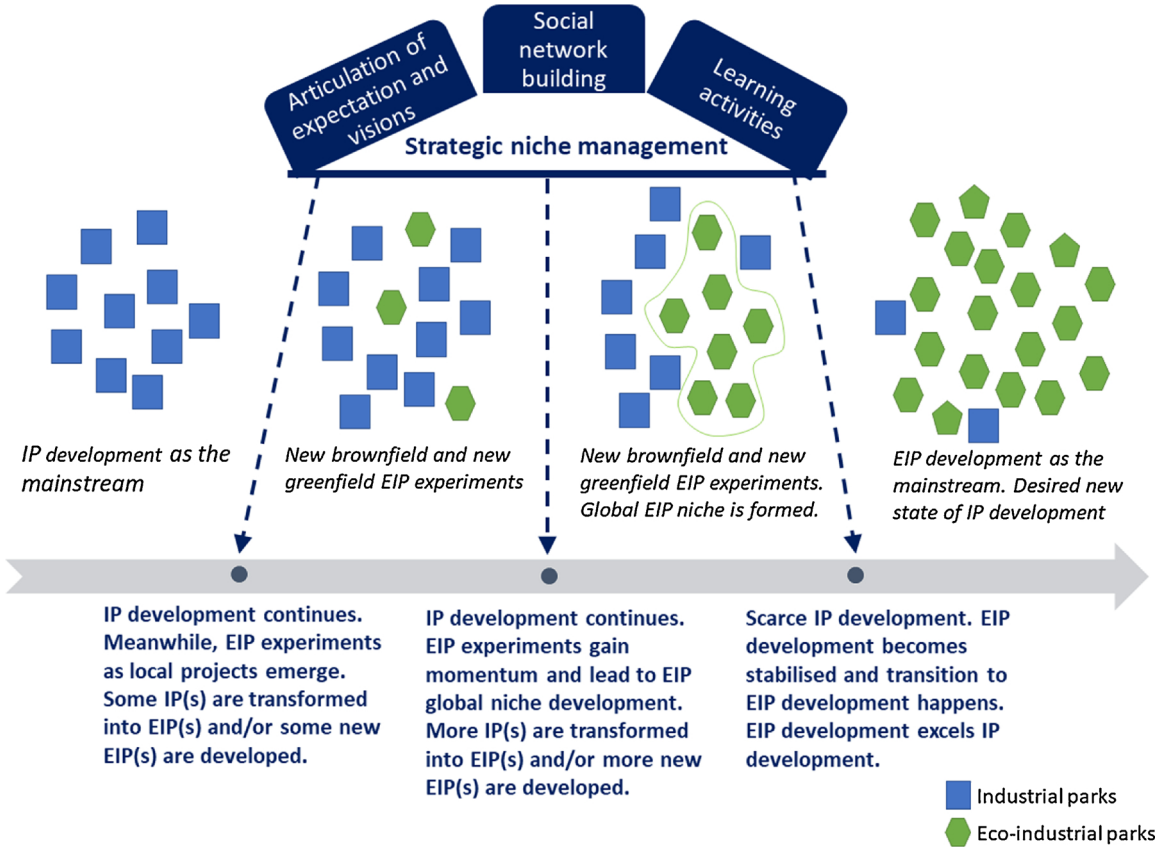

Fig. 1. Sustainability transitions of IP development into EIP development. Processes for SNM on evolution of EIP development; that is, EIP experiments as local projects, from local projects to global niches, and finally from global niches to EIP development as the mainstream. Authors' own elaboration based on Geels (2011), Schot and Geels (2008), Geels and Raven (2006), Chertow and Ehrenfeld (2012), Lambert and Boons (2002), and Gibbs (2009).

Here we emphasise that EIP development has an evolutionary perspective but consider EIP development more like a development trend that is expected to excel IP development, rather than focusing on evolution of industrial symbiosis in some specific EIP experiments (Chertow and Ehrenfeld, 2012; Paquin and Howard-Grenville, 2012; Baas and Boons, 2004; Domenech and Davies, 2011).

Referring to SNM studies (Schot and Geels, 2008; Caniëls and Romijn, 2008; Geels, 2011; Geels and Raven, 2006), we propose that proper combination and interaction between three internal niche processes can lead, firstly, to development of local greenfield and brownfield EIP experiments; secondly, to global EIP niche formation where there are still IPs but greenfield and brownfield EIP development gains some momentum; and, finally, to transitions into EIP development where EIPs excel IPs and EIP development becomes the mainstream. This evolution from local EIP experiments to global EIP niches and then from global EIP niches to sustainability transitions is conditioned and triggered by the three niche processes. Global EIP niches can be thought as accumulations of local EIP experiments and involve an emerging network that has similar or common concerns, problem agendas, expectations, visions, interests, etc.

Following Schot and Geels (2008), we suggest that three elements will be more effective at achieving sustainability transitions of IP development. These are (1) *expectations and visions* for EIP development, if they are specific enough and shared by various actors; (2) *network building*, if EIP networks are sufficiently broad and deep to articulate multiple views and to engage resources from the represented organisations; and (3) *learning processes*, if they are directed at both first-order learning (that is, observing, analysing the situation and learning facts and data) and second-order learning (that is, thinking of assumptions and values and changing behaviours and routines).

Finally, it is important to point out some theoretical assumptions behind the SNM framework that would not fit directly into EIP studies and its assumptions. Studies from ST and SNM are in favour of mainly radical technical innovations and take them to their research focus, whereas EIP development is also generous to incremental innovations that drive for systemic changes once accumulated. Indeed, realising EIPs does not specifically require introduction and diffusion of some particular technical product and process innovations such as wind energy, biogas, public transport systems, electric vehicle transport systems, etc., as usually studied by SNM scholars (Caniëls and Romijn, 2008). EIP development, as an industrial ecology in practice (Ehrenfeld and Gertler, 1997), is more about changing the industrial production routines through product, process and organisational innovations that may be achieved through institutional changes. Any physical or non-physical exchange between system members in EIPs is realised through an innovative solution and leads to an innovative solution as the result. The product or process innovation out of industrial symbiosis can be in an incremental or radical form depending on the exchange and its results. However, these innovations engaging various actors at the EIP level accumulates into systemic innovations.

4. Methodology

A systematic literature review (SLR) (Fischl et al., 2014; Petticrew and Roberts, 2006), including a case survey (Lucas, 1974), was chosen as the method of the present article due to the fact that EIP literature is rich in empirical case studies. We believe that extracting the EIP cases from the literature and re-interpreting them with a different theoretical perspective can provide valuable knowledge to elaborate on how transitions into EIPs can be achieved.

The case survey method enables us to have a rich set of case materials (Kivimaa et al., 2017; Newig and Fritsch, 2009) that have previously been generated for different research objectives under different research designs with different research perspectives. We were aware that the proper synthesis of such case material would require a smart bricolage ability, especially considering the "risk of bias in summarising" (Kivimaa et al., 2017) studies that we have not conducted (Petticrew and Roberts, 2006). Considering this, we have devoted enough time and commitment for the synthesis to benefit from the advantage of having numerous case studies, which would not have been possible through direct insight gathering from the primary sources.

In order to identify the cases from the literature, the SLR method was preferred for this study over a traditional or narrative literature review. Fink (1998) defined SLR as "a systematic, explicit and reproducible design for identifying, evaluating and interpreting the existing body of recorded documents". In more reflexive terms, the idea is to gather and re-interpret the earlier interpretations of EIP cases and present them in a new context (Alvesson and Skoldberg, 2009), developing new knowledge and addressing the objective of this article. The new context is the proposed theoretical framework, which builds on the SNM approach, as explained earlier. Following this methodology, diverse case studies could be brought together under a common theoretical framework.

In order to ensure thoroughness and rigour (Tranfield et al., 2003; Fischl et al., 2014), this article follows a solid SLR method with three concrete steps – (i) literature search, (ii) literature analysis, and (iii) literature synthesis – in order to use the existing knowledge effectively (Fischl et al., 2014).

The systematic literature review started with a literature search, where the crucial element was to choose the database(s) and the keyword(s) to be searched (Baker, 2000). Then, in the literature analysis step, selected studies were descriptively analysed in terms of various aspects related to journals, publication years, and geographical focus of studies. The EIP cases that would be further elaborated at the next step were also identified in this step.

Finally, in the literature synthesis, each EIP case was re-interpreted based on analytical processes of SNM as explained above. It is worth stating that none of the EIP cases included in that study were developed using SNM as the ex-ante prescriptive policy framework. Instead, we built on SNM as the underpinning of our theoretical framework, which is used as an ex-post analytical framework for re-interpretation in order to understand how transitions to EIP development can be achieved to derive some policy implications. The literature synthesis step covered the crucial discussions in line with the theoretical framework and led to various research implications about critical and interesting issues that require further investigation in the EIP literature. During the synthesis step of SLR, the units of analysis were the EIP cases in selected articles out of the literature search step, rather than the full article itself.

4.1. Literature search

In this step, the initial and crucial decision was related to selection of keywords. In the literature, the concept of EIPs refers to IPs having a focus on environmental and social pillars of sustainability through 'industrial ecology', or, more specifically, 'industrial symbiosis'. On the other hand, different studies in the literature refer to 'industrial parks" as 'local industrial productions systems', 'industrial districts', 'industrial clusters', 'industrial agglomerations', 'industrial estates', etc. Our interest is related to the potential transitions of IP development into EIP development through brownfield and greenfield projects. However, the literature also contains other studies, rather than EIP development, that focus on other ways of making IPs more sustainable. Including 'industrial parks' and its used synonyms as keywords in the literature search would bring all other sustainability solution possibilities for IPs. Doing so would be beyond the scope of this article, which argues that 'EIPs' would be a better possibility for addressing the problematique of sustainability concerns related to IP development. Therefore, three keywords were selected: 'eco-industrial' and its parent concepts 'industrial ecology' and 'industrial symbiosis'.

Web of Science was selected as the database because of its reputation as a useful and trustworthy source, as the oldest and most widely used database with rich and well-structured citation and bibliographic data dating back to 1900 (Mikki, 2009; Chadegani et al., 2013). Moreover, its coverage is mostly in English and it has a systematic and established journal selection criteria based on expert views, citation impact, international diversity, publication standards, etc.

Reviewing the literature through the search for the keywords 'eco-industrial', 'industrial symbiosis', or 'industrial ecology' in the title, keywords or abstracts of the articles in the Web of Science database rendered 3040 publications in English language for all years. The search was conducted on the 12th of December 2017. Filters on research domain to be 'social sciences' and document types to be 'articles' were then applied to the results, which decreased the number of publications to 1389. The review was limited to journal articles because they address a wider scientific audience and are subject to different forms of peer-review process, which increases the quality of the studies. Next, exclusion criteria, which are the measures to determine which articles will be excluded from the review, and inclusion criteria, which are the measures to determine which articles will be included in the review, were identified. Exclusion criteria were set to be elimination of articles related to technical studies, such as optimisation, programming, configuration development, emission reduction, specific production methods, quantification of performance, emergy analysis, etc. Inclusion criteria were set as articles that touch both social and technical aspects of EIPs and regional/local industrial symbiosis and industrial ecology. Taking these exclusion and inclusion criteria into consideration, titles and abstracts of the available articles were scrutinised; this step resulted in 115 articles for literature analysis. A further review was conducted over these 115 articles in order to identify the materialised EIP cases; that is, excluding those that are only at the proposal or planning stage, which would be re-interpreted during literature synthesis drawing upon SNM internal processes. This gave us 66 articles with a sample of 104 EIP cases. Finally, based on these articles, discussions on local EIP experiments, global EIP niche development and sustainability transitions into EIP development were built. The six-step procedure is illustrated in Fig. 2.

4.2. Literature analysis

In this step, we conducted a meta-analysis of 115 selected articles for a quantitative representation of time and journal distribution of publications, as well as frequency of geographic locations studied in the articles. Moreover, we identified EIP cases that would be subjected further to literature synthesis. The full list of countries, together with references to the articles studying them, is attached as Appendix A.

Through analysis of number of articles published each year over a sample of 115 articles selected for analysis, we found that there has been a considerable and relatively stable interest in EIP development in social sciences research domain since 2007 (87%, n = 101). Starting from 2015 and peaking in 2016 (18%, n = 21), an increase was observed in the total number of articles published (see Fig. 3). Five journals represent the majority of the total sample (71%, n = 82). These are *Journal of Cleaner Production* (n = 51), *Journal of Industrial Ecology* (n = 15), *Journal of Environmental Management* (n = 6), *Sustainability* (n = 6), and *Regional Studies* (n = 4). The rest of the articles (n = 33) were published in 26 different journals related to the fields of environment, sustainability, technology, geography, urban planning, regional science and economics, indicating that eco-industrial development as a research topic has gained interest from scholars from different backgrounds and had the chance to be studied as an inter-disciplinary field. Fig. 4 presents the journals with more than one

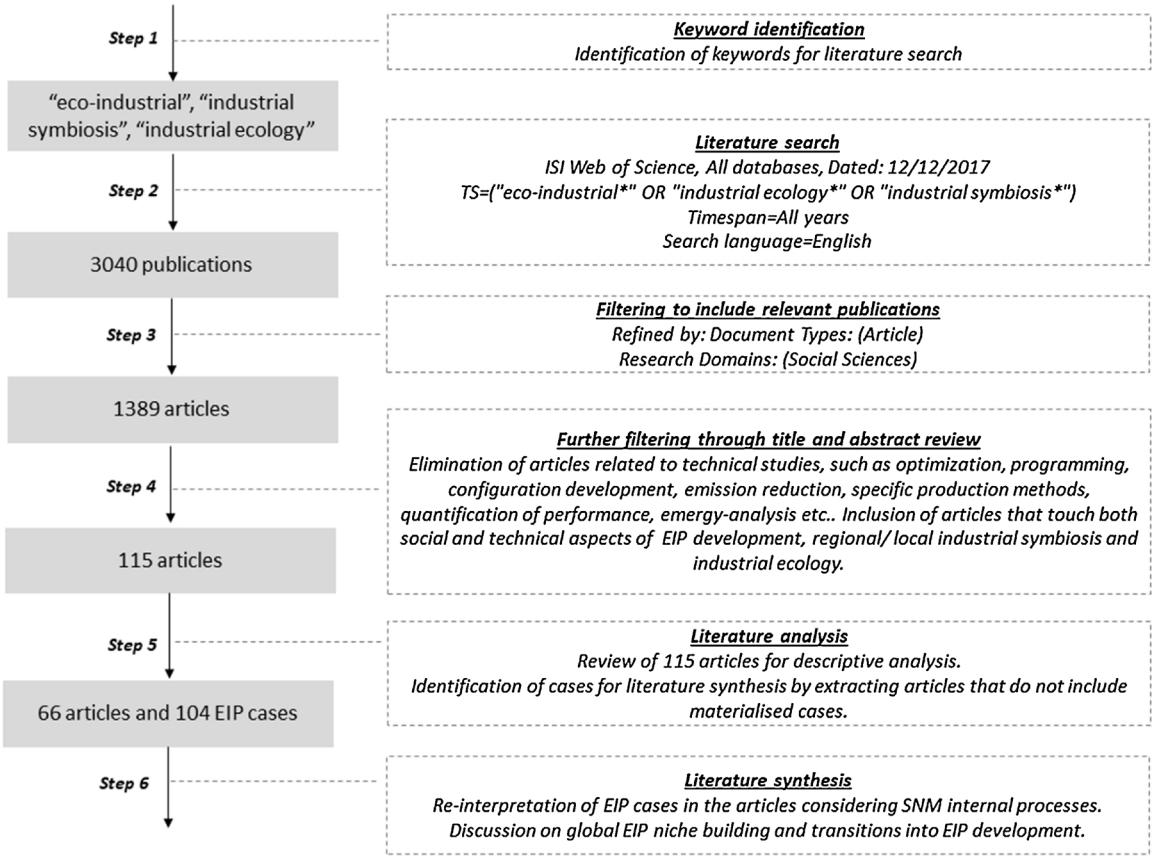

Fig. 2. Systematic literature review embedding a case survey in six steps.

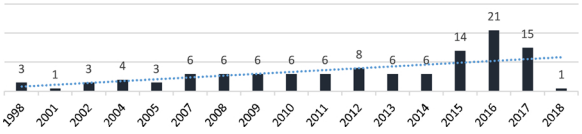

Fig. 3. Number of publications over years, n = 115.

publication within our literature analysis sample. Based on these analyses, it can be concluded that research on EIPs in social sciences domain stands still as a fresh line and may be enriched within interdisciplinary studies being operationalised in concepts from different social science theories. This enrichment would further extend our understanding of if and how transitions to EIP development can be achieved.

A picture of the geographical distribution of empirical contexts of the studies can reflect how the focus of different geographies on EIP development differs in intensity by looking at the frequency of countries studied in the article sample. To draw such a picture, the countries in focus were analysed and listed. The results showed that not all studies selected for literature analysis have specific geographical empirical contexts (n = 12). Still, it was observed that an importantly large sample of studies (n = 103) focused on analysis and interpretation of different aspects of EIP development in 31 different countries throughout the world. Among these studies, a relatively large number (n = 87) had a single-country focus, while some others (n = 16) have empirical contexts from multiple countries, as illustrated in Fig. 5.

Going further into the multi-country focus articles, new countries appear on the list, such as the United Kingdom, Ukraine, Switzerland,

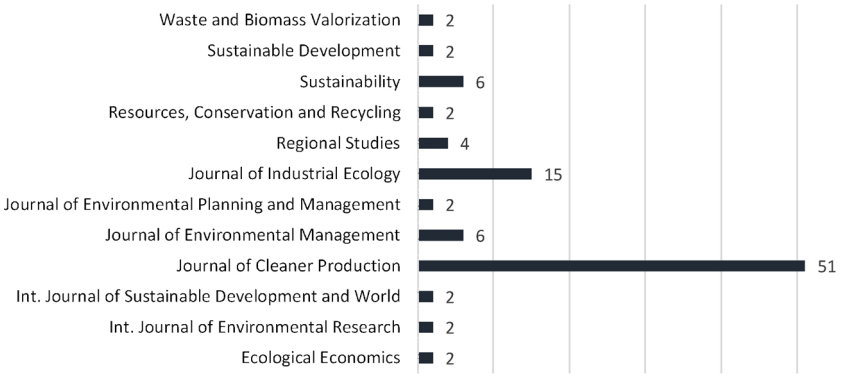

Fig. 4. Number of publications at most relevant journals, n = 115, included if > 1 article.

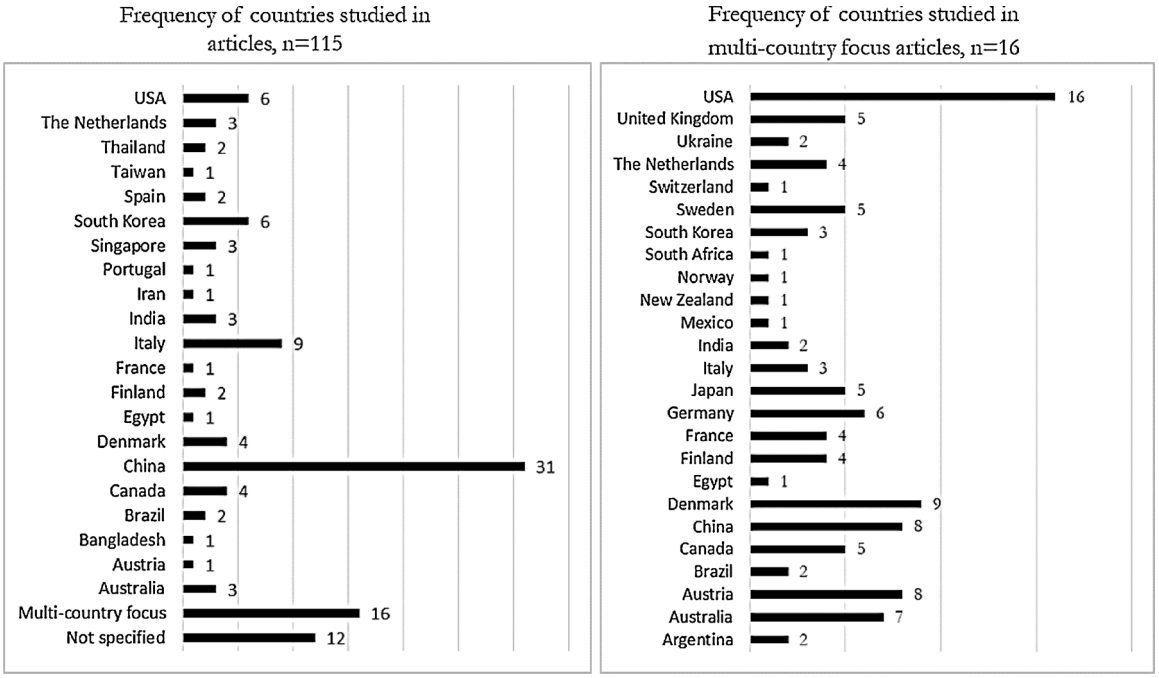

Fig. 5. Frequency of countries as empirical contexts studied in articles.

Sweden, South Africa, Norway, New Zealand, Mexico, Japan, Germany and Argentina. Moreover, when compared to other countries, Denmark, which has a benchmarked self-organised and perhaps the most cited EIP initiative (namely, Kalundborg EIP), has a relatively radical increase in its frequency of studies with a multi-country focus. This implies the interest in cross-comparison of cases with the best practices. The National Industrial Symbiosis Programme (NISP) of United Kingdom, as another benchmark example, also appears in the articles with a multi-country focus. However, NISP is not included in literature synthesis as it is a national-scale industrial symbiosis initiative. Articles with a multi-country focus provide experience and knowledge from and across different contexts, which arguably creates a more fruitful learning ground for readers.

As stated, the third step of our review is the synthesis of EIP cases from the selected literature studies. The frequency of countries focused on in each of the studies has already been presented but it is still necessary to list the EIP cases already interpreted in the literature. We have analysed each selected article thoroughly and identified all involved EIP cases. Articles that do not include already developed EIP cases, but instead analyse potential EIPs, have not been counted in the synthesis. However, articles that do not have specific EIP case analysis and instead have country-level analyses on different EIP development and management aspects based on the data collected from various EIP initiatives are included. Excluding such articles could have resulted in skipping crucial SNM processes' analysis for the EIP development in the related geographies as they provide insightful knowledge about the background of EIP development in the country under analysis. After applying these inclusion and exclusion criteria, the final EIP list was composed of 104 EIP cases from 24 countries studied in 66 articles. The global distribution of EIPs is illustrated in Fig. 6. Furthermore, list of identified EIP cases together with reference articles are given in Appendix B.

5. Literature synthesis

While re-interpreting identified EIP cases from the literature, three "interrelated and mutually reinforcing" (Caniëls and Romijn, 2008) processes of the SNM framework are considered, as explained in the theoretical framework. This section presents a learning outcome and discusses how EIP development has remained at the level of local projects in some geographies and evolved into EIP niche level in others. By doing so, we intend to elucidate how potential transitions from IP development into EIP development can be achieved and studied through giving policy and research implications.

5.1. Articulation of expectations and visions

Expectations from EIP development are strongly shaped by motivations of the involved actors; as there are various involved actors with different interests, expectations can vary, even within the same geography, and they are not clearly articulated most of the time. In general, however, motivation for the industries are almost always economic and whenever the EIP project does not seem economically feasible, the industry is not interested and firms do not prioritise the social and environmental potential of industrial symbiosis. Besides, industrial actors that do not have any related experience and are not equipped with enough background knowledge related to EIP development (Park et al., 2016) are not willing to initiate such experiments. On the other hand, expectations for governmental institutions, especially considering planned EIPs, are positive and motivated mostly by global pro-sustainability development landscape pressure, environmental pollution and resource scarcity problems at the regional or national levels and concerns related to sustaining country's industry in the international market. In the case of South Korea, for example, financially oriented motivation of industries is clearly articulated in various case studies, such as the *Ulsan* and *Macheon* experiments (Behera et al., 2012; Kim, 2007), whereas government has been developing ambitious top-down planned EIP development mechanisms while also considering the country's domestic context (Park et al., 2016; Park et al., 2008).

Furthermore, same-group actors at different geographies may have different expectations as well. In some EIP cases, industrial actors, such as *Kalundborg* (Valentine, 2016; Chertow, 2007; Branson, 2016), *Industrial Eco-System Project* (Lambert and Boons, 2002; Heeres et al., 2004) and *Kwinana* (Chertow and Ehrenfeld, 2012; Giurco et al., 2011; MacLachlan, 2013) took the lead in initiating successful symbiotic

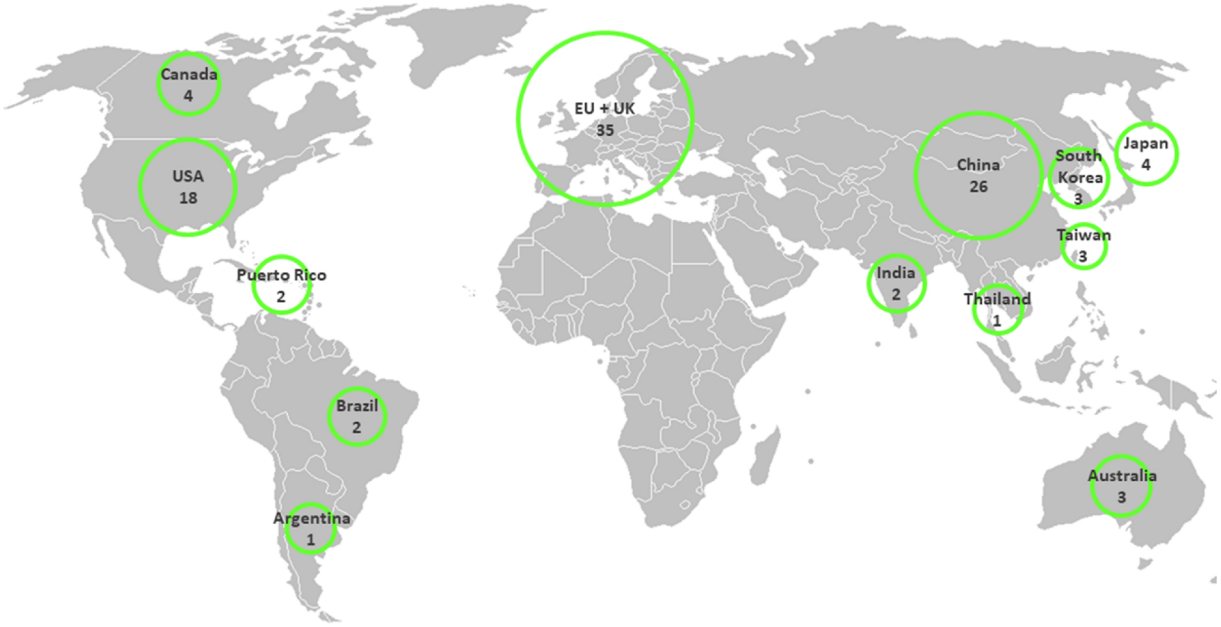

Fig. 6. Global distribution of the identified EIP cases. The number of EIP cases are indicated on the geographic location where they have been developed.

exchanges in collaboration with local and regional governmental institutions. They expected and then realised that industrial symbiosis could bring substantial economic and environmental profits and have been willing to invest in such projects.

Another important point is the importance of having common expectations from the EIP development. Even for a single EIP experiment, actors who have different interests and motivations may hold diverging expectations and may not communicate to each other clearly. Differences in motivations may lead to misunderstanding or arbitrary understanding of what an EIP is, especially when there is a lack of learning mechanisms. This problem is observed at the *Macheon* experiment (Kim, 2007), where government agents, industries and local citizens had different understandings about industrial symbiosis and developed different expectations from this specific EIP experiment, which threatened the aim and sustainability of the project.

Expectations of actors are highly interlinked with the vision of EIP development in related geography. Visions related to EIP development can be addressed through three evolution models proposed by the EIP literature: planned EIP, facilitated EIP and self-organised EIP. In the EIP literature, some leading scholars have discussed the importance of building upon existing and potential linkages within a locality (Gibbs and Deutz 2007), using existing strengths (Gibbs et al., 2005), identifying and uncovering existing symbiosis (Lambert and Boons, 2002; Chertow, 2007) in EIP development, and promoting self-organised and facilitated EIP models in this respect. However, it has been claimed that planning is still important if it is applied in the early stages of EIP development and if it is combined with a facilitated model to achieve long-term goals for eco-transitions (Yu et al., 2015a).

Despite this, a top-down approach leading to planned EIPs is prevalent in cases from North America, South America, Asia and Australia. Especially in USA and China, EIP development has been strongly guided by the government (Yu et al., 2015c; Gibbs and Deutz, 2005; Chertow, 2007), which has led to a higher number of EIP projects (see Fig. 6) when compared to all other countries. However, there are cases from these geographies where top-down planning was combined with a bottom-up approach and turned out to be a facilitated model, as in the cases of *Burnside* (Lambert and Boons, 2002), *Kawasaki* (Chertow and Ehrenfeld, 2012; Mathews and Tan, 2011; Farel et al., 2016), and *Central Gulf Coast* (Farel et al., 2016). The *Kwinana* case, as another exception, has been developed in a combined top-down and bottom-up fashion (Farel et al., 2016) as it was developed by the government as a greenfield site in 1952 but EIP practices were not planned and they 'happened over time' (MacLachlan, 2013).

In Europe there is a variety in EIP development visions where self-organising and facilitation mechanisms for brownfield EIP projects have been competing with planning trends for greenfield EIPs, which was not the case on the other above-mentioned regions. Bottom-up self-organised development as a result of voluntary cooperation has been followed at various European EIPs, such as *Styria* (Zhang et al., 2013; Chertow and Ehrenfeld, 2012; Chertow, 2007; Ashton et al., 2017), *Kalundborg* (Bellantuono et al., 2017; Lambert and Boons, 2002; Valentine, 2016; Chertow and Ehrenfeld, 2012; Branson, 2016; Gibbs et al., 2005), *Knapsack Chemical Park* (Farel et al., 2016), *BASF Verbund* (Farel et al., 2016), *Porto Marghera* (Mannino et al., 2015), *Bioraffinerie Les Sohettes* (Farel et al., 2016) and *Industrial Eco-System Project* (Lambert and Boons, 2002; Heeres et al., 2004). Although the trigger factors for these local projects were related to concerns of industries, facilitation mechanisms were introduced later through public and private organisations. On the other hand, for some other cases from Europe, such as *Biopark Terneuzen* (Farel et al., 2016), *Moerdjik* (Heeres et al., 2004; Farel et al., 2016), *Monthey*, *Norrkoping and Linkoping*, *Kymi* and *Deux Synthe* (Farel et al., 2016), bottom-up involvement has emerged later, leading to the facilitation model, although EIP mechanisms initially were introduced in a top-down fashion.

We have noticed that most of the EIP cases were established on a local vision built by expectations of particular actors targeted mostly at the transition of particular IPs for brownfield experiments or developing greenfield EIP projects. A broader long-term vision for transitions of IP development into EIP development only appears in countries where a top-down approach with national-level goals has been followed, such as China, South Korea, and Thailand through brownfield projects, and the USA, mostly through greenfield projects. However, brownfield projects from Asia using existing linkages and strengths within an IP have been more fruitful than the greenfield projects in the US (Chertow and Ehrenfeld, 2012). Moreover, more successful and sustained EIP experiments from those countries have been the ones that engaged in facilitation to keep EIP projects viable at later development stages, such as *Tianjin* and *Dalian* (Yu et al., 2015a), *Ulsan* (Behera et al.,

2012), and *Devens* (Veleva et al., 2015). In such experiments, a combination of top-down and bottom-up approaches have provided the background for interactions of the related actors to build networks under coordination activities provided by mostly public agents, which have also considered the need for learning processes in order to have diverging expectations and visions.

Moreover, the vision for EIP development also plays a crucial role with regard to protection of niche experiments in terms of regulatory, policy, and funding frameworks. Protection measures, such as tax regimes, environmental regulations, national policy programmes, financing incentives, and so on, condition and trigger, or in some cases even hinder EIP development, and decisions related to them are made at the political and often at national level. In this regard, integration of top-down planning into EIP development is observed to be critical. In geographies where, for EIP development, the government plays an initiator role (as in China, South Korea, Thailand, the US or Canada), or a facilitator role (as in Denmark, Australia, the Netherlands or Sweden), EIP experiments gain legitimacy and stability resulting from government support and protection. Furthermore, support from international landscape can also be beneficial for nurturing EIP experiments. In China, for instance, governments and industries have further participated in EIP development efforts through financial support from international development agencies like the United Nations Environmental Program (UNEP), the Asian Development Bank (ADB), and the Canadian International Development Agency (CIDA) (Geng et al., 2007). These international support mechanisms are also observed in experiments such as *Biopark Terneuzen* (Farel et al., 2016), *Deux Synthe* (Farel et al., 2016), *AvestaPolarit*, *Eco Dyfi*, *Ecotech* (Gibbs and Deutz, 2007) in which funding from European Union (EU) was received.

Policy implications

Based on the lessons learnt from the EIP cases, we suggest that top-down planning with a stronger focus on brownfield EIP experiments can provide promising conditions for governments to build specific expectations with specific motivations. Then, bringing in facilitation mechanisms that engage industries, research centres and citizens may lead to the convergence of motivations and shared expectations of wide variety of actors. Thus, an effective combination of a top-down and bottom-up approach stressing more brownfield projects through providing support and protection mechanisms would be more suitable considering the long-term vision required for transitions from IP development into EIP development.

Research implications

We propose following research implications related to expectations and visions for EIP development:

***Research implication 1*:** Evolving expectations and visions for EIP development covering a wide variety of related actors and their motivations requires an explicit focus of the EIP literature.

Research implication 2: A broader vision for transitions of IP development into EIP development in comparison to vision for transitions into particular EIPs has not been explicitly examined in the EIP literature.

5.2. Social network building

The network perspective in the EIP literature has been mostly addressed in reference to the development of industrial symbiosis exchange networks focusing on different aspects of network building, such as network connectedness and resilience through social network analysis (Zhang et al., 2013; Chopra and Khanna, 2014); networking behaviours of the firms in industrial symbiosis networks (Gibbs et al., 2005); social relationships and shared norms among actors in industrial symbiosis networks (Ashton and Bain, 2012); growth patterns for industrial symbiosis networks (Zhu and Ruth, 2014); embeddedness and proximity in industrial symbiosis networks (Schiller et al., 2014; Domenech and Davies, 2011); and the role of EIP coordinating bodies (Tessitore et al., 2015). These studies have provided important insights into the structure and dynamics of the industrial symbiosis networks. However, EIP development requires a wider constellation of actors including external institutions such as governmental bodies, regional and local development agencies, universities and research centres, local communities, non-governmental organisations (NGO) representing the community interests, etc., in order to involve multiple views and engage resources from different agents.

In the *Kalundborg* experiment, which is considered a benchmark EIP example by various scholars (Branson, 2016; Park et al., 2008; Chertow et al., 2008; Gibbs and Deutz, 2005), a social network was built among industries, coordinating body, local government, regulatory authorities, universities and research centres (Costa and Ferrao, 2010; Chertow, 2007; Valentine, 2016; Chertow and Ehrenfeld, 2012) and this wider network has conditioned the industrial symbiosis network within the park. This was the case for various other EIP experiments such as *Chamusca* (Costa and Ferrao, 2010), *Deux Synthe* (Farel et al., 2016), *Landskrona* (Park et al., 2008; Adamides and Mouzakitis, 2009), *Norrkoping and Linkoping* (Farel et al., 2016), *Kawasaki* (Chertow and Ehrenfeld, 2012; Mathews and Tan, 2011), *Ulsan* (Behera et al., 2012), *Daedok Technovalley* (Oh et al., 2005; Pilouk and Koottatep, 2017), *Northern Region Industrial Estate* (Panyathanakun et al., 2013), *Kwinana* (Giurco et al., 2011), and various Chinese EIPs including *Guigang Group* (Zhu and Côté, 2004; Fang et al., 2007), *Suzhou* (Yuan et al., 2010; Yu et al., 2015b), *Weifang Binhai* (Liu et al., 2015), *Tianjin* (Yu et al., 2014b), *Shanghai Chemical* (Yune et al., 2016; Zhang et al., 2009), *Dalian* (Yu et al., 2015a; Geng et al., 2008), *Rizhao* (Yu et al., 2015c), and *Qijiang* (Sun et al., 2017). Industrial symbiosis network within the park can then be considered as part of the wider EIP development network.

In the literature, a crucial structure of EIP development network has been considered as the coordinating body (Chertow and Ehrenfeld, 2012), which other articles referred to as the management body (Tessitore et al., 2015). The coordinating body in an EIP is generally responsible for strengthening networking, ensuring communication and information exchange among all of the network actors and especially among industrial actors in symbiosis network to facilitate the identification and establishment of symbiotic exchange potentials among the participating companies (Yu et al., 2015a) and more importantly among actors in the wider EIP development network. This role can be played by a private company, an industry association, or public authorities depending primarily on the expectations and visions of the EIP development in the concerned region. For instance, in China (Yu et al., 2015a), South Korea (Behera et al., 2012; Park et al., 2008) and Italy (Tessitore et al., 2015), where there is a national-level EIP development vision planned in a top-down manner, coordinating bodies are established and represented by public authorities. In contrast, coordinating bodies in EIP experiments like *Kwinana* (Chertow and Ehrenfeld, 2012), which have a mixture of top-down and bottom-up vision, demonstrate a more mixed structure for coordinating bodies that are composed of representation from the industrial actors, government and academia, and appreciate and communicate a wider range of articulated views.

Drawing on the articles included in literature synthesis, another important structure of the EIP development network appears to be a local champion (Chertow, 2007; Roberts, 2004; Heeres et al., 2004) for the purposes of goal setting and creating the actor network, which is in line with the SNM perspective (Caniëls and Romijn, 2008). Hewes and Lyons (2008) elaborated on the role of local champions in development of *Komsomolske* and *Cherkassey* EIPs in Ukraine, where the champions were locally embedded within the community. Although the local champions were explicit in these two EIP experiments, the role of local champions was deliberately unidentified in some other cases, such as *Industrial Eco-System* and *Rietvelden/Vutter Sustainable Revitilisation* experiments from the Netherlands, to avoid prejudice among industrial

actors, since many of them would be suitable for the task (Hewes and Lyons, 2008). The existence of local champions has been also favoured in EIP development in South Korea, where regional EIP centres established by the government act as local champions (Park et al., 2016); an exception is the *Ulsan* experiment, where the local champion was an academic researcher (Behera et al., 2012). Local champions in all those experiments promoted and strengthened bottom-up activities in order to gather all relevant actors for promoting social connections and developing trust in the EIP development networks.

Policy implications

Relying on experiences related to network building from the articles, we propose that the network perspective in EIP development should be widened, aiming at a combination of industries, which form the industrial symbiosis network, and external actors such as government bodies, research institutes, universities, informal institutes like industrial associations and NGOs. A perspective on such a wider EIP development network would be broad and deep enough to reflect multiple views. Moreover, networking building can be more efficient if it is guided by a coordinating body that ensures all actors communicate effectively, and also if it is supported by local champions that facilitate interaction and trust development among network actors. Clearly, vision for EIP development constructed through top-down and/or bottom-up approaches should impact the variety in actor structure, their interactions, or existence of coordinating body or local champions.

Research implications

We arrive at the following research implications considering social network building:

***Research implication 3*:** Structures of broader networks for EIP development, which involves not only industrial actors in symbiosis networks but also external institutions such as governmental bodies, university and research institutes, NGOs, industrial associations, local community, etc., and the interaction among them remain underexplored in EIP literature.

***Research implication 4*:** The EIP literature lacks an understanding of the correlation between the EIP development visions, tailored by top-down, bottom-up, and mixed approaches, and network building characteristics, related to involved actors and their interactions.

5.3. Learning activities

Learning has a crucial role in sustaining niches at the level of single niche experiments or a set of demonstrations experiments (Schot and Geels, 2008). Despite this, it has not found an explicit interest in EIP literature. A deeper look into the articles has been necessary to synthesise cases with respect to learning activities embedded in their evolution path.

The depth and breadth of learning processes – that is, first-order or second-order learning – are found to be related to characteristics of EIP development networks. When the EIP development networks are broad and connect various EIP experiments, as in countries like China, where there is a top-down approach for vision on national-level transitions into EIP development, second-order learning seems to be more likely. One reason for this is the "structured repeated visioning" (Schot and Geels, 2008) through various EIP experiments under the protection of the same umbrella programmes, such as the National Demonstration EIP Program (NDEIP) and the National Demonstration Circular Economy Zone Program (NPCEZ) in China (Zhang et al., 2010). Another reason is related to the high number of EIP cases, which were initiated and protected by these programmes through concurrent experimentation, and aggregation of learning outcomes from these experiments. For instance, Chinese governmental organisations have, since the beginning of the 21st century, been accumulating knowledge through monitoring results from different EIP experiments and have been facilitating learning for IPs by disseminating this knowledge through publications and by exchanging lessons via useful capacity-building events such as seminars, forums, workshops, trainings, business meetings, etc., as well as dissemination through media. However, there is still a lack of a learning system in China with a common platform for information sharing and communication among IPs, and such a system would create the knowledge and practice sharing network among all IPs and EIPs (Zhu et al., 2015).

We also observed that network diversity, both in industrial symbiosis networks and wider EIP development networks, enhances learning processes. Considering industrial symbiosis networks that are centred on one or a few major industries, the absence of diversity may "hinder learning and critical reflection about the experiment" (Weber et al., 1999). This was the case in *Porto Marghera* (Mannino et al., 2015) in Italy, a failed EIP experiment in which high dependency on a single industry reduced the diversity and thus the learning for the resilience of the network.

Indeed, the experiments from the literature show that heterogeneity in terms of sectoral and size differences inside the park facilitates favourable contexts, especially for observing, analysing and learning from the facts and data with a focus on technological issues; that is, first-order learning. Communication and disseminations events as capacity-building measures, organised by coordinating bodies, anchor tenants, local champions, environmental agencies, or governmental institutions, have provided mediums for first-order learning in many EIPs, such as *Burnside* (Lambert and Boons, 2002), *ValuePark Schkopau* (Liwarska-Bizukojc et al., 2009), *Devens* (Veleva et al., 2016), *Kwinana* (MacLachlan, 2013), *Kalundborg* (Branson, 2016), *Guigang Group* (Zhu and Côté, 2004), *Suzhou* (Yu et al., 2015b), *Weifang Binhai* (Liu et al., 2015), *Xi'an High-Tech* (Shi and Yu, 2014), *Dalian*, *Tianjin*, (Yu et al., 2015a), *Qijiang* (Sun et al., 2017), *Ebara* (Bellantuono et al., 2017), *Kokubu* (Bellantuono et al., 2017), *Ulsan* (Behera et al., 2012), and *Northern Region Industrial Estate* (Panyathanakun et al., 2013). Information systems technologies can also be important tools to facilitate the exchange of information and materials, as in cases such as *Chamusca* (Costa and Ferrao, 2010), *Landskrona*, (Adamides and Mouzakitis, 2009), *Tianjin*, *Kalundborg*, etc. Then, repetition and accumulation of first-order learning over time, as in the cases of *Devens*, *Kwinana*, and *Kalundborg*, led to the rethinking of assumptions and changing of production routines in such EIPs (that is, second-order learning), where not only technological issues but also social, managerial and organisational network features were addressed.

Another important aspect of learning in niche building is related to transfer of experiences and lessons from one experiment to other places (Weber et al., 1999) as such cross-fertilisation across experiments can occur (Caniëls and Romijn, 2008). In that respect, the *Kalundborg* case stands as the most influential EIP experiment (Branson, 2016; Chertow et al., 2008; Deutz and Gibbs, 2008) and served as a reference benchmark learning centre for the development of various other EIP experiments (Adamides and Mouzakitis, 2009; Chertow and Ehrenfeld, 2012) distributed over wide geographies (Gibbs et al., 2005; Park et al., 2008). In view of this, international collaborations can play a role in terms of knowledge transfer and co-creation, such as in the *Suzhou* experiment where knowledge from experience in Singapore has been adopted by China for EIP development; the *Biopark Terneuzen* experiment (Farel et al., 2016), which was a part of an international project funded by the European Union by international partners; or national-level EIP development programmes in countries like China (NDEIP and NPCEZ) (Bai et al., 2014), South Korea (National Plan for Eco-industrial Park Development) (Park et al., 2016), or Thailand (Development of Eco-Industrial Estates and Networks Project) (Pilouk and Koottatep, 2017), for which governmental organisations have been collaborating

with international institutes and experts.

Policy implications

In light of these aspects, we argue that learning activities and processes require an explicit focus in EIP development as they sustain the impact of EIP experiments during their evolution over time. If first-order learning can be achieved continuously via capacity-building measures for actors in industrial symbiosis networks and wider EIP development networks, it can accumulate into second-order learning, which facilitates the viability of an EIP experiment and also the emergence of expectations and visions for EIP development at wider geographies. Network characteristics like diversity, connectedness and size also have an influence on learning activities. Moreover, cross-fertilisation across EIP experiments from different places is crucial so the experiments can learn from each other.

Research implications

We arrive at following research implications related to learning activities:

Research implication 5: Learning activities, processes or mechanisms have received little attention in the EIP literature. The existing analytical levels, or processes related to learning for analysis and development of sustainability niche experiments from other research streams such as ST can be used and adapted to EIP development.

Research implication 6: Transfer of learning from one experiment to other places is considered important for EIP development. However, it has received scant attention in the existing EIP literature and requires further investigation.

5.4. Local EIP experiments, global EIP niche formation and transitions

EIP development as a sustainability strategy has organisational characteristics and requirements that are close to the characteristics and requirements of the existing mainstream industrial development but also promises substantial changes in the management and operational logics of IPs and industries located in and around IPs in the long-term. Various EIP experiments at different geographies have shown that an operating EIP can be the result of evolution over decades (Mathews and Tan, 2011). Although EIP development does not require a radical divergence from the development patterns of IPs, EIP experiments from the literature revealed that it could not have gained its internal momentum rapidly and easily and at various geographies. Instead, it stayed at local isolated experiments level, like most of the strategic niche experiments (Schot and Geels, 2008), and often did not lead to niche formation and obviously could not replace the IP development trend and lead to a transition.

Although SNM as a policy tool suggests that niches are assumed to emerge through collective actions by bottom-up approaches (Schot and Geels, 2008), the review of EIP experiments from the literature, building on SNM as an ex-post analytical tool, has demonstrated that the most promising EIP niche development is observed at geographies where top-down planning mechanisms were more prevalent, such as China, South Korea and the US. However, even when the top-down planning runs as the main trigger for EIP development, the necessary role of facilitating, enabling, coordinating the networks for EIP development (Chertow and Ehrenfeld, 2012) indicates the analytical and practical importance of combination of top-down and bottom-up mechanisms.

In China, since the Ministry of Environmental Protection (MEP) initiated EIP projects in 2001, a total of 108 projects – mostly brownfield but also a few greenfield proposals – have been approved and 31 of those have met the criteria and become EIPs (Liu et al., 2017); meanwhile, the MEP has been collaborating with other governmental agencies like the Ministry of Commerce (MOC), the Ministry of Finance (MOF), the National Development and Reform Commission (NDRC) and the Ministry of Science and Technology (MOST). This governmental-level collaboration, having positive expectations about EIP development in China, has provided spaces for experimentation (Shi and Yu, 2014) and triggered various IPs to apply to be an EIP, as well as greenfield EIP projects through well-established two programmes, NDEIP and NPCEZ, that have practical quantitative evaluation indicators. However, having two national-level programmes, one focusing on EIP development with a more ecological perspective, and the other focusing on circular economy for IPs with a more economic perspective, has created a blurred understanding about what an EIP is and how to become one (Zhang et al., 2010).

The present article included 26 EIP Chinese experiments. Chinese experience shows that brownfield experiments have been more popular (Bai et al., 2014) and successful (Shi et al., 2012) than greenfield experiments. Although many EIPs in China still struggle with challenges related to technologies, management and regulations, at the national level, we would argue that China provides the most nurturing environment for EIP niche formation considering the number of experiments, which is the highest globally (see Fig. 6), ongoing protection policies of the Chinese Government and a rich set of different sectors involved in projects (Fang et al., 2007), including mining, metallurgy, electric power, chemicals and petro-chemicals, construction materials, general mechanics, electronics, transportation, airplane manufacture, textiles, paper, beer, alcohol and pharmaceuticals. However, compared to other international EIPs, Chinese EIPs are observed to be more dependent on the Central Government for design, management, and financial support (Ghisellini et al., 2016). This may be problematic if and when the government decided to withdraw the niche protection as suggested by the SNM literature (Caniëls and Romijn, 2008; Kemp et al., 1998) as strong on-going protection can restrict autonomous, bottom-up learning processes (Weber et al., 1999). To date, Chinese government have provided continuous support for EIP development since 2001 when the first EIP projects were started (Jiao and Boons, 2017). This support could be strengthened by adding more financial support and enforcing the supervisory task of coordinating agencies for approved EIPs (Zhang et al., 2010). Moreover, a learning system with a common platform for information sharing and communication would promote experiences from benchmark EIPs (Zhu et al., 2015), such as *Tianjin*, *Guigang Group* and *Dalian*, and strengthen the niche formation process in China.

EIP development in other Asian countries (n = 13) also followed EIP development in a similar vision as in China. The top-down approach is observed to be prevalent in Japan through the Eco-town Programme (Pilouk and Koottatep, 2017), South Korea through the National Plan for EIP Development (Park et al., 2016), Taiwan through the Green Economy Program (Li et al., 2015), Thailand through the Development of Eco-Industrial Estates and Networks Projects and Community-Based Eco-Industrial Estate Framework (Panyathanakun et al., 2013), and also in India (Ashton and Bain, 2012; Bellantuono et al., 2017), although a national level programme has not been observed in the Indian cases.

Synthesis of the 18 EIP experiments from the US involved in this review have revealed that EIP development has not been particularly fruitful. These projects were outcomes of a strong top-down push in 1996 from the President's Council for Sustainable Development through a task force for creating various greenfield EIP projects. However, experiments remained at the level of local projects and even they could not sustain themselves for years and industrial actors

generally remained passive throughout the project lifetimes (Heeres et al., 2004). The reason for this was claimed to be the central planning, with attempts to even predetermine IP tenants, which did not end in organic systems (Chertow and Ehrenfeld, 2012). However, more fruitful EIP experiments from Puerto Rico (n = 2), integrating top-down strategies into bottom-up initiatives (Chertow et al., 2008; Chertow, 2007), demonstrated evolving notable industrial symbiosis exchanges over time.

Compared to other continents, Europe has the longest list of EIP cases (n = 35), which indicates on-going momentum for continuous development of EIPs. Inspiring experiments can be observed in Europe (examples include *Kalundborg*, *Ecopark Hartberg*, *Styria*, *Rantasalmi*, *ValuePark Schkopau*, *Chamusca*, *Landskrona*, *Industrial Eco-System Project*, *Rietvelden/Vutter Sustainable Revitilisation*, *Moerdjik, Biopark Terneuzen*, *Komsomlske* and *Cherkassey*). Still it is difficult to identify a promising EIP niche building in any European country; instead, EIP experiments have remained isolated events without bridges in between. Even *Kalundborg*, which is considered to be the benchmark EIP example, did not repeat, even in Denmark, and there have been no other Danish cases. Similar EIP experiments in Denmark may have led to the niche formation, but *Kalundborg* remained a unique local experiment in the country. Considering this, local government organisations have recently launched new projects to extend industrial symbiosis mind-set to other locations of municipal oversight (Valentine, 2016). Expanding this approach of Danish local government, a learning system at the European level that could facilitate cross-fertilisation between these distributed experiments by disseminating information and building wider EIP development networks may support EIP niche building at both the specific country level and the continent level.

At another geography, the few EIP experiments (n = 3) from South America (Bellantuono et al., 2017) also remained as isolated experiments and did not succeed in changing the strategies of mainstream actors involved in IP development, although they did receive governmental support through a top-down approach. This situation may be claimed to be similar in Australia, considering the low number of EIP experiments (n = 3) identified in the literature. However, the *Kwinana* experiment, which followed a combination of top-down and bottom-up approaches, has been one of the most studied EIPs due to its successful reputation on how it has been evolved into an EIP even though industrial symbiosis was not planned or foreseen when *Kwinana* was originally established as a greenfield site (MacLachlan, 2013). In this respect, *Kwinana* has been influential for other EIP experiments at different locations.

Policy implications

Based on the information gathered from EIP experiments in this synthesis, we observed that the general trend of EIP development appears to remain at the stage of local projects and is not connected to a broader strategy to develop EIP niches in most of the countries. Still, it can be claimed that the countries that developed national-level protection programmes for the transition of IPs at the country level into EIPs have made a greater contribution to global niche building. Drawing on the SNM perspective, we suggest that isolated EIP experiments can be further developed into niches by interconnecting similar experiments or expanding them beyond the local level by means of effective policy mechanisms whereby common visions can be formulated through network management by enabling learning and exchanging lessons learnt from different experiments.

Research implications

Finally, we arrive at the following research implications related to global EIP niche building and transitions into EIP development:

Research implication 7: Although various case studies related to EIP development have been conducted, concepts such as niche experiments or global niche building have not been examined in EIP literature. Theoretical frameworks for examining various single EIP experiments for sustainability transitions of IP development are missing in the literature.

Research implication 8: So far, the ST stream and EIP development literatures have not been often studied together. However, it would be fruitful for EIP development research to bring in insights from different theoretical frameworks in ST literature while learning from other sustainability practices that have been the objects of ST studies.

6. Conclusion

Certainly, EIPs are sustainable practices and transitions into EIP development are not easy to realise. Existing actors in industrial production systems have a tendency to resist fundamental changes in their operational and production routines, and this brings lock-ins in the existing systems. For this reason, IP development still is very popular despite its problematique related to environmental sustainability concerns. Transforming existing IPs into EIPs or developing new EIPs instead of IPs are not often the options that the related actors choose. Therein lies the crux of the matter: How can EIP development become mainstream and how can such a transition from IP development into EIP development be achieved?

While there is no one specific answer to these complex questions, we argue that there is a lot to learn from the rich EIP case studies available in the literature and we can contribute to the EIP literature using different perspectives. In this vein, our objective in this article was twofold: (i) to understand and shed some light on how transitions into EIP development can be achieved through lessons from the EIP cases that have been studied in the existing state of the art; and (ii) to establish a research agenda that would elaborate on transitions into EIP development with the aim of bringing a sustainability transitions perspective to the EIP literature. To accomplish these aims, we systematically analysed the EIP literature and synthesised the identified 104 EIP cases from 24 countries.

To conceptually guide the literature synthesis, we developed a theoretical framework following certain theoretical standpoints from the ST and EIP literatures. From the ST field, we mainly built on the SNM framework with a particular focus on its three interlinked niche processes (Schot and Geels, 2008; Smith and Raven, 2012; Kemp et al., 1998), while considering the differentiation between local and global niche levels (Geels and Raven, 2006). We integrated the SNM framework into the EIP literature with an evolutionary perspective for conceptual elaboration of the sustainability transitions to EIP development. In doing so, we connected the EIP literature and ST field, which have not been nurtured from each other very often.

Drawing on the developed theoretical framework for understanding and re-interpretation of the identified EIP cases, we completed the literature synthesis considering four conceptual building blocks: articulation of expectations and visions; building of social networks; learning activities; and local EIP experiments, global EIP formation and transitions. Based on our learning from the existing state of the art with regard to these conceptual blocks, we arrived at some policy implications regarding how to achieve sustainability transitions into EIP development (see Table 1). We recognise that there are no universally correct policy implications and that each geographical context needs to consider the local constraints before implementing any policy implication. Therefore, we have carefully derived these implications so that they can offer enough flexibility to

Table 1
Policy implications and research agenda with potential avenues for future research.

Policy implications	Research agenda
Articulation of expectations and visions: Top-down planning with a stronger focus on brownfield EIP experiments can provide promising conditions for governments to build specific expectations with specific motivations. Then, bringing in facilitation mechanisms that engage industries, research centres and citizens may lead to the convergence of motivations and shared expectations of wide variety of actors. Thus, an effective combination of a top-down and bottom-up approach stressing more brownfield projects through providing support and protection mechanisms would be more suitable considering the long-term vision required for transitions from IP development into EIP development.	***Research implication 1*:** Evolving expectations and visions for EIP development covering a wide variety of related actors and their motivations requires an explicit focus of the EIP literature. ***Research implication 2:*** A broader vision for transitions of IP development into EIP development in comparison to vision for transitions into particular EIPs has not been explicitly examined in the EIP literature.
Social network building: The network perspective in EIP development should be widened, aiming at a combination of industries, which form the industrial symbiosis network, and external actors such as government bodies, research institutes, universities, informal institutes like industrial associations and NGOs. A perspective on such a wider EIP development network would be broad and deep enough to reflect multiple views. Moreover, networking building can be more efficient if it is guided by a coordinating body that ensures all actors communicate effectively, and also if it is supported by local champions that facilitate interaction and trust development among network actors. Clearly, vision for EIP development constructed through top-down and/or bottom-up approaches should impact the variety in actor structure, their interactions, or existence of coordinating body or local champions.	***Research implication 3*:** Structures of broader networks for EIP development, which involves not only industrial actors in symbiosis networks but also external institutions such as governmental bodies, university and research institutes, NGOs, industrial associations, local community, etc., and the interaction among them remain underexplored in EIP literature. ***Research implication 4*:** The EIP literature lacks an understanding of the correlation between the EIP development visions, tailored by top-down, bottom-up, and mixed approaches, and network building characteristics, related to involved actors and their interactions.
Learning activities: Learning activities and processes require an explicit focus in EIP development as they sustain the impact of EIP experiments during their evolution over time. If first-order learning can be achieved continuously via capacity-building measures for actors in industrial symbiosis networks and wider EIP development networks, it can accumulate into second-order learning, which facilitates the viability of an EIP experiment and also the emergence of expectations and visions for EIP development at wider geographies. Network characteristics like diversity, connectedness and size also have an influence on learning activities. Moreover, cross-fertilisation across EIP experiments from different places is crucial so the experiments can learn from each other.	***Research implication 5:*** Learning activities, processes or mechanisms have received little attention in the EIP literature. The existing analytical levels, or processes related to learning for analysis and development of sustainability niche experiments from other research streams such as ST can be used and adapted to EIP development. ***Research implication 6***: Transfer of learning from one experiment to other places is considered important for EIP development. However, it has received scant attention in the existing EIP literature and requires further investigation.
Local EIP experiments, global EIP formation and transitions: Isolated EIP experiments can be further developed into niches by interconnecting similar experiments or expanding them beyond the local level by means of effective policy mechanisms whereby common visions can be formulated through network management by enabling learning and exchanging lessons learnt from different experiments.	***Research implication 7:*** Although various case studies related to EIP development have been conducted, concepts such as niche experiments or global niche building have not been examined in EIP literature. Theoretical frameworks for examining various single EIP experiments for sustainability transitions of IP development are missing in the literature. ***Research implication 8***: So far, the ST stream and EIP development literatures have not been often studied together. However, it would be fruitful for EIP development research to bring in insights from different theoretical frameworks in ST literature while learning from other sustainability practices that have been the objects of ST studies.

be tailored and further detailed considering the geographical space and scale on which they can be followed. Moreover, deriving policy implications in this article should be seen as an attempt to provide a global perspective on EIP development for connecting various geographies through network building activities so that they can learn from each other to articulate the expectations and visions guiding a common agenda for sustainability transitions of IP development.

We argue that the theoretical framework and the synthesis presented in this article are crucial steps towards examining EIP development from the perspective of sustainability transitions. In line with this, we derived some research implications for guiding the future research related to EIP development in that respect (see Table 1).

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Appendix A

*LA = Literature analysis; LS = Literature synthesis; Articles included in literature synthesis are at grey shaded rows.

LA Nr	Author	Name	Journal	Studied geography	LS Nr
1	(Ribeiro, et al., 2018)	An integrated approach towards transforming an industrial park into an eco-industrial park: the case of Salaise-Sablons	Journal of Environmental Planning and Management	France	
2	(Taddeo, et al., 2017)	The Development of Industrial Symbiosis in Existing Contexts. Experiences from Three Italian Clusters	Ecological Economics	Italy	
3	(Fraccascia, et al., 2017)	Rethinking Resilience in Industrial Symbiosis: Conceptualization and Measurements	Ecological Economics	China Denmark	
4	(Liu, et al., 2017)	Comprehensive development of industrial symbiosis for the response of greenhouse gases emission mitigation: Challenges and opportunities in China	Energy Policy	China	1
5	(Chen, et al., 2017)	Clustering enterprises into eco-industrial parks: Can interfirm alliances help small and medium-sized enterprises?	Journal of Cleaner Production	China	
6	(Bellantuono, et al., 2017)	The organization of eco-industrial parks and their sustainable practices	Journal of Cleaner Production	Austria, Denmark, Finland, France, Germany, UK, Italy, Spain, Sweden, Canada, USA, Argentina, Brazil, China, Japan, India, Australia	2
7	(Li, et al., 2017)	The vulnerability of industrial symbiosis: A case study of Qijiang Industrial Park, China	Journal of Cleaner Production	China	
8	(Pilouk & Koottatep, 2017)	Environmental performance indicators as the key for eco-industrial parks in Thailand	Journal of Cleaner Production	Thailand	3
9	(Hwang, et al., 2017a)	Green business park project management: Barriers and solutions for sustainable development	Journal of Cleaner Production	Singapore	
10	(Ceglia, et al., 2017)	Critical elements for eco-retrofitting a conventional industrial park: Social barriers to be overcome	Journal of Environmental Management	Brazil	
11	(Boons, et al., 2017)	Industrial Symbiosis Dynamics and the Problem of Equivalence	Journal of Industrial Ecology	not specified	
12	(Hwang, et al., 2017b)	Identifying Critical Success Factors for Green Business Parks: Case Study of Singapore	Journal of Management in Engineering	Singapore	
13	(Jiao & Boons, 2017)	Policy durability of Circular Economy in China: A process analysis of policy translation	Resources Conservation and Recycling	China	
14	(Liu & Côté, 2017)	A Framework for Integrating Ecosystem Services into China's Circular Economy: The Case of Eco-Industrial Parks	Sustainability	China	4
15	(Ashton, et al., 2017)	Life and Death of Industrial Ecosystems	Sustainability	Denmark, Australia, Austria, USA	5
16	(Sun, et al., 2017)	Coordination of Industrial Symbiosis through Anchoring	Sustainability	China	6
17	(Veleva, et al., 2016)	Benchmarking eco-industrial park development: the case of Devens	Benchmarking – An International Journal	USA	7
18	(Vahidi, et al., 2016)	Challenges and Opportunities of Industrial Ecology Development in Iran	International Journal of Environmental Research	Iran	
19	(Horváth & Harazin, 2016)	A framework for an industrial ecological decision support system to foster partnerships between businesses and governments for sustainable development	Journal of Cleaner Production	not specified	
20	(Park, et al., 2016)	A review of the National Eco-Industrial Park Development Program in Korea: Progress and achievements in the first phase, 2005-2010	Journal of Cleaner Production	South Korea	8
21	(Ghisellini, et al., 2016)	A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems	Journal of Cleaner Production	Canada, USA, EU, Brazil, Argentina, Egypt, South Africa, India, China, Australia, South Korea, Japan, New Zealand	9
22	(Hwang, et al., 2016)	Causal relationship of eco-industrial park development factors: a structural equation analysis	Journal of Cleaner Production	South Korea	
23	(Guo, et al., 2016)	Evaluation of promoting industrial symbiosis in a chemical industrial park: A case of Midong	Journal of Cleaner Production	China	10

24	(Notarnicola, et al., 2016)	Industrial symbiosis in the Taranto industrial district: current level, constraints and potential new synergies	Journal of Cleaner Production	Italy	
25	(Felicio, et al., 2016)	Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems	Journal of Cleaner Production	not specified	
26	(Valentine, 2016)	Kalundborg Symbiosis: fostering progressive innovation in environmental networks	Journal of Cleaner Production	Denmark	11
27	(Taddeo, 2016)	Local industrial systems towards the eco-industrial parks: the model of the ecologically equipped industrial areas	Journal of Cleaner Production	Italy	
28	(Geng, et al., 2016)	Recent progress on innovative eco-industrial development	Journal of Cleaner Production	not specified	
29	(Branson, 2016)	Re-constructing Kalundborg: the reality of bilateral symbiosis and other insights	Journal of Cleaner Production	Denmark	12
30	(Daddi, et al., 2016)	Regional policies and eco-industrial development: the voluntary environmental certification scheme of the eco-industrial parks in Tuscany (Italy)	Journal of Cleaner Production	Italy	13
31	(Côté & Liu, 2016)	Strategies for reducing greenhouse gas emissions at an industrial park level: a case study of Debert Air Industrial Park, Nova Scotia	Journal of Cleaner Production	Canada	14
32	(Dong, et al., 2016)	Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China	Journal of Cleaner Production	China	
33	(Layton, et al., 2016)	Industrial Ecosystems and Food Webs: An Expansion and Update of Existing Data for Eco-Industrial Parks and Understanding the Ecological Food Webs They Wish to Mimic	Journal of Industrial Ecology	Denmark	
34	(Velenturf & Jensen, 2016)	Promoting Industrial Symbiosis: Using the Concept of Proximity to Explore Social Network Development	Journal of Industrial Ecology	not specified	
35	(Farel, et al., 2016)	Sustainable Manufacturing Through Creation and Governance of Eco-Industrial Parks	Journal of Manufacturing Science and Engineering-Transactions of the ASME	Denmark, South Korea, Australia, Switzerland, France, USA, Japan, The Netherlands, China, Finland, Germany, Sweden, Austria	15
36	(Yune, et al., 2016)	Greening Chinese chemical industrial park by implementing industrial ecology strategies: A case study	Resources Conservation and Recycling	China	16
37	(LeBlanc, et al., 2016)	Potential for Eco-Industrial Park Development in Moncton, New Brunswick (Canada): A Comparative Analysis	Sustainability	Canada	
38	(Yu, et al., 2015c)	Evolution of industrial symbiosis in an eco-industrial park in China	Journal of Cleaner Production	China	17
39	(Yu, et al., 2015b)	From an eco-industrial park towards an eco-city: a case study in Suzhou, China	Journal of Cleaner Production	China	18
40	(Liu, et al., 2015)	Implementing a three-level approach in industrial symbiosis	Journal of Cleaner Production	China	19
41	(Puente, et al., 2015)	Industrial symbiosis opportunities for small and medium sized enterprises: preliminary study in the Besaya region (Cantabria, Northern Spain)	Journal of Cleaner Production	Spain	
42	(Qu, et al., 2015)	Sustainable development of eco-industrial parks in China: effects of managers' environmental awareness on the relationships between practice and performance	Journal of Cleaner Production	China	
43	(Mannino, et al., 2015)	The decline of eco-industrial development in Porto Marghera, Italy	Journal of Cleaner Production	Italy	20
44	(Veleva, et al., 2015)	Understanding and addressing business needs and sustainability challenges: lessons from Devens eco-industrial park	Journal of Cleaner Production	USA	21
45	(Li, et al., 2015)	Building green supply chains in eco-industrial parks towards a green economy: Barriers and strategies	Journal of Environmental Management	China	22
46	(Patnaik & Poyyamoli, 2015)	Developing an eco-industrial park in Puducherry region, India - a SWOT analysis	Journal of Environmental Planning and Management	India	
47	(Zhu, et al., 2015)	Barriers to Promoting Eco-Industrial Parks Development in China: Perspectives from Senior Officials at National Industrial Parks	Journal of Industrial Ecology	China	23
48	(Yu, et al., 2015a)	What Makes Eco-Transformation of Industrial Parks Take Off in China?	Journal of Industrial Ecology	China	24
49	(Tessitore, et al., 2015)	Eco-Industrial Parks Development and Integrated Management Challenges: Findings from Italy	Sustainability	Italy	25

50	(Iacondini, et al., 2015)	Feasibility of Industrial Symbiosis in Italy as an Opportunity for Economic Development: Critical Success Factor Analysis, Impact and Constrains of the Specific Italian Regulations	Waste and Biomass Valorization	Italy	
51	(Madsen, et al., 2015)	Industrial Symbiosis Exchanges: Developing a Guideline to Companies	Waste and Biomass Valorization	not specified	
52	(Schiller, et al., 2014)	Analyzing networks in industrial ecology - A review of Social-Material Network Analyses	Journal of Cleaner Production	not specified	
53	(Bai, et al., 2014)	Insights on the development progress of National Demonstration eco-industrial parks in China	Journal of Cleaner Production	China	26
54	(Yu, et al., 2014b)	Process analysis of eco-industrial park development - the case of Tianjin, China	Journal of Cleaner Production	China	27
55	(Jiao & Boons, 2014)	Toward a research agenda for policy intervention and facilitation to enhance industrial symbiosis based on a comprehensive literature review	Journal of Cleaner Production	China	28
56	(Patala, et al., 2014)	Towards a broader perspective on the forms of eco-industrial networks	Journal of Cleaner Production	not specified	
57	(Shi & Yu, 2014)	Eco-Industrial Parks from Strategic Niches to Development Mainstream: The Cases of China	Sustainability	China	29
58	(MacLachlan, 2013)	Kwinana Industrial Area: agglomeration economies and industrial symbiosis on Western Australia's Cockburn Sound	Australian Geographer	Australia	30
59	(Zhang, et al., 2013)	Social network analysis and network connectedness analysis for industrial symbiotic systems: model development and case study	Frontiers of Earth Science	Denmark, USA, Japan, Austria, China	31
60	(Panyathanakun, et al., 2013)	Development of eco-industrial estates in Thailand: initiatives in the northern region community-based eco-industrial estate	Journal of Cleaner Production	Thailand	32
61	(Spekkink, 2013)	Institutional capacity building for industrial symbiosis in the Canal Zone of Zeeland in the Netherlands: a process analysis	Journal of Cleaner Production	The Netherlands	
62	(Romero & Ruiz, 2013)	Framework for Applying a Complex Adaptive System Approach to Model the Operation of Eco-Industrial Parks	Journal of Industrial Ecology	Norway, USA, China, Austria, Canada, Australia	
63	(Conticelli & Tondelli, 2013)	Application of Strategic Environmental Assessment to Eco-Industrial Parks: Raibano Case in Italy	Journal of Urban Planning and Development	Italy	
64	(Gregson, et al., 2012)	Territorial Agglomeration and Industrial Symbiosis: Sitakunda-Bhatiary, Bangladesh, as a Secondary Processing Complex	Economic Geography	Bangladesh	
65	(Behera, et al., 2012)	Evolution of 'designed' industrial symbiosis networks in the Ulsan Eco-industrial Park: 'research and development into business' as the enabling framework	Journal of Cleaner Production	South Korea	33
66	(Taddeo, et al., 2012)	Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site	Journal of Cleaner Production	Italy	
67	(Ashton & Bain, 2012)	Assessing the "Short Mental Distance" in Eco-Industrial Networks	Journal of Industrial Ecology	India	34
68	(Shi, et al., 2012)	China's Quest for Eco-industrial Parks, Part II Reflections on a Decade of Exploration	Journal of Industrial Ecology	China	35
69	(Boons & Spekkink, 2012)	Levels of Institutional Capacity and Actor Expectations about Industrial Symbiosis	Journal of Industrial Ecology	The Netherlands	
70	(Chertow & Ehrenfeld, 2012)	Organizing Self-Organizing Systems	Journal of Industrial Ecology	Denmark, USA, China, South Korea, Australia, Austria, The Netherlands, UK	36
71	(Wells & Zapata, 2012)	Renewable Eco-industrial Development A New Frontier for Industrial Ecology	Journal of Industrial Ecology	not specified	
72	(Sakr, et al., 2011)	Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context	Journal of Cleaner Production	Egypt	
73	(Giurco, et al., 2011)	Developing industrial water reuse synergies in Port Melbourne: cost effectiveness, barriers and opportunities	Journal of Cleaner Production	Australia	37

74	(Zamorano, et al., 2011)	Diagnosis and proposals for waste management in industrial areas in the service sector: case study in the metropolitan area of Granada (Spain)	Journal of Cleaner Production	Spain	
75	(Lehtoranta, et al., 2011)	Industrial symbiosis and the policy instruments of sustainable consumption and production	Journal of Cleaner Production	Finland	
76	(Boons, et al., 2011)	The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review	Journal of Cleaner Production	China, UK, Australia, Japan, USA, Ukraine	
77	(Mathews & Tan, 2011)	Progress Toward a Circular Economy in China The Drivers (and Inhibitors) of Eco-industrial Initiative	Journal of Industrial Ecology	China	38
78	(Wang, et al., 2010)	Pursuing sustainable industrial development through the eco-industrial parks Three case studies of China	Annals of the New York Academy of Sciences	China	39
79	(Yuan, et al., 2010)	Improving Competitive Advantage with Environmental Infrastructure Sharing: A Case Study of China-Singapore Suzhou Industrial Park	International Journal of Environmental Research	China	40
80	(Desrochers & Leppala, 2010)	Industrial Symbiosis: Old Wine in Recycled Bottles? Some Perspective from the History of Economic and Geographical Thought	International Regional Science Review	not specified	
81	(Costa & Ferrao, 2010)	A case study of industrial symbiosis development using a middle-out approach	Journal of Cleaner Production	Portugal	41
82	(Shi, et al., 2010)	Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China	Journal of Cleaner Production	China	42
83	(Zhang, et al., 2010)	Eco-industrial parks: national pilot practices in China	Journal of Cleaner Production	China	43
84	(Elabras Veiga & Magrini, 2009)	Eco-industrial park development in Rio de Janeiro, Brazil: a tool for sustainable development	Journal of Cleaner Production	Brazil	
85	(Adamides & Mouzakitis, 2009)	Industrial ecosystems as technological niches	Journal of Cleaner Production	Denmark, Germany, Sweden	44
86	(Liwarska-Bizukojc, et al., 2009)	The conceptual model of an eco-industrial park based upon ecological relationships	Journal of Cleaner Production	Austria	45
87	(Geng, et al., 2009)	Assessment of the National Eco-Industrial Park Standard for Promoting Industrial Symbiosis in China	Journal of Industrial Ecology	China	46
88	(Wright, et al., 2009)	Diversity and Connectance in an Industrial Context The Case of Burnside Industrial Park	Journal of Industrial Ecology	Canada	47
89	(Zhang, et al., 2009)	Comparative analysis of socio-economic and environmental performances for Chinese EIPs: case studies in Baotou, Suzhou, and Shanghai	Sustainability Science	China	48
90	(Geng, et al., 2008)	Evaluating the applicability of the Chinese eco-industrial park standard in two industrial zones	International Journal of Sustainable Development and World Ecology	China	49
91	(Park, et al., 2008)	Strategies for sustainable development of industrial park in Ulsan, South Korea - From spontaneous evolution to systematic expansion of industrial symbiosis	Journal of Environmental Management	South Korea	50
92	(McManus & Gibbs, 2008)	Industrial ecosystems? The use of tropes in the literature of industrial ecology and eco-industrial parks	Progress in Human Geography	not specified	
93	(Deutz & Gibbs, 2008)	Industrial Ecology and Regional Development: Eco-Industrial Development as Cluster Policy	Regional Studies	USA	51
94	(Chertow, et al., 2008)	Industrial Symbiosis in Puerto Rico: Environmentally Related Agglomeration Economies	Regional Studies	Puerto Rico	52
95	(Hewes & Lyons, 2008)	The Humanistic Side of Eco-Industrial Parks: Champions and the Role of Trust	Regional Studies	Ukraine, USA	53
96	(Gibbs & Deutz, 2007)	Reflections on implementing industrial ecology through eco-industrial park development	Journal of Cleaner Production	USA, UK, Italy, Finland, France, Germany, Austria, The Netherlands, Sweden, Denmark	54
97	(Fang, et al., 2007)	Industrial sustainability in China: Practice and prospects for eco-industrial development	Journal of Environmental Management	China	55

98	(Chertow, 2007)	Uncovering industrial symbiosis	Journal of Industrial Ecology	USA, Canada	56
99	(Kim, 2007)	Building an eco-industrial park as a public project in South Korea. The stakeholders' understanding of and involvement in the project	Sustainable Development	South Korea	57
100	(Geng, et al., 2007)	Empirical analysis of eco-industrial development in China	Sustainable Development	China	58
101	(Haskins, 2007)	A systems engineering framework for eco-industrial park formation	Systems Engineering	not specified	
102	(Gibbs & Deutz, 2005)	Implementing industrial ecology? Planning for eco-industrial parks in the USA	Geoforum	USA	59
103	(Oh, et al., 2005)	Eco-Industrial Park Design: a Daedeok Technovalley case study	Habitat International	South Korea	60
104	(Gibbs, et al., 2005)	Industrial ecology and eco-industrial development: A potential paradigm for local and regional development?	Regional Studies	USA, UK, Italy, Finland, France, Germany, Austria, Denmark, Sweden, Germany	61
105	(Yang & Lay, 2004)	Applying ecosystem concepts to the planning of industrial areas: a case study of Singapore's Jurong Island	Journal of Cleaner Production	Singapore	
106	(Heeres, et al., 2004)	Eco-industrial park initiatives in the USA and the Netherlands: first lessons	Journal of Cleaner Production	The Netherlands	62
107	(Zhu & Côté, 2004)	Integrating green supply chain management into an embryonic eco-industrial development: a case study of the Guitang Group	Journal of Cleaner Production	China	63
108	(Roberts, 2004)	The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study	Journal of Cleaner Production	Australia	64
109	(Geng & Côté, 2002)	Scavengers and decomposers in an eco-industrial park	International Journal of Sustainable Development and World Ecology	Canada	65
110	(Singhal & Kapur, 2002)	Industrial estate planning and management in India - an integrated approach towards industrial ecology	Journal of Environmental Management	India	
111	(Lambert & Boons, 2002)	Eco-industrial parks: stimulating sustainable development in mixed industrial parks	Technovation	Canada, The Netherlands, USA	66
112	(Korhonen, 2001)	Regional industrial ecology: examples from regional economic systems of forest industry and energy supply in Finland	Journal of Environmental Management	Finland	
113	(Martin, et al., 1998)	Applying industrial ecology to industrial parks: An economic and environmental analysis	Economic Development Quarterly	USA Mexico	
114	(Carr, 1998)	Choctaw Eco-Industrial Park: an ecological approach to industrial land-use planning and design	Landscape and Urban Planning	USA	
115	(Chertow, 1998)	Waste, industrial ecology, and sustainability	Social Research	Denmark	

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Appendix B

*Countries of EIP cases are given next to EIP names in form of abbreviations as stated by International Organization for Standardization.

Nr	Name of the case and references	Nr	Name of the case and references
1	Burnside EIP (CA) (Bellantuono, et al., 2017; Lambert and Boons, 2002; Geng and Côté, 2002; Wright et al., 2009; Chertow, 2007)	53	Moerdjik EIP Project (NL) (Heeres et al., 2004; Farel et al., 2016)
2	Alberto (CA) (Chertow, 2007)	54	Biopark Terneuzen (NL) (Farel, et al., 2016)
3	Debert Air Industrial Park (CA) (Côté and Liu, 2016)	55	Komsomlske (UA) (Hewes and Lyons, 2008)
4	Innovista (CA) (Bellantuono, et al., 2017)	56	Cherkassey (UA) (Hewes and Lyons, 2008)
5	Fairfield, Baltimore (USA) (Chertow, 2007; Heeres et al., 2004)	57	European Sites ABLE Project (UK) (Gibbs and Deutz, 2007)
6	Brownsville Regional Industrial Symbiosis Project (USA) (Bellantuono et al., 2017; Chertow, 2007; Heeres et al., 2004)	58	AvestaPolarit (UK) (Gibbs and Deutz, 2007)
7	Cape Charles Sustainable Technologies Industrial Park (USA) (Bellantuono et al., 2017; Gibbs and Deutz, 2005; Chertow, 2007; Heeres et al., 2004; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)	59	Eco Dyfi (UK) (Gibbs and Deutz, 2007)

8 Central Gulf Coast Project (USA) (Gibbs and Deutz, 2005; Farel, et al., 2016; Gibbs and Deutz, 2007)
9 Riverside EIP, Burlington, Vermont (USA) (Chertow, 2007)
10 Green Institute EIP, Minneapolis, Minnesota (USA) (Chertow, 2007)
11 Stonyfield Londonderry EIP, Londonderry, New Hampshire (USA) (Gibbs and Deutz, 2005; Chertow, 2007; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
12 Red Hills Ecoplex, Mississipi (USA) (Gibbs and Deutz, 2005; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
13 Ecolibrium, Computer and lectronic Disposition, Austin, Texas (USA) (Gibbs and Deutz, 2005; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
14 Front Royal, Eco-Office Park, Virginia (USA) (Gibbs and Deutz, 2005; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
15 Dallas EIP, Texas (USA) (Gibbs and Deutz, 2005; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
16 Triangle J, North Carolina (USA) (Chertow, 2007)
17 Phillips Eco Enterprise Center, Minnesota (USA) (Gibbs and Deutz, 2005; Deutz and Gibbs, 2008; Gibbs and Deutz, 2007)
18 Bassett Creek, Minnesota (USA) (Gibbs and Deutz, 2005; Gibbs, 2008; Deutz, 2007)
19 Devens (USA) (Bellantuono et al., 2017; Veleva et al., 2015; Veleva et al., 2016; Deutz, 2005; Lyons, 2008; Gibbs, 2008; Deutz, 2007)
20 Campbell Industrial Park, Hawaii (USA) (Ehrenfeld, 2012)
21 Jacksonville, Florida (USA) (Ehrenfeld, 2012)
22 Choctaw, Oklahoma (USA) (Zhang et al., 2013)
23 Puerto Rico – Guayama (PR) (Ehrenfeld, 2012; Chertow, 2007; Farel et al., 2016; Chertow et al., 2008)
24 Puerto Rico – Barceloneta (PR) (Chertow, 2007; Chertow et al., 2008; Ashton et al., 2017)
25 La Cantabrica (AR) (Bellantuono et al., 2017)
26 Paracambi (AR) (Bellantuono, et al., 2017)
27 Santa Cruz (AR) (Bellantuono et al., 2017)
28 Ecopark Hartberg (AT) (Bellantuono et al., 2017; Farel et al., 2016; Liwarska-Bizukojc et al., 2009)
29 Styria (AT) (Zhang et al., 2013; Ehrenfeld, 2012; Chertow, 2007; Ashton et al., 2017)
30 Kalundborg Symbiosis (DK) (Bellantuono et al., 2017; Zhang et al., 2013; Boons, 2002; Valentine, 2016; Ehrenfeld, 2012; Branson, 2016; Gibbs et al., 2005; Ashton et al., 2017) (Deutz, 2005; Park et al., 2008; Ferrao, 2010; Chertow, 2007; Farel et al., 2016; Tan, 2011; Mouzakitis, 2009; Zhang et al., 2009; Chertow et al., 2008; Gibbs, 2008)
31 Kymi (FI) (Farel et al., 2016)
32 Rantasalmi (FI) (Bellantuono et al., 2017)
33 Uimaharju (FI) (Bellantuono et al., 2017)
34 Deux Synthe (FR) (Farel et al., 2016)
35 Ecosite du Pays de Thau (FR) (Deutz, 2007)
36 Bioraffinerie Les Sohettes (FR) (Farel et al., 2016)
37 Arbois Mediterranee (FR) (Bellantuono, et al., 2017)
38 Artois-Flandres (FR) (Bellantuono et al., 2017)
39 Plaine de l'Ain (FR) (Bellantuono et al., 2017)
40 ValuePark Schkopau (DE) (Bellantuono et al., 2017; Liwarska-Bizukojc et al., 2009)
60 Ecotech (UK) (Gibbs and Deutz, 2007)
61 Humber Industrial Symbiosis Project (UK) (Gibbs and Deutz, 2007)
62 Crewe Business Park (UK) (Bellantuono et al., 2017)
63 The Guigang Group/ The Guitang Group (CN) (ellantuono et al., 2017; Zhang et al., 2013; hu and Côté, 2004; Chertow and Ehrenfeld, 2012; Chertow, 2007; Mathews and Tan, 2011; Farel et al., 2016; Fang et al., 2007)
64 The Pingdingshan Coal Mining Group (CN) (Mathews and Tan, 2011)
65 The Lubei Group (CN) (Zhang et al., 2013; Fang et al., 2007; Mathews and Tan, 2011)
66 The Suzhou Industrial Park (SIP) (CN) (Yuan et al., 2010; Yu et al., 2015b; Mathews and Tan, 2011; Zhang et al., 2009; Fang et al., 2007)
67 Suzhou Hi-Tech Development Zone (CN) (Fang et al., 2007)
68 Yantai Development Zone (CN) (Fang et al., 2007)
69 Guiyang – Kaiyang (CN) (Fang et al., 2007)
70 Hai-Hua / Weifang Coastal Development Zone / Weifang Binhai Economic-Technological Development Area (BEDA) (CN) (Liu et al., 2015; Fang et al., 2007)
71 Tianjin Economic-Technological Development Area (TEDA) (CN) (Bellantuono et al., 2017; Zhang et al., 2013; Yu et al., 2015a; Yu et al., 2014b; Yu, 2014; Ehrenfeld, 2012; Fang et al., 2007; Geng et al., 2009; Shi et al., 2010; Tan, 2011; Geng et al., 2008; Farel et al., 2016)
72 Fuzhou Economic and Technological Development Area (FEDA) (CN) (Yu, 2014)
73 Xi'an High-Tech Zone (CN) (Yu, 2014)
74 Baotou National Ecological Industrial Demonstration Park (BNEIDP) (CN) (Fang et al., 2007; Zhang et al., 2009)
75 Huangxing (CN) (Zhang et al., 2013; Fang et al., 2007)
76 Shanghai Chemical Industry Park (SCIP) (CN) (Yune et al., 2016; Zhang et al., 2009)
77 Dalian Economic Development Zone (DEDZ) (CN) (Yu et al., 2015a; Fang et al., 2007; Geng et al., 2008)
78 Shenyang Economic and Technological Development Zone (SETDZ)(CN) (Ghisellini et al., 2016)
79 Dafeng EIP Project (CN) (Wang et al., 2010)
80 Nanhai EIP Project (CN) (Fang et al., 2007; Wang et al., 2010)
81 Lubei EIP Project (CN) (Wang et al., 2010)
82 Fushun (CN) (Fang et al., 2007)
83 Midong Chemical Industrial Park (MCIP) (CN) (Guo et al., 2016)
84 Rizhao Economic and Technology Development Area (REDA) (CN) (Yu et al., 2015c)
85 Xinjiang Shihezi EIP (CN) (Zhang et al., 2013)
86 Shanghai Wujing EIP (CN) (Zhang et al., 2013)
87 Qijiang Industrial Symbiosis Park (CN) (Sun et al., 2017)
88 Nanning Sugar Co (CN) (Bellantuono, et al., 2017)
89 EBARA Corporation (JP) (Bellantuono et al., 2017)
90 Kawasaki (JP) (Ehrenfeld, 2012; Tan, 2011; Farel et al., 2016)
91 Kitakyushu (JP) (Zhang et al., 2013)
92 Kokubu (JP) (Bellantuono et al., 2017)

41 Knapsack Chemical Park (DE) (Farel et al., 2016)
42 BASF Verbund (DE) (Farel et al., 2016)
43 Porto Marghera (IT) (Mannino et al., 2015)
44 Torino Enviornmental Park (IT) (Bellantuono et al., 2017)
45 Chamusca (PT) (Ferrao, 2010)
46 Lopez Soriano (ES) (Bellantuono et al., 2017)
47 The Landskrona Industrial Symbiosis (SE) (Park et al., 2008; Mouzakitis, 2009)
48 Norrkoping and Linkoping (SE) (Farel et al., 2016)
49 Vreten Park (SE) (Bellantuono et al., 2017)
50 Monthey (CH) (Farel et al., 2016)
51 Industrial Eco-System Project (NL) (Boons, 2002; Heeres et al., 2004)
52 Rietvelden/Vutter Sustainable Revitilisation Project (NL) (Heeres et al., 2004)
93 The Nanjangud Industrial Area (IN) (Bain, 2012)
94 Naroda (IN) (Bellantuono et al., 2017)
95 Ulsan EIP (KR) (Ehrenfeld, 2012; Park et al., 2008; Farel et al., 2016; Tan, 2011; Behera et al., 2012)
96 Daedok Technovalley Development Project (KR) (Oh et al., 2005)
97 Macheon Industrial Park (KR) (Kim, 2007)
98 Lin-Hai Industrial Park – China Steel Corp. (TW) (Li et al., 2015)
99 Da-Yuan Industrial Park – Cheng Loong Corp. (TW) (Li et al., 2015)
100 Lin-Yuan Industrial Park – Formosa Plastic Corp. (TW) (Li et al., 2015)
101 Northern Region Industrial Estate (TH) (Panyathanakun et al., 2013)
102 Kwinana Industrial Area (KIA) (AU) (Bellantuono et al., 2017; MacLachlan, 2013; Giurco et al., 2011; Ehrenfeld, 2012; Chertow, 2007; Farel et al., 2016; Tan, 2011; Ashton et al., 2017)
103 Gladstone Industrial Area (AU) (Chertow, 2007)
104 Synergy Industrial Park (AU) (Park et al., 2008)

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Article II

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Unfolding eco-industrial parks through niche experimentation: Insights from three Italian cases

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ABSTRACT

This article aims to understand and explain how eco-industrial parks can unfold over the traditional industrial production systems. Differentiating between the domain theory and method theory, we present an analytical framing that draws upon the strategic niche management perspective from the sustainability transitions field as the method theory, and then contribute to the field of industrial ecology, which is the domain theory behind eco-industrial development. With the experimentation concept being central to our conceptualisation, we consider the journey of the industrial production systems to become eco-industrial parks as niche experimentation and eco-industrial parks as niches. Employing a qualitative multiple case study, we analyse the experimentation within three cases from Tuscany and Emilia-Romagna regions of Italy. The results of our analyses indicate that the continuous experimentation of the eco-industrial park practices within a broad actor-network, through learning processes, leads to shared expectations and visions regarding environmental benefits and economic gains of industrial ecology, which enable the eco-industrial parks to unfold. Still, there is no single rigid model that explains the unfolding eco-industrial parks, because the continuously interacting and interdependent niche-building processes assemble the niche experimentation journey, which is also shaped by the spatial context.

1. Introduction

In recent decades, increasing attention has been given to the sustainability problematique of the traditional linear industrial development model decoupled from the sustainability concerns. The call for a new development model that aims to positively impact economic, environmental and social capitals is a main challenge for various sectors of the industry, including, but not limited to, iron and steel (Karakaya et al., 2018), biogas (Raven and Geels, 2010), fashion (Karaosman et al., 2017), food (Smith, 2006), and construction (Ma et al., 2019).

As one of the salient and promising sustainable industrial development approaches, industrial ecology (IE) emphasises the analogy between industry and nature (Ayres, 2004; Korhonen et al., 2001) and proposes a paradigm shift through imitating the natural ecosystems by incorporating innovation into the industrial production processes. The present article focuses on a particular IE implementation model: eco-industrial park (EIP) development (Chertow, 2000). The EIP development has been traditionally studied and practically applied to transform the industrial production systems into cyclical systems – so-called industrial ecosystems (Frosch and Gallapoulus, 1989) – to address the sustainability problematique at local and regional scales (Deutz and Gibbs, 2004).

During the last few decades, the EIP development has been widely addressed in the regional development policies. Although there have been successful EIP cases (see Susur et al., 2019b, for a review on globally-distributed 104 EIP cases), a transition into the EIP development at a wider level has not occurred yet. This may be explained through resistance due to the existing individual-performance-oriented routines within the industrial production systems (Tudor et al., 2007; Ceglia et al., 2017; Li et al., 2015; Romero and Ruiz, 2013). Previously, the IE literature questioned if and how the IE philosophy could bring a real paradigm shift in industrial production routines (Ehrenfeld, 2000; Gibbs, 2009). Narrowing that debate, the present article seeks to understand and

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explain how the EIPs can unfold over the traditional industrial production systems.

Our methodological approach is twofold. Analytically, we use the strategic niche management (SNM) perspective from the sustainability transitions research field (Schot and Geels, 2008; Smith and Raven, 2012) as our method theory (Lukka and Vinnari, 2014), That perspective has been prominent for analysing novel local sustainability projects, the so-called niche experiments, as the seeds for sustainability transitions (Kemp et al., 1998; Borghei and Magnusson, 2018). Refining the SNM perspective for our EIP-focused inquiry, we conceptualise the journey to become an EIP as *niche experimentation* and EIPs as *niches*. We then analyse three niche-building processes (Schot and Geels, 2008): (i) the coupling of expectations and visions, (ii) building of networks, and (iii) learning processes, considering the mediating effect of the spatial context.

Empirically, we follow a qualitative multiple case study methodology. We bring three EIP cases from Italy, an advanced country in terms of the EIP development (Taddeo et al., 2012; Daddi et al., 2016; Taddeo et al., 2017), and focus on the regions of Tuscany and Emilia Romagna. Following semi-structured interviews and the documentation analysis, we provide a multiple case study that goes beyond a data-driven empirical analysis as we strengthen our theorization and power of interpretation by analytically building on the SNM perspective. As an outcome of our empirical analysis guided by our analytical framing, we derive and present a framework that illustrates the unfolding EIPs through the niche experimentation.

A few earlier studies borrowed from or instrumentally used sustainability transitions frameworks for analysing different scale IE implementations (e.g. Adamides and Mouzakitis, 2009; Gibbs, 2009; Rotmans and Loorbach, 2009; Verguts et al., 2016; Susur et al., 2019a). The present study differs from those previous attempts in several ways through our theoretical and methodological contributions.

With regard to theoretical contributions, firstly, we bring the domain theory and method theory differentiation to the IE literature and sustainability transitions field. More specifically, we illustrate the usefulness of the SNM perspective from the sustainability transitions field as a method theory for the EIP development-related studies within the IE domain theory. Secondly, we systematically strengthen the link between the IE literature and the sustainability transitions field and extend the EIP literature by bringing new interpretation lines drawing upon SNM. Thirdly, our analytical framing differs from above-mentioned previous studies because we focus on how EIPs unfold through the niche-building processes, taking the niche experimentation central to our conceptualisation. We approach the journey to be an EIP as the niche experimentation that would result in an EIP, which is conceptualised as an emerging community involving broad range of relevant actors seeking better sustainability performance in the defined industrial production system through networking and learning processes. We also bring the spatial context as the mediating factor for the EIP experimentation. The internal niche-building processes under the influence of spatial context guide our interpretations and we contribute to the EIP literature in terms of understanding how EIPs can unfold by observing the EIP experimentation in certain contexts.

As for methodological contributions, we seek first and foremost to answer a novel research question. Secondly, we distinguish between the analytical framing and empirical methodology for our research inquiry. Initially, we frame our study analytically while refining and operationalising the method theory. That enables to us to formulate the constructs of our study based on the concepts from the SNM perspective. We then provide our empirical approach in which we follow a qualitative multiple case study through which we select and analyse multiple EIP experimentation journeys. Finally, our empirical methodology allows us to bring a rich set of new insights from two regions in Italy, an experienced country in that field.

Along with those contributions, we further argue that the IE literature's recently constructed link to the sustainability transitions field still needs be expanded, not only to enrich the theoretical background and expand the boundaries of the field by advancing the knowledge generation, but also to consolidate and extend that debate on the transitional nature of the IE implementations.

The remainder of the article is structured as follows. Firstly, we give the background of transitions into the EIP development and secondly, our analytical framing approach. We then introduce our case study methodology, incorporating the Italian context and a brief description of the selected EIP cases. We then provide the results on the niche processes of the unfolding EIPs. Building on the results, we present the discussions based on our cross-case analysis and provide an overall framework on the EIP experimentation journey of the unfolding EIPs. Finally, we offer conclusions with a summary of the main findings and implications for researchers, policy-makers and practitioners.

2. Transitions into the EIP development

The EIP development is inspired by the IE vision that argues for a transition into a novel industrial paradigm, calling for systemic changes in the dominant industrial production routines (Tibbs, 1992; Ehrenfeld, 2000). This new industrial production system model is about either transforming the existing industrial production systems into EIPs in the form of brownfield projects or, alternatively, designing/constructing new EIPs in the form of greenfield projects (Lambert and Boons, 2002). Although there have been successful EIP cases at various geographies, including but not limited to Denmark (Valentine, 2016), China (Fang et al., 2007), South Korea (Park et al., 2008), USA (Veleva et al., 2015), the EIP development could not gain the required momentum to bring a fundamental shift into the current industrial production systems at wider geographies.

Traditional technical understanding on the EIP development has mostly emphasised the EIP practices as the symbiotic exchange of the material assets (water, energy, by-products) (Chertow, 2000) within the firm-based industrial ecosystem networks inside the EIPs. However, the transition into the EIP development requires a systematic engagement of multiple institutional actors into the industrial ecosystems. Those actors include the EIP management bodies (Gibbs et al., 2005); individual firms in the production systems (Chertow, 2000; Haskins, 2008), which already form complex systems with large number of interacting components (Sopha et al., 2010); regional champions (Hewes and Lyons, 2008); governmental institutions; universities and research institutes (Lowe, 2001). The constellation of those actors and their expectations and visions of what the EIPs should deliver to the surrounding context may vary from region to region (United Nations Industrial Development Organization, 2014). Moreover, the spatial context also mediates the EIP development, as changes do not occur in a vacuum and are embedded in their social, technical, institutional and political environments (Baas and Huisingh, 2008; Baas, 2008). The traditional technical-oriented EIP development approach is not competent enough to understand and explain the complex dynamics among this wide range of actors (Gibbs, 2009).

Therefore, a systemic approach is needed to stress the engagement of diverse actors into the industrial ecosystem network through the IE-informed and IE-inspired EIP practices. Those practices can aim to exchange material assets and also non-

material assets such as knowledge, information and expertise (Lombardi and Laybourn, 2012) among the actors of the broad industrial ecosystems. With such an approach, the EIP development will not result only in incremental innovations for the involved firms (such as process optimisation, eco-efficiency, recycling, reuse, etc.) – as it was previously criticised for doing (Truffer and Coenen, 2012; Gibbs, 2009) – but could also bring systemic innovations for broad range of institutional actors through long-term fundamental changes in industrial production routines (Doranova et al., 2012; Organisation for Economic Co-operation and Development, 2012; Machiba, 2010).

That argumentation also constructs the potential link between the EIP development and the sustainability transitions field. The next two sections explain how we methodologically contribute to that link in analytical and empirical grounds.

3. Analytical framing

The research on sustainability transitions has received increasing attention in the field of innovation studies in recent decades, leading to calls for a need of radical and systemic changes in the existing production and consumption routines, given the important risks associated with ongoing environmental challenges (Kemp et al., 1998; Geels, 2002; Truffer and Coenen, 2012). The field provides comprehensive analytical frameworks to understand and explain the sustainability transitions through different innovations, and the SNM perspective is one its most salient frameworks (Markard et al., 2012).

The *niche* and *experiment* concepts are central to SNM's theoretical and practical foundations (Borghei and Magnusson, 2018; Weber et al., 1999). With an evolutionary perspective, the SNM studies reason that the experiments that refer to the sustainability-oriented local projects are key elements for building the niches, and that niches gain momentum in time through continuous experimentation and bring the desired sustainability transitions (Geels, 2002). The experiments contribute to the niches through three internal niche-building processes: coupling of expectations and visions, building of social networks and learning processes (Schot and Geels, 2008). Niches can be understood as the innovation incubators in which a community with shared expectations and visions emerges and provides the direction of the desired transitions (Geels and Raven, 2006). That community provides the conditions for the successful penetration of the sustainability-oriented innovations into the mainstream practices by mediating the expectations and providing the resources required for further local projects; this mediation is also shaped by the external environment and the context (Raven and Geels, 2010).

Taking the *experimentation* concept central to our analytical approach, we frame our study by drawing upon the foundations of SNM. As such, we use the SNM perspective that originates from the sustainability of transitions field as the method theory, because it can explain how EIPs can unfold over the traditional industrial production system through the EIP practices. This enables us to answer our research question in the IE research field, which is actually our domain theory. This also brings an interdisciplinary research approach to our study (see Lukka and Vinnari, 2014, for further understanding on method theory and domain theory differentiation).

We challenge the SNM perspective while operationalising it for our EIP-focused inquiry. We start conceptualising the journey to become an EIP as niche experimentation and EIPs as niches. That means we focus on the experimentation as a journey that involves the planning and implementation of various EIP practices within the industrial production systems, instead of focusing on the projects/experiments, as SNM studies have traditionally done. We propose that experimentation of the EIP practices may, in time, replace the existing individual-performance-oriented routines of the industrial production systems and EIPs can unfold as niches following the IE-inspired collective-benefit-oriented routines.

To understand how the EIPs unfold, we propose to follow three internal niche-building processes of SNM while analysing the EIP experimentation journey. We argue that the experimentation of the EIP practices may lead to unfolding EIPs through those niche-building processes. The emerging community that would provide support for further EIP practices is key to our conceptualisation and is not limited to the network of the involved firms in the industrial production system. We argue that emerging community involves all relevant institutional actors that have an impact on other actors in the making of the unfolding EIPs.

While developing the following constructs, we build on the conceptual foundations of the SNM perspective (see Schot and Geels, 2008; Raven and Geels, 2010; Weber et al., 1999). The first process under focus is the *coupling of expectations and visions*. The expectations and visions of the involved actors shape the progress of the experimentation, and if they are shared by the majority of the related actors, then the success of an unfolding EIP is more likely. These expectations and visions also create the basis for a shared understanding on the future EIP practices. The second process is about *network building*. This process facilitates interactions between different actors and is particularly important for the EIP experimentation as the EIP practices are based on material and non-material resource exchanges between the industrial ecosystem actors. *Learning,* as the third process, generates the required knowledge for the involved actors to continue experimentation of the EIP practices more effectively. Learning processes can improve the actors' capacity to understand the IE-informed EIP development by providing them the relevant information and experiences. Internalising and digesting that knowledge can lead to changes in actors' value framing, which is required for successful experimentation.

Finally, we argue that the *spatial context* may further support or hinder the incubation of the EIP practices throughout the experimentation. This creates the need to consider the policies and regulations of central and regional government, regional culture, available markets, industrial structures, already-existing networks, etc. Therefore, the regional context and its relationship to the national context are also embedded in our framing as the spatial context that may mediate the unfolding EIPs.

4. Empirical methodology

We adopted a multiple case study methodology to understand and explain how the EIPs can unfold over the traditional industrial production systems. The case study method is particularly useful for answering *how* questions in order to understand and explain complex phenomena like the EIP development. Multiple cases can provide stronger grounds as they enable cross-analysis and comparison, which can bring a more reflexive interpretation through the discussions (Yin, 2014; Alvesson and Skoldberg, 2009; Eisenhardt and Graebner, 2007).

We chose Italy as our empirical context as it has advanced geography in terms of the EIP development (Taddeo et al., 2012; Daddi et al., 2016; Taddeo et al., 2017), which means it can provide appropriate grounds for conducting an insightful case study considering our research objective. Throughout the study, we used multiple primary and secondary evidences considering the data triangulation of the case study (Denzin and Lincoln, 2005; Eisenhardt and Graebner, 2007). Overall, we followed a structured case study methodology following three main steps (see Fig. 1).

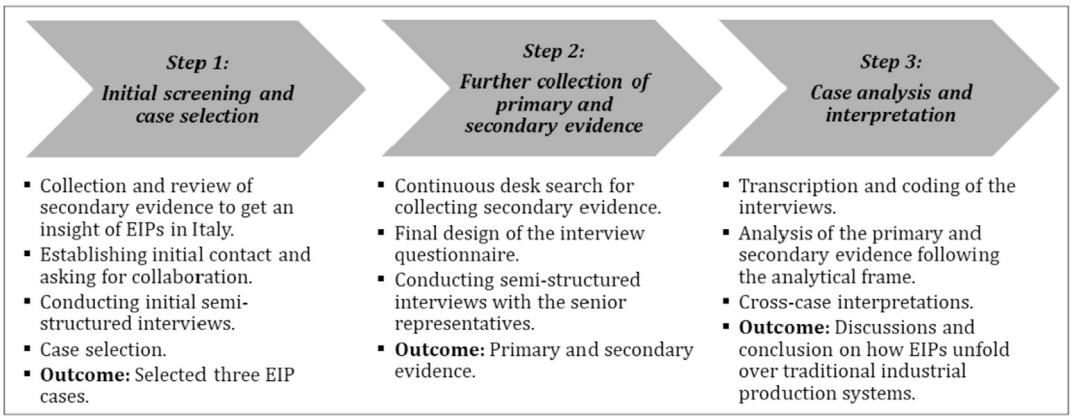

Fig. 1. Case study methodology steps.

We started the first step – *initial screening and case selection* – by reviewing the secondary evidence collected through the desk search in order to obtain insights into the general background with respect to the EIP development in Italy. We then screened the identified Italian EIP experiences by conducting brief semi-structured interviews and analysing the collected secondary evidence. That screening was steered by criteria including the existence of the management body in EIP and its size and age, as well as willingness to collaborate for our research study. At the end of this step, we ended with three cases: The First Macrolotto of Prato, Ponte a Egola, and The Green Economy and Sustainable Development Project, which emerged in Tuscany and Emilia Romagna regions of Italy (see Table 1 and Fig. 2 below for general characteristics of the cases).

In the second step – *further collection of primary and secondary evidence* – we conducted semi-structured interviews with the senior representatives of the cases and secondary data involved the collected documents including programme reports, policy statements, company data, and relevant publications. Initially, we finalised the design of the semi-structured interviews to be conducted with the relevant interviewees who had been actively involved in the EIP experimentation journey of each case. The interviews included two semi-structured question sections. The first of these sections was designed following the contours of our analytical framing, asking about the niche-building processes, also including the background of the experimentation of the EIP practices. This section remained the same for all conducted interviews. The second section included specific questions for each case based on the already-outlined overview of its context as a result of the initial screening and case selection step. This enabled us to design in-depth questions based on a more solid background and appreciated by the interviewees as an indication of our particular interest in their case.

For the First of Macrolotto of Prato, interviews (n = 2) were conducted with two senior members of Confindustria Toscana Nord, which has been in charge of the environmental management. For Ponte a Egola, interviews (n = 3) were conducted with senior representative of Tannery Consortium of Ponte a Egola, the entity that has been in charge of the environmental management since the settlement of the industrial production system. Finally, for the Green Economy Project, interviews (n = 2) were conducted with the senior representative of ASTER, which has been the entity in charge of technical coordination of the experiment as a part of the consortium for the innovation and technological transfer in the Emilia-Romagna region. The interviews not only served as the primary data source, but also ended in reliable secondary evidence provided by the interviewees, which enforced the data triangulation. In Table 2 below, we summarise the source of primary evidence as well as our main inventory of the collected secondary evidence.

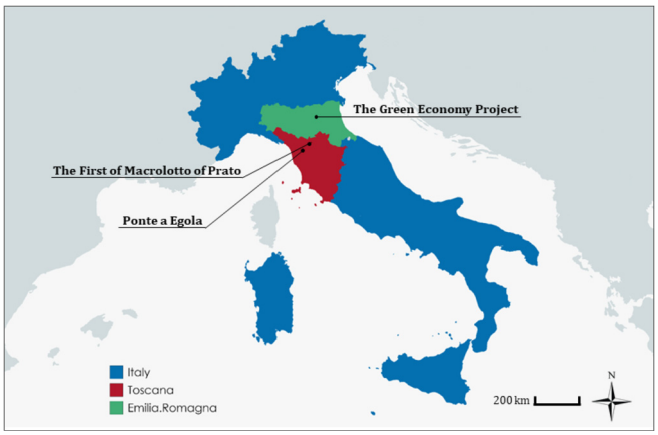

Fig. 2. The selected EIP cases in Italy.

In the third step – *case analysis and interpretation* – we

Table 1
General characteristics of the cases.

Characteristics	The First Macrolotto of Prato	Ponte e Egola	The Green Economy Project
Location	Tuscany	Tuscany	Emilia Romagna
Companies involved in the experimentation	380	160	13
Management body	CONSER Confindustria Toscana Nord	Cuoio Depur Tannery Consortium of Ponte a Egola	ENEA ASTER
Financing	Public/Private	Public/Private	Public/Private
EIP characteristics since	1990	1970	2013

Table 2
Sources of primary and secondary evidence.

Case	Source of primary evidence	Main secondary evidence inventory
The First Macrolotto of Prato	Interviews with senior members of Confindustria Toscana Nord.	– Report: The First Industrial Macrolotto of Prato- Sustainability Analysis, LIFE-SIAM Project (ENEA, 2006). – Report: Declaration of Sustainability of The First Industrial Macrolotto of Prato, LIFE-SIAM Project (CONSER, 2007). – Report: Guide to eco-innovation, sustainability policies and operational projects in Ecologically Equipped Productive Areas, LIFE Project (La Rete Cartesio, 2013). – Report: The Ecologically Equipped Productive Areas in Italy – State of the Art and Perspectives (ERVET, 2010). – Archives found in the official website of CONSER.
Ponte a Egola	Interviews with senior members of Tannery Consortium of Ponte a Egola.	– Report: Environmental Analysis on Productivity of Ponte a Egola (Cuoiodepur & APEA, 2016). – Report: GreenItaly - An idea for the future to face the crisis (Unioncamere and Symbola, 2010). – Report: The District of Tannery and Leather (Cuoiodepur, 2016). – Presentation: EEPA as new realty for Ponte e Egola (Natali and Gradilone, 2015). – Archives found in the official website of The Tannery Consortium of Ponte a Egola, Cuoio Depur, and APEA Ponte a Egola.
The Green Economy Project	Interviews with the coordinator of the project from ASTER.	– Integration of industrial processes in a perspective of circular economy (Mencherini, 2016). – Industrial symbiosis in Emilia-Romagna region: Results from a first application in the agro-industry sector (Cutaia et al., 2015). – Archives found in the official website of ENEA.

primarily transcribed and coded the semi-structured interviews. For the analysis, we followed our analytical framing, focusing on the coupling of visions and expectations, the social network building, the learning processes and spatial context behind the experimentation of the EIP practices in each case. Our methodological choice to conduct a multiple case study provided suitable grounds to theoretically replicate the instrumental application of our conceptualisation in more than one setting (Yin, 2014). We were able to aggregate and cross-discuss the insights from three experimentation journeys that have allowed us to outline an overall framework to understand and explain how the EIPs unfold over the traditional industrial production systems and to draw conclusions through comprehensive interpretations and relevant implications.

We should also recognise some methodological limitations. The potential recall bias (Miles, 1979) that may emerge from retrospective insights of the interviewees was considered throughout the study. Another limitation was that the case studies did not involve any direct observation of the niche-building processes in the making of the experimentation. We have addressed those limitations by triangulating the insights and experiences of the interviewees by the secondary data sources to complement our analyses and interpretation, as also suggested in Gioia et al. (2010) and Eisenhardt and Graebner (2007).

Moreover, considering the traditional validity approach through the generalisability criteria, it is worth noting that a study designed similarly to ours may end in varying findings in other country contexts and even in other Italian regions. This is because each sustainability transition journey may carry particular characteristics due to different constellation of involved actors, their experiences and also the future expectations (Garud and Gehman, 2012). Therefore, we underline that our empirical methodology, guided by our analytical framing, serves for the research validity in terms of the transferability criteria instead of generalisability (Guba and Lincoln, 1994). The overall conceptualisation and the theoretically guided results and discussions of this study can provide the foundational grounds for understanding and explaining the unfolding EIPs in other contexts for researchers and can provide relevant implications for practitioners and policy-makers. However, each sustainability transition journey requires a tailored research inquiry and action- and/or policy-oriented strategy considering its specific context-dependent characteristics.

5. Case study background

5.1. The Italian context

The landscape provided by the European Union, which has been encouraging Member States to increase the environmental performance of its territories, has nurtured the Italian context to boost the transition of industrial production systems into more sustainable and eco-compatible spaces. Along these lines, the Ecologically Equipped Productive Areas (EEPAs) was the first initiative introduced by the Italian Government in 1998 (Tessitore et al., 2015), and the first concrete attempt in Italy to search for a new industrial production model through the application of the IE principles on the EIP development model (Daddi et al., 2015).

Although the EEPAs initiative was introduced at the national level, it did not accumulate into national guidelines and each Italian region has disciplined its implementation considering its specific regulatory, geographic, industrial, technical and socio-economic characteristics. Nine out of 20 Italian regions have indicated an intention to experiment with the Italian version of the EIP development through the EEPA certification. Of these, five regions (Emilia-Romagna, Liguria, Marche, Piedmont and Tuscany) have started the regional implementation, and the other four regions (Abruzzo, Apulia, Calabria, and Sardinia) have been developing related policies and strategies (Taddeo, 2016).

The Italian EIP development pattern has also been influenced by initiatives other than EEPAs. In particular, the Eco-Management and Audit Scheme (EMAS) has been contributing to the involvement of industrial clusters in the district level EIP development since 1993. The EMAS Cluster Certificate by the Italian National EMAS Competent Body has been a special recognition for the clusters that implement EIP management models (Daddi et al., 2016).

In the present article, the selected cases for observation of the EIP experimentation are from the regions of Tuscany and Emilia-Romagna. Considering their approaches to the EIP development, both regions aim to increase the environmental performance of their territories while maximising the economic benefits. Moreover, both regions have introduced the related regulations and resolutions into the force relatively close to each other, compared

with other regions.

5.2. Brief description of the cases

The First of Macrolotto of Prato specializes in wool production and has been an important economic hub for the development of Tuscany region since 1990. It represents one of the main Italian EIPs considering its history of continuous environmental improvements under the influence of the district EMAS initiative. It started with the EEPA programme but abandoned it before becoming certified. Its main EIP characteristics are related to the centralized environmental services, its wastewater recycling plant and the reputable performance of its management body as a facilitator of the EIP practices. The brownfield experimentation in this case has evolved through a combination of top-down and self−organised EIP practices (see Chertow, 2007, for further reading on the differentiation of self-organised and top-down approaches).

Ponte a Egola is an older and smaller industrial production system in Tuscany, which was established in 1970. As in the first case, the emergence of the brownfield EIP experimentation has been observed as a combination of top-down and self-organised approaches. The EIP experimentation has been highly influenced by the EMAS-certificated Tannery District to which Ponte a Egola pertains. Under the vision of the Tannery District, many efforts have been put into the recovery and reuse of by-products and the use of shared facilities. On the other hand, the top-down planned EEPA programme has also been followed for improving the green areas, waste management, shared infrastructure and services, and energy efficiency at the system level. The EEPA process started in 2013 and the qualification was obtained in 2016. It is the first and only certified EEPA in Tuscany.

Finally, ***Green Economy and Sustainable Development Project*** started in 2013. It differs from the other two cases because this brownfield experimentation did not identify a specifically bounded industrial production system and aimed to involve variety of industrial actors located in Emilia-Romagna region. It started through a top-down manner and continued in the form of facilitation aiming to boost the EIP practices among the located companies, research and development centres, and other regional formal and informal actors. Fig. 3 below describes the cases.

6. Case analysis through the niche-building processes

6.1. Coupling of expectations and visions

During experimentation in ***The First Macrolotto of Prato*** case, the EIP practices have been mostly developed through a bottom-up trend without a theoretical knowledge of the concept. As the EIP representative expressed in the interview, "*the area has evolved into a symbiotic industrial ecosystem without an academic approach*".

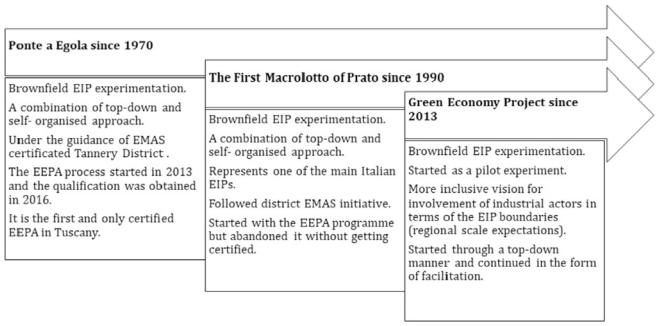

Fig. 3. Brief description of the selected cases.

Initial visions and expectations were shaped mainly by the private character of the area, and the environmental commitment of the actors was led by top-down pressure through environmental regulations. The starting point towards a more conscious understanding of sustainability was the first environmental assessment, which was carried out in 1999 through a top-down intervention. Even though it did not lead to an immediate transition into an EIP, it shaped the industrial development processes by creating awareness among the actors and calling attention to the main sustainability-related problems of the industrial production.

Meanwhile, the management body has succeeded in revealing economic advantages of the EIP practices by introducing the sustainability concept as a competitive advantage in the market. This was also addressed in the interviews: "… *the area is mainly dedicated to the textile industry where the clients are from the fashion world, where the topics related to the sustainable production have been increasingly important. This means that for many companies, sustainability had to become a must and also turned into be an economic added value*". Moreover, the economic advantage-oriented sustainable development visions of the actors have continued to evolve around the District EMAS and EEPA programme, although the area abandoned the EEPA before becoming certified.

In the case of ***Ponte a Egola***, sustainability has been perceived as a continuous improvement process that cannot be decoupled from the industrial development. The interviewee from the representative consortium of the EIP stated that: *"since our production activities are quite polluting, finding sustainable solutions has always been our aim. Our search for environmental compatibility is on-going. We know that the technology continuously improves, and our industry, to survive, should always be technologically advanced and environmentally clean"*. Moreover, the long-standing participatory and collaborative culture among the institutional actors has fundamentally contributed to the evolving visions and expectations on the EIP practices.

Before getting involved in the EEPA programme in 2013, the EIP practices were structured around sharing the common infrastructure, and recovery and recycling of the materials among the involved industrial actors. The expectations of the actors have been broadened after the involvement in the EEPA programme towards urbanization aspects such as green areas, sound-absorbing asphalts, energy-efficient lighting systems, and waste management. Moreover, the importance of the management body as a trusted actor has been credited more among the regional actors. Meanwhile, the experience gained for the EMAS certification has also contributed to the actors' commitment towards the EIP practices and it facilitated the EEPA certification in 2016. The EIP experimentation journey of this case has been taken as a reference point by other interested industrial production systems in the implementation of the EIP practices, which have leveraged the motivations of the industrial actors from individual-profit-oriented level to a true environmental commitment at the area level.

Finally, the ***Green Economy and Sustainable Development Project*** started the EIP experimentation in a top-down manner and then followed a facilitation approach by spreading the knowledge and culture of the IE philosophy behind the EIP practices, aiming to involve traditionally separated industrial actors in a collective manner in a symbiotic collaboration with each other and also with other regional institutional actors. Since the beginning of the experimentation, the expectations were driven towards realisation of an EIP model into practice, through a theory-based approach. This was because it was a top-down introduced project by the well-informed actors on the topic. Moreover, the experimentation took place at a period when the concepts related to IE had already gained momentum in the region. The expectations regarding the implementation of the EIP practices were linked to the potential

economic advantage that can be achieved on the already matured responsive market that was available at the regional level.

6.2. Network building

The First Macrolotto of Prato case represents a broad network of actors and can be characterized by complex interactions among them. The network involves actors from *governmental institutions* like the Regional Government of Tuscany, Prato Municipality, the Ministry of Environment, the Ministry of Productive Activities, EMAS Italy Committee, and The Environmental Protection Agency of Tuscany Region (ARPAT); the Italian National Institute for Environmental Protection and Research (ISPRA); *intermediary organisations* like CONSER (the first management body), Confindustria Toscana Nord (the current management body), the Management of Prato District, the Industrial Association of Prato, and the Chamber of Commerce of Prato; *private companies* such as the water management company GIDA and located companies; *non-profit organisations* such as IDRA and Greenpeace; *research centres* like the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA); and *investment banks* like Fidi Toscana and Cassa di Risparmio.

The role of the first management body, CONSER, has been crucial as a facilitator of interactions in the network and creator of visions linked to the environmental sustainability benefits. Even before the EIP concept was highlighted and specified by the EEPA programme, CONSER had played the role in the management of water, energy, security, and dissemination. Its outstanding management performance was recognised in 2004 at the national level and its management approach was selected among the 23 best practices in terms of environmental management systems targeted to fostering collaboration among small and medium-sized enterprises (SMEs). The current management body is Confindustria Toscana Nord, which was created in 2015 as an attempt to reinforce the territorial industrial representation and increase the efficiency of the industrial activities. Its networking facilitation strategy has been inclusive at broader levels compared to CONSER, so the interaction to communicate with regional, national and international actors has been stressed as well. As a specific networking strategy, CONSER has been organising periodic meetings that provide a space to the actors to share their voices and derive the potential synergies. This was also expressed in the interviews by the EIP representatives as *"… the meetings accumulate into a kind of state of the art and a platform to share updates. This helps to carry out the different initiatives in the best possible way incorporating different actors".*

Another important aspect highlighted in the interviews concerned the good communication strategies regarding the associated economic gains of the EIP practices, which resulted in high number of private companies in the EIP network. This was also mediated by the fact that the area has been a concentrated and homogeneous one and has been composed of mainly textile companies, which allowed the Macrolotto to develop a series of EIP practices. Moreover, Chinese industrial immigration has been strong in Prato, and Chinese textile manufacturers have located in facilities vacated by the companies that left mainly because of the economic crisis. Chinese manufacturers have been adapting to the regional standards and now just a small group of polluting industrial actors remain in the area.

Regarding ***Ponte a Egola*****,** there is also a broad network of actors collaborating with each other to advance the environmental sustainability following the EIP practices. These actors are from *governmental institutions* like the Regional Government of Tuscany, the Municipality of San Miniato, The Environmental Protection Agency of Tuscany Region (ARPAT); *intermediary organisations* like Tannery Consortium (the cooperative society of the located companies), Cuoio Depur Consortium (entitled as the management body of the area), National Confederation of Craft Workers (CNA Area del Cuoio, the representative association of the regional craft workers), and Technological Pole of Navacchio (which brings together businesses, universities, researchers and investors to boost their ideas); located *companies*; and *universities and research centres* like Sant'Anna University, Tannery Technological Pole and Cerco Lab (the spin-off of the University of Florence).

Perhaps the most active actor during the EIP experimentation has been the Tannery Consortium, which was created in 1976 to manage the concerns of variety of actors. The creation of the consortium coincides with the beginning of the industrialization process of the area and has played an important role in the urbanization and relocation of the tannery activity. The contribution of the consortium to the emerging participatory and collaborative culture has been undeniable. It plays a central role in addressing the sustainability issues by leveraging the homogeneity of the area through facilitating the collaboration among SMEs and other institutional actors. Moreover, the consortium has been the representative entity for the EEPA and District EMAS programmes.

The EEPA programme, as an important seed during the EIP experimentation, started with the call of the Tuscany Region, to which the San Miniato Municipality, as the owner of the land, responded by volunteering itself as the entity in charge of the EEPA planning. A working group composed of the municipality, private actors, universities and other regional actors was then created to share the tasks and the new management body was chosen as Cuoio Depur through common deliberation. The management body, in close collaboration with the governmental institutions, aimed to add economic value to the located industrial actors and help them manage their environmental impact. Cuoio Depur has been in charge of the organisation, realisation, and maintenance of the EEPA-related activities. Furthermore, the continuity in the working group structure allowed for common decision-making grounds among the regional institutional actors and different points of views were integrated throughout the experimentation. Even since the EEPA certification, the working group remains in place and meets periodically.

Finally, for the ***Green Economy and Sustainable Development Project*****,** a broad network has emerged during the experimentation, including *governmental institutions* like the Emilia–Romagna Regional Government and the Regional Planning Office of Rimini; *intermediary organisations* like the Consortium for Innovation and Technology Transfer of Emilia-Romagna (Aster), the Environment Society Social Cooperative (Coop Formula Ambiente), the Italian Union of Chambers of Commerce, Industry, Handicraft and Agriculture (Unioncamere) and the Agricultural Cooperative Conserve Italia; *universities and research centres* such as the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Energy and Environment Laboratory Piacenza (LEAP) and MatER Research Centre of Politecnico di Milano, and the Emilia-Romagna High Technological Network, which brings together the centres for industrial agro-food research (Ciri Agrifood), renewable sources, environment, sea and energy research (CIRI Frame), advanced industrial material research (CIRI Mam), and the research centre for packaging (CIPACK); and *private industrial actors* like Agricoltori Riunti Piacentini (ARP), Barilla & R Fratelli, the cooperative multi-business industrial group CCPL, General Machine Company (CGM), Schmack Biogas, and Valfrutta-Conserve Italia.

The project was financed by Unioncamere and Aster was the lead in conducting the EIP experimentation. Aster played a key role in identifying the initial potential synergies leveraging on its familiarity with the industrial network in the region and collection of relevant data from the companies. The regional network embedded

in the industrial context presented the region as an ideal testbed for this pilot experimentation and boosted the competencies and resources to stimulate the sustainable industrial development.

The experimentation was started over the existing synergistic composition between the industrial actors producing industrial waste and the technology developer advancing the biomass treatment. It was then relatively simple to identify upstream and downstream elements for the development of further potential synergies. Moreover, the classification of economic activity codes (ATECO codes) of the companies particularly helped to determine whether there were other possible synergies that were not easily recognizable from the provided data. That was especially important because synergies between sectors outside the project were also recognized, which facilitated scaling up of the network at broader levels.

Apart from Aster, there were other synergy facilitators such as research laboratories of the High Technology Network and ENEA, which were acquired with relevant technological, scientific and research skills. Moreover, ENEA was responsible for disseminating the knowledge about the EIP practices to the industrial actors. The size of the companies also positively influenced the emerging EIP network. The project representative from ASTER in our interview stated that "*… big companies were more likely to be aware of the EIP practices in comparison to the smaller ones.*"

6.3. Learning

During ***the First Macrolotto of Prato*** experimentation, the learning process has been iterative and the attitude of the management body towards raising awareness was essential. Initially, the difficulties of realising the EIP practices were apparent in terms of restricted regulations and missing interests from the industry due to economic concerns, but the management body treated those issues as potential sources of adaptation through learning. The dissemination of knowledge and environmental awareness has been promoted in the industrial production system through educational courses, special training sessions and meetings, planning of guidelines, and promotion of environmental certifications for the industrial actors, to increase regional awareness to engage with more actors. The idea that environmental and economic benefit can be coupled has been stressed during the learning activities. The management body representative expressed that "*… since too long we have been talking about the environment-related concerns, the need to save resources … However, when talking to public and private entities it is important to show the practical results … Because when things are perceived as investments and not just as costs, there are more positive responses in terms of involvement from different organisations*". Moreover, the knowledge dissemination was not limited to the benefit of the regional actors. The management body has been acting as an EIP development influencer across Italy and Europe.

In the case of ***Ponte a Egola***, learning has been mostly oriented towards the importance of extending the useful life of important resources. The actors' understanding of the potential collective benefits through the EIP practices has been mediated by the existing participatory and collaborative culture of the industrial production system. That culture was reinforced by the fact that the management body was not an ex-novo figure, but rather had been running its activities with its strong technical and managerial capabilities long before the EIP experimentation journey. Therefore, the area was able to take advantage of trust and mutual interests. The representative of EIP commented that *"it could be difficult to create an instrument from scratch that could create high level of trust and interest in the EIP practices, because it would require very high managerial and training costs."* Knowledge dissemination has also been supported by other regional actors, such as the Tannery Technological Pole and Cerco Lab, which provided the infrastructure and competencies for learning activities.

Considering the ***Green Economy and Sustainable Development Project*****,** among the fundamental concerns of the organised learning activities were communicating to the regional actors and transferring them the potential economic and environmental benefits of the EIP practices. Since the beginning of the experimentation, actors had different standpoints regarding their expectations about the EIP development. For this reason, it was very important to create a common understanding and convince them of the importance of their involvement in synergistic relationships. When the industrial actors were able to understand the savings from waste disposal and purchase of raw materials, the reduction of carbon emissions and pollution, and the synergy opportunities that they could get advantage from, they became more engaged in the project. To facilitate the comprehension of the concept, knowledge on the best practice EIPs at the national and global level was provided to the actors. Furthermore, the existing know-how of Aster and ENEA has been an advantage as it accelerated the gathering and analysis of the data from the companies.

7. Discussion on the unfolding EIPs: Niche experimentation

7.1. Through interacting niche-building processes

The results revealed that the analysed EIP experimentation within the three cases has been implemented under the brownfield model. We can conclude that niche processes of each have been in constant interaction and interdependent on one another, as also argued by Schot and Geels (2008). Each niche process has had an essential influence on others during the experimentation. That interdependence makes it difficult to understand their individual development dynamics separately, which reinforces the need to analyse the niche processes under their dynamic interactions, as also reasoned by Elmustapha et al. (2018).

Starting from the coupling of expectations and visions, the implementation of the EIP practices considering three cases can be interpreted as a continuous search for economic advantages, as Daddi et al. (2015) also claimed when referring to the Italian approach. Yet, during the experimentation, the economic development trend has been shifting from individual-performance-oriented focus considering only economic sustainability towards collective-benefit-oriented collaboration with other actors. This also implies that the building of networks among the actors has been a fundamental enzyme to the reaction of articulating visions and expectations, as Gibbs (2009) also explained for other EIP cases.

The evolution of the analysed EIP experimentation journeys can be understood as an adaptive and continuous process during which the visions and expectations of the regional community have been converging through learning processes, which at the same time have had an impact on the size of the EIP networks. For example, in the early stages of the First Macrolotto of Prato experiment, a relatively narrow network existed, mainly involving the located industries. However, during the experimentation, new actors like private saving banks (such as Cassa di Risparmio) and non-profit organisations (such as Greenpeace) were involved as well. Enlightened visions about the EIP development alerted local actors to the importance of looking beyond the local interests and being more open-minded to new interactions. Network adaptation not only implies the continuous entry of new actors to the EIP networks, but also that some others have been leaving, and existing interactions have been changing as well. Therefore, the EIP network, as a reflection of changes in visions and expectations, has been changing in terms of the actors involved and the relational

dynamics among them.

In all three cases, broad networks have been observed where fundamental roles have been played by the management bodies, the governmental institutions, intermediary organisations, universities and research centres, and the private companies. The intermediary organisations, especially the agency of the management body (see Tessitore et al., 2015; Daddi et al., 2015, for further reading on the management bodies in Italian approach) can be claimed to play the central role in the unfolding EIPs as they have been coordinating and/or providing shared services and infrastructure, facilitating interactions among the network members, identifying synergies, creating awareness, scaling up existent EIP practices and designing new ones. The governmental institutions' role has also been fundamental in enabling and boosting the EIP experimentation, especially through developing relevant regulatory and incentivising mechanisms. For example, the Italian Government recognises the EIP development as a strategic regional development model and reasons that EIPs shall not only serve for better environmental performances but also foster job creations and contribute to the regional economic development. This has also nurtured the involvement of the regional governments in the EIP experimentation for three cases.

Moreover, the universities and research centres have provided learning tools for the dissemination of knowledge and brought a theory-based vision for testing in the field. They have also substantially advanced the identification possible synergies among actors that contributed to the realisation of the EIP practices and, consequently, the involvement of more industrial actors to the EIP networks, as seen clearly in the Green Economy and Sustainable Development Project. The learning processes have built on existing knowledge and contributed to the new knowledge within the EIP networks. The accumulating knowledge has shaped expectations and visions by providing understanding of whether and how these EIP practices could add to the regional economies. The industrial actors have been integrating the EIP development vision to their expectations by changing their assumptions about the sustainability and becoming attached to the EIP networks that benefit economically and ecologically from emerging synergies.

7.2. Within the spatial context

Our results have shown that the niche-building processes of the analysed EIP experimentation journeys within the three cases experimentation processes have been mediated by the spatial contexts. Although the brownfield EIP experimentation was common for three cases, we have not observed a rigid model on how the EIPs unfold. This can be explained by the argument that the niche-building processes are highly dependent on the realities of the different industrial production systems and the context in which they operate. Moreover, Italy has no national guidelines in terms of EIP requirements and different regions take specific approaches. Therefore, the EIP experimentation management and its contribution to the EIP emergence have been highly influenced by the specific regional characteristics. For example, regional governments' pressures, incentives or different regional implementation strategies on the programmes such as EEPA and EMAS have been shaping both the planning and implementation of the experimentation in different regions. This also reinforces the importance of considering spatial variants when studying sustainability transitions, as also argued by Coenen et al. (2012).

Moreover, the analyses of three cases have shown that relatively more homogenous industrial production systems composed of SMEs are more likely to develop the EIP practices. Similar size and sector industries may share similar concerns in terms of resilience strategies to changing socio-economic environment, which can also contribute to the (further) construction of participatory and collaborative culture in the regions. The unfolding EIPs in Tuscany represent good examples of this. Tuscany is one of the most advanced Italian regions in terms of the EIP development and the areas in that territory show the characteristics of homogeneity and companies of small dimension. However, it may be necessary to note that the lack of heterogeneity may restrict the type of potential symbiotic exchanges and make the areas more focused on particular synergies, such as recycling and recovery consortiums, a common management body, or shared infrastructure, as also indicated by Daddi et al. (2015) while discussing the Italian approach.

7.3. Overall framework

Following our initial analytical framing and taking the EIP niche experimentation as central to our inquiry, we analysed three EIP cases to understand and explain how they unfold over the traditional industrial production systems, focusing on three niche-building processes under the mediating influence of the spatial context at regional and national scales. Building on the empirical insights from three Italian EIP experimentation journeys guided by our initial analytical approach, we have derived a framework to demonstrate the transition from industrial productions systems into the EIPs through an experimentation journey (see Fig. 4 below).

As the figure shows, the experimentation journey is steered by three niche-building processes: coupling of expectations and visions, social network building and learning processes. The spatial context has a mediating influence on the interaction and functioning of those processes. The main actors involved in the EIP experimentation involve industrial actors in the production system, management bodies, governmental institutions, intermediary organisations, universities and research centres, non-profit organisations and private companies. The broad network continuously built by this broad range of actors designs and implements different learning tools that contribute to changing expectations and visions diverging from individual-performance-oriented focus towards collective-benefit-oriented collaboration focus. The emerging EIP niche community implements the IE practices, not only prioritising the individual economic benefits but also considering the sustainable regional economies. The regional industrial composition related to the size and sector of the companies, as well as (existing) collaborative culture and trust, affects the effectiveness of the niche-building processes and may foster a relatively smoother transition into the EIP niches. Moreover, in the absence of a unique national strategy policy for the EIP development, each region may develop specific implementation strategies for centrally designed policy actions.

8. Conclusion and implications

This article has sought to understand and explain how EIPs unfold over traditional industrial production systems for extending the debate on whether and how the IE philosophy can bring a real paradigm shift in industrial production routines. We have taken the niche and experimentation concepts from the sustainability transitions field – which are central to our analytical framing – and mainly drawn upon the foundations of the SNM perspective as our method theory. Empirically, we have followed a qualitative multiple case study and bring three EIP cases from the Emilia-Romagna and Tuscany regions of Italy. We have analysed three EIP experimentation journeys by focusing on three internal niche processes under the mediating impact of regional and national context where they are embedded in. Our empirical inquiry, guided by our

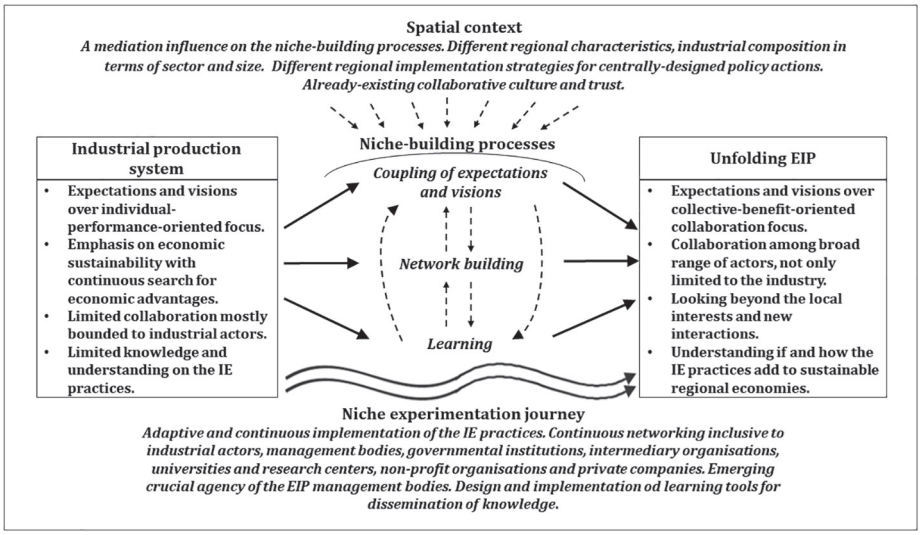

Fig. 4. The framework of the EIP niche experimentation to understand how EIPs unfold over the traditional industrial production systems.

analytical framing, enabled us to derive an overall framework that illustrates the unfolding EIPs through an experimentation journey (see Fig. 4 in Section 7 above).

8.1. The unfolding EIPs through niche experimentation

The results of the multiple case study revealed that the way in which the EIPs unfold depends on the interacting and interdependent niche-building processes during the experimentation. The three Italian EIP experimentation journeys analysed here carry characteristics of a brownfield EIP development model. The niche processes have been under the mediating impact of the regional context in which the industrial production systems function. Considering the Italian context, each region has its own specific requirements for the EIP development and there is no unique EIP development guideline at the national level.

The emerging EIP networks have been composed of different institutional actors, including the governmental institutions, the intermediary organisations, non-profit organisations, universities and research centres and the industrial actors in the production systems. This suggests that the EIP networks should not only focus on the industry involved in the symbiotic exchanges, but also on other actors that contribute to the emerging community with converging visions on the continuous implementation of the IE practices.

The visions and expectations of the actors have been articulating through the learning processes towards a shared understanding of the EIP development. During the experimentation, not only the environmental gains of the EIP practices but also their economic benefits have been increasingly realised among the network actors. However, their initial motivations were established around the expectations about the economic benefits. Moreover, the niche processes of each EIP experimentation journey have been constantly interacting with and interdependent on each other; this calls for consideration of the divergent blurred lines in between them, which makes it complicated to analyse each niche process separately.

8.2. Action- and policy-oriented implications

In this article, we built on our analytical framing for ex-post analysis of the EIP experimentation in three cases and we came up with an overall framework that illustrates how EIPs unfold over the traditional industrial production systems. The learning offered through the results and discussion may serve for the regional policy-makers and practitioners for further EIP experimentation in the Emilia-Romagna and Tuscany regions. Moreover, the overall framework we derived may be used as an ex-ante management tool for future EIP experimentation elsewhere. We suggest that the potential for an industrial production system to transform into an EIP calls for specific niche formation policies. Specific importance can be given to the network building process targeting various regional actors (not only focusing on the industry), which will couple their expectations and visions through learning mechanisms disseminating the knowledge on the EIP practices. Moreover, continuous experimentation of the EIP practices will not only lead to an increased number of EIPs in the regions but may also bring a shift in traditional industrial production routines through the IE philosophy on a wider scale.

8.3. Research implications

The case study provided in this article can be extended to different EIP cases to understand their emergence and to further test the plausibility of our analytical framing for the analysis and explanation on how EIPs unfold over different industrial production systems at different spatial contexts. Moreover, further research could study in detail the interdependency of the niche processes and their impact on each other during the experimentation. Finally, future studies could test the plausibility of other analytical frameworks, such as technological innovation systems and multi-level perspective from sustainability transitions field, in order to understand and explain the IE-related transitions.

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The emergence of regional industrial ecosystem niches: A conceptual framework and a case study

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ABSTRACT

The objective of this paper is to understand how industrial symbiosis initiatives can contribute to the emergence of regional industrial ecosystems for sustainability transitions of local industrial production systems. We offer a conceptual framework that integrates industrial ecology literature and strategic niche management perspective from the sustainability transitions research field. The framework provides a conceptual foundation for analysing the individual industrial symbiosis initiatives and their aggregated contribution to the emergence of regional industrial ecosystems. Analytically, we conceptualise two different heuristic levels – the local industrial symbiosis experiments level and the regional industrial ecosystems niche level – which are interlinked through three niche processes. We represent the merits of our conceptualisation through a case study in an empirical setting where we selected a highly industrialised and rarely explored region; namely, the Autonomous Region of Catalonia in Spain. We identify and analyse eight industrial symbiosis initiatives that evolved during 18 years in the region. In the light of our conceptual framework, the results show that interlinked initiatives from the region have been gradually adding up to emerging regional industrial ecosystems. However, the region is still missing a broad regional network with articulated expectations and visions and shared cognitive, formal and normative rules. If emerging regional network provides support and protection for new initiatives, a regional culture change can be realised to achieve sustainability transition of local industrial production systems employing closed industrial production loops. The theoretical contribution of this paper is that we combine two different research streams that have not often learned from each other and we also develop a novel conceptual approach for ex-post evaluation of regional industrial ecosystem development. Moreover, our conceptual framework can be extended as a prescriptive management tool for planning and implementation of industrial symbiosis initiatives in Catalonia as well as in other regions.

1. Introduction

Industrial production has been crucial for the growth of local economies, especially since the Industrial Revolution. In this respect, the development of *local industrial production systems* (LIPS), which is composed of agglomerated industries in specific locations, has been central to regional development strategies (UNIDO, 2014). In the meantime, sustainability has become a mainstream concern related to industrial development and problems have emerged related to resource scarcity and environmental pollution due to territorially concentrated industrial production activities from LIPS (Shi et al., 2010; Liu et al., 2017; Fernández and Ruiz, 2009; Côté and Liu, 2016; UNIDO, 2012).

In this vein, the *industrial ecology* literature argues that the problematic of the industrial production systems is the linear industrial production routines, which are based on the extract-produce-throw away approach to resources (Frosch and Gallapoulus, 1989). Scholars in the field have developed *industrial symbiosis* practices for closing industrial production loops in order to have circular industrial production routines (Sterr and Ott, 2004). Industrial symbiosis aims to benefit from the advantages of industrial agglomerations in LIPS to adopt and develop industrial ecosystems (Ashton, 2008; Lowe and Evans, 1995). It is analogous to mimicking the principles of natural ecosystems to the industrial processes (McManus and Gibbs, 2008; Frosch and Gallapoulus,

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1989; Ehrenfeld, 2003) through physical (resources, materials, water, energy, infrastructure and natural habitat) and non-physical (information, knowledge, expertise, management) exchanges across system actors (Chertow, 2000; Lombardi and Laybourn, 2012). The regional perspective has been central in this literature, which analyses and discusses various cases where LIPS of varying geographical sizes have implemented industrial symbiosis initiatives to trigger the emergence of regional industrial ecosystems (Boons et al., 2011; Baas and Boons, 2004; Ashton, 2009).

Over time, industrial ecology has been conceptualised as a systemic innovation model (Machiba, 2010; Gibbs, 2009; OECD, 2009; Adamides and Mouzakitis, 2009), which can lead to fundamental technological, organisational and institutional changes in industrial production systems (Adamides and Mouzakitis, 2009) through interactions of a wide variety of actors. Following this, various scholars from the field have argued and agreed that industrial ecology triggers innovation (Mirata and Emtairah, 2005; Boons et al., 2017; Taddeo et al., 2017; Valentine, 2016; Lombardi et al., 2012). However, an explicit link between industrial ecology and innovation studies has not yet been constructed.

Along similar lines to the systemic innovations needed due to sustainability concerns, the most salient and promising research stream from innovation studies is *sustainability transitions* (ST). In the ST field, it is claimed that systemic and radical changes have to be realised, given the important risks associated with ongoing sustainability challenges (Schot and Geels, 2008; Smith and Raven, 2012; Markard et al., 2012). Scholars in the field have studied transitions through fundamental sustainable changes in technological, organisational and institutional terms under influence of a broad range of actors (Truffer and Coenen, 2012; Geels, 2002; Raven, 2007; Farla et al., 2012).

However, ST scholars have not paid attention to industrial ecology literature and on the other side, there are only a few studies from industrial ecology literature that have built on the ST frameworks. Those studies have generally adopted some concepts from the transition literature (*e.g.* Baas and Huisingh, 2008; Rotmans and Loorbach, 2009; Verguts et al., 2016) and some have made a relatively deep operationalisation of industrial production systems and industrial symbiosis initiatives with analytical lenses provided by the ST field (*e.g.* Gibbs, 2009; Adamides and Mouzakitis, 2009). However, the way in which transitions into industrial ecosystems following industrial ecology principles can take place has not been sufficiently addressed (Gibbs, 2009). Apparently, there is a missing link between these two research fields. We partially address this gap in our recent review paper (Susur et al., 2019) in which we study the sustainability transitions from industrial park development into eco-industrial park (EIP) development. There we build on theoretical standpoints emerging from both the ST and EIP literatures while synthesising the EIP cases extracted from the existing state of the art. It is worth noting that the EIP development is one research branch of industrial ecology literature among others and we argue that various further questions contributing to the industrial ecology literature can be illuminated by bringing insights from the ST field.

We derive our research question in this paper considering the potential contribution of industrial symbiosis initiatives in the emergence of regional industrial ecosystems to address the sustainability problematic of LIPS:

> *How can industrial symbiosis initiatives contribute to the emergence of regional industrial ecosystems for sustainability transitions of LIPS?*

To answer this question, we present a conceptual foundation for the operationalisation and empirical assessment of that contribution. We first develop a conceptual framework integrating the industrial ecology literature and strategic niche management (SNM) framework from the ST field to strengthen our previous arguement related to the potential in bringing insights from the ST field into the industrial ecology literature. The SNM framework underlines the importance of experimentation and focuses on aggregation of niche experiments for developing niches that would lead to sustainability transitions (Weber et al., 1999; Schot and Geels, 2008). So far, SNM framework has not been applied as a policy tool for introducing new sustainable technologies and practices; instead, it has been used as ex-post analytical framework for ex-post analysis and evaluation of cases such as biofuels (Van der Laak et al., 2007), biomass gasification (Verbong et al., 2010), organic food (Smith, 2006), biogas plants (Geels and Raven, 2006), sustainable transport innovations (Weber et al., 1999) with a particular focus on battery powered vehicles (Kemp et al., 1998) and hybrid electric vehicles (Sushandoyo and Magnusson, 2014).

The SNM studies elaborated on three internal niche processes that are eminent for understanding the niche development trajectories (Geels and Raven, 2006; Schot and Geels, 2008; Van der Laak et al., 2007): (i) *articulation of expectations and visions;* (ii) *building of social networks*; and (iii) *learning activities*. The framework indicates that these three interacting, mutually reinforcing and co-evolving processes lead to a niche development process, which progresses at two levels concurrently: the local projects level and the global niche level (Schot and Geels, 2008; Raven, 2005; Raven and Geels, 2010). The local projects level is composed of individual niche experiments that can build on each other over time (Geels and Raven, 2006) and the global niche level results from sequences and accumulation of these experiments transcending local contexts (Smith and Raven, 2012) through three internal niche processes.

In our conceptual framework, we show that the SNM perspective provides useful insights for the reconceptualization and empirical analysis of industrial symbiosis initiatives and regional industrial ecosystems. We argue that local industrial symbiosis initiatives and regional industrial ecosystems can be conceptualised as two different but interlinked heuristic levels and the emergence of regional industrial ecosystems can be explained by first identifying the local initiatives and then analysing their aggregating contribution through three analytical niche processes. Representing the merits of our conceptual framework, we employed a case study involving eight industrial symbiosis initiatives distributed over 18 years from the Autonomous Region of Catalonia in Spain (referred to hereafter as Catalonia) to understand the emergence of regional industrial ecosystems.

The main theoretical contribution of this paper is that we integrate two different research streams −industrial ecology and the SNM framework from the ST field − that have not often learned from each other, and we develop a comprehensive framework that provides the conceptual grounds for an empirical assessment of how contribution of set of industrial symbiosis initiatives to emergence of regional industrial ecosystems can be understood and explained. Operationalisation of our conceptual framework in a real setting also enables a novel case study methodology for industrial ecology literature, which did not provide an explicit methodological focus on a wide set of industrial symbiosis initiatives as separate units of analysis from the same region for assessing the emergence dynamics of regional industrial ecosystems. Introducing insights from the ST field, we generate new understandings by means of new empirical evidence from the Catalonia region, which has not been studied in the industrial ecology literature before. That regional empirical study illustrated our conceptual approach on how to study cumulative contribution of a set of industrial symbiosis initiatives to the regional industrial

ecosystems and resulted in empirical assessments for the chosen region. That may guide other studies to analyse other relevant contexts with a refined or the same conceptual approach as ours.

The developed conceptual framework is used in this paper as an analytical lens for ex-post evaluation (*see also* Schot and Geels, 2008; Raven and Geels, 2010; Van der Laak et al., 2007; Verbong et al., 2010 for further reading on similar approaches) of industrial ecosystem development in a region, but it can also be extended as a prescriptive management tool for planning and implementation of industrial symbiosis initiatives, both in Catalonia and in other regions. Finally, this paper also has some practical implications as it contributes to better understanding of intricately evolving dynamics for the emergence of regional industrial ecosystems, which strongly relate to the decisions and actions of industrial actors of all sizes, non-governmental organisations, entrepreneurs, universities and research institutes.

The remainder of the paper is structured as follows. In Section 2, we develop a conceptual framework, integrating industrial ecology literature and the SNM framework. Then, in Section 3 we present our methodology detailing the design of the selected regional case as our empirical context, triangulation in data and insight gathering, and finally data and insight analysis. In Section 4, we provide results and discussions through analysis of eight industrial symbiosis initiatives from the region in light of our conceptual framework. We present our interpretations on how those initiatives have been contributing to the emergence of regional industrial ecosystems for sustainability transitions of LIPS in the selected region. Finally, in Section 5, we offer our conclusion together with our contributions, implications and some suggestions for future research avenues.

2. Conceptual framework

In this paper, we approach industrial ecology as a systemic innovation model and emphasise the emergence of regional industrial ecosystems, considering the importance of regional focus (*see generally* Boons et al., 2011; Ashton, 2009; Deutz and Gibbs, 2008; Ristola and Mirata, 2007) in industrial ecology literature. Integrating industrial ecology literature and the SNM framework, we developed a conceptual framework (Fig. 1) that can be used in real settings for analysing and understanding the contribution of industrial symbiosis initiatives to the emergence of regional industrial ecosystems. Our framework distinguishes two mutually reinforcing and coevolving levels of analysis: the ***local industrial symbiosis experiments level*** and the ***regional industrial ecosystems niche level***.

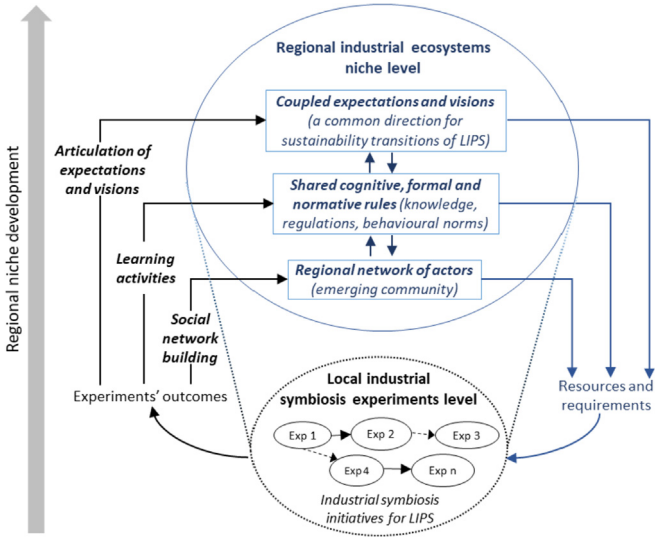

Fig. 1. Conceptual framework. Emergence of regional industrial ecosystems for sustainability transitions of LIPS. Adapted from (Geels and Raven, 2006; Schot and Geels, 2008; Baas and Boons, 2004; Raven and Geels, 2010).

The first level is the ***local industrial symbiosis experiments level***, which is composed of individual local industrial symbiosis initiatives. At this level, we conceptualise industrial symbiosis initiatives – that are, practical applications of industrial ecology – as local niche experiments. We refer to industrial symbiosis initiatives as any kind of experiment in the form of a project, research, task, mission, network formation action, etc. that may have been completed or on-going with an objective of supporting sustainability transitions of LIPS in the specific geography under focus. The industrial ecology literature provides a rich set of case studies on various industrial symbiosis initiatives (*see also* Susur et al., 2019 for a rich set of local level initiatives), among the most studied of which are Kalundborg (Valentine, 2016), Kwinana (Giurco et al., 2011), Tianjin (Yu et al., 2014), Dalian (Geng et al., 2008), Ulsan (Behera et al., 2012) and Devens (Veleva et al., 2015). Our approach has a wider focus than most of those studies, with the intention of involving multiple initiatives from the same region. Such an approach is prominent in the SNM studies but has received scant attention in the industrial ecology literature. More significantly, we stress the need to analyse the interlinkages between multiple initiatives (that is, in forms of either direct support or influence) and the potential aggregation of those initiatives for building regional industrial ecosystems, which is addressed in the next heuristic level of our framework.

The second level is the ***regional industrial ecosystems niche level*** following the underpinnings of the SNM framework regarding differentiation between the local projects level and the global niche level (Raven, 2005; Schot and Geels, 2008; Geels and Raven, 2006; Raven and Geels, 2010). We conceptualise regional industrial ecosystems at the niche level as a *regional network of actors* representing an emerging community that can overcome the lock-in to the linear industrial production routines in the region through establishing *shared cognitive and normative rules* and *coupling expectations and visions* of its wide variety of actors. Industrial ecosystems at the regional level have been studied in the industrial ecology literature before. The most relevant study to our conceptualisation was conducted by Baas and Boons (2004), who emphasised an evolution of regional industrial ecosystems at different stages of regional efficiency based on firms' autonomous decision-making and regional learning relying on mutual recognition, before arriving at the final stage of sustainable industrial production systems in regard to actors' strategic vision on sustainability. Nevertheless, the majority of the industrial ecology literature has approached regional industrial ecosystems as a regional industrial symbiosis network of industrial organisations (*e.g.* Heeres et al., 2004; Ashton, 2009) and has not explicitly analysed the *network building* by wide variety of regional actors – that is, formal institutions, research centres and universities, non-governmental organisations, entrepreneurial organisations, etc. – together with industrial organisations. Indeed, those actors are potentially engaged in *learning activities* collectively and, as such, contribute to *articulation of expectations and visions* in the region, which are actually considered as core elements for the niche building in the SNM studies (*see* Van Eijck and Romijn, 2008; Coenen et al., 2010; Van der Laak et al., 2007; Weber et al., 1999.

While conceptualising the links between two heuristic levels of our framework, we bring insights from the SNM studies (*specifically from* Geels and Raven, 2006; Raven and Geels, 2010) and argue that individual local industrial symbiosis experiments at the first level can build on each other and gradually add up to a ***regional***

industrial ecosystems niche level over time. For this gradual process, we specifically distinguish three interacting analytical processes building on the SNM framework: the ***articulation of expectations and visions***, ***social network building*** and ***learning activities***, which can be seen as aggregating outcomes of initiatives from the ***local industrial symbiosis experiments level***.

2.1. Articulation of expectations and visions

Articulation of expectations and visions is the first niche process considered for successful niche building in the SNM framework (Schot and Geels, 2008), which explains that when expectations and visions are specific, tangible, robust and shared by a wide variety of actors (Raven, 2005; Caniëls and Romijn, 2008; Coenen et al., 2010), they can be coupled to address certain sustainability challenges for building more effective niches (Weber et al., 1999). Concepts of expectations and visions were considered in industrial ecology literature as well, but not comprehensively and explicitly in the central arguments of the relevant studies.

Some already studied aspects of actors' *expectations* from industrial symbiosis initiatives can be listed as: the importance of managing institutions' and community's expectations for sustainability benefits to regions (Deutz and Gibbs, 2008; Rosano and Schianetz, 2014); the role of institutional capacity in forming expectations (Boons and Spekkink, 2012); the problematique of over-inflated and unrealistic expectations of developers and policy-makers (Deutz and Lyons, 2008; McManus and Gibbs, 2008; Sterr and Ott, 2004); the significance of diverging expectations (Baas and Boons, 2007) and converging expectations of actors (Valentine, 2016); and evolving expectations during the construction of industrial symbiosis networks (Ashton and Bain, 2012).

Furthermore, the *vision* concept was also addressed in industrial ecology literature in terms of building and expanding the vision of industrial ecology (Ashton and Bain, 2012; Adamides and Mouzakitis, 2009; Korhonen et al., 2001; Gibbs, 2008; Chertow et al., 2008); emphasising the importance of having a common strategic vision of sustainable development by regional actors (Baas and Boons, 2004; Spekkink, 2013; Veleva et al., 2016; Daddi et al., 2016; Rosano and Schianetz, 2014) and having a leader, a champion (Hewes and Lyons, 2008) or an anchor firm (Mulrow et al., 2017) in the region to tout this vision; and also explaining the national level visions of countries like China and South Korea for transforming LIPS into national level industrial ecosystem networks (Yu et al., 2015).

Yet, only a few studies (*e.g.* Baas and Boons, 2004; Baas and Huisingh, 2008; Boons and Spekkink, 2012) have addressed the articulation of expectations and visions during the evolution of regional industrial ecosystems. In this vein, bringing the SNM perspective to our conceptual framework, we further elaborate on the importance of that articulation process in creating coupled expectations and visions that can lead to a common direction for the journey of sustainability transitions of LIPS. Such a challenging long-term journey can be completed if new local industrial symbiosis experiments in the region are continuously designed with a visioning in line with coupling expectations and visions of the regional actors and if regional expectations and visions are robust, specific, ambitious and, at the same time, realistic.

2.2. Social network building

The second niche process is about network building (Schot and Geels, 2008) in the SNM literature, which argues that if the local networks are broad, deep and heterogenous (Van der Laak et al., 2007) – that is, inclusive to a variety of relevant actors from different experiments involving industrial organisations, formal institutions, non-governmental organisations, research centres and universities, local community, etc. (Coenen et al., 2010) – then a wider community can emerge with dedicated actors for protecting and supporting the niche building process in terms of facilitating resources and requirements for both new and already-developed local projects (Raven and Geels, 2010).

Network building has been a central topic in industrial ecology literature as well, while mostly referring to industrial symbiosis exchange networks between industrial organisations. Scholars from the industrial ecology field have looked at different aspects of network building, such as growth patterns of symbiosis networks (Zhu and Ruth, 2014); structural characteristics and the role of different actors in symbiosis networks through social network analysis perspective (Chopra and Khanna, 2014); multiple dimensions of embeddedness in symbiosis networks (Ashton and Bain, 2012); social relationships between industrial organisations (Ghali et al., 2014); the role of trust and local champions in industrial symbiosis networks (Hewes and Lyons, 2008); and the importance of coordinating bodies to facilitate symbiotic connections between industrial organisations (Tessitore et al., 2015). However, relatively few studies (*e.g.* Baas and Boons, 2004; Boons et al., 2011) have focused on network building covering a variety of actors, rather than only focusing on industrial organisations in the symbiosis networks.

Incorporating the SNM approach, our conceptual framework holds such a wider network perspective, covering relevant regional actors (governmental and non-governmental organisations, research centres and universities, local champions, managing/coordinating bodies, entrepreneurs, local community, etc.) that participate in the planning and implementation of industrial symbiosis niche experiments. We propose that local industrial symbiosis experiments can lead to a regional network of actors as an emerging community for regional niche building if social network building process is broad, deep and heterogenous enough to involve multiple stakeholders and to mobilise their available resources. Such an emerging community can protect on-going regional niche building process and bring support in terms of necessary resources and requirements for continuous industrial symbiosis experimentation in the region.

2.3. Learning activities

The final niche process is related to *learning* in the SNM framework (Schot and Geels, 2008). The learning concept has been widely addressed in the industrial ecology literature as well. Going back to the roots of industrial ecology, its essential argument is based on learning from an analogy with nature and its ecosystems (Frosch and Gallapoulus, 1989). Then, the industrial ecology literature gave considerable attention to collective learning by the industrial organisations in production systems (MacLachlan, 2013; Grant et al., 2010) and on collective learning by all relevant regional stakeholders (Baas and Boons, 2004; Roberts, 2004; Veleva et al., 2016; Lambert and Boons, 2002) through means of communication events (trainings, seminars, conferences, workshops, etc.), media (television, radio, internet, newspapers, magazines, etc.), and information communication technologies (information and knowledge sharing and management platforms).

Building on and extending those studies, our conceptual framework emphasises the notion of regional collective learning to create a regional shared culture, which we define as shared cognitive, formal and normative rules that refer to common knowledge, required regulations and converging behavioural patterns of the network actors respectively building on Geels and Raven (2006), Geels (2004) and Raven and Geels (2010) from the

ST field. We argue that learning activities are not only expected to trigger first-order learning through which actors can identify a problem and correct it without changing the underlying rules, but also – and even more importantly – they may facilitate second-order learning through real implementations (*see generally* Boon et al., 2014; Grin and Van de Graaf, 1996 for further reading on second-order learning). Consequently, a regional shared culture may be constructed through changes in the underlying rules and status quo governing the mainstream behaviour (*see also* Mirata and Emtairah, 2005; Argyris, 1997; Schot and Geels, 2008). The second-order learning can be enforced by developing tacit knowledge (Ghali et al., 2014) by the exchange of local and international good practices and experiences (Boons et al., 2017) and the continous experimentation with local industrial symbiosis projects. Effective interactions and dialogues are expected to facilitate this process (Baas, 2011). Moreover, second-order learning can be achieved more smoothly if there are regional champions (*see generally* Hewes and Lyons, 2008; Qu et al., 2015) and coordinating bodies (*see generally* Domenech and Davies, 2011; Boons and Spekkink, 2012) that can act as good examples and facilitate interactions, creation of common language, and joint-problem solving for a wide variety of regional actors.

Our conceptual framework proposes that proper combination of these three niche processes can lead to the emergence of a regional industrial ecosystems niche level that involves a regional network of actors holding coupled expectations and visions through shared cognitive, formal and normative rules. This regional niche level then can provide support and protection measures for the resources and requirements – tax regime, environmental regulations, policy programmes, financing incentives, etc. – needed to plan and implement new industrial symbiosis niche experiments in the region. Thus, we conceptualise a continuous feedback mechanism between two heuristic levels of analysis that may lead to continuity and stability in regional industrial ecosystem development. We propose that if this feedback cycle sustains for long enough, a regional culture change may occur and LIPS in the region may employ closed industrial production loops and experience sustainability transitions into circular industrial production routines.

Similar to the ontological accounts of the conceptual frameworks from the ST field (*see* Geels, 2010 for an elaboration on this), such as the multi-level perspective (Geels, 2002; Kemp et al., 1998) and the technological innovations systems framework (Bergek et al., 2008; Hekkert and Negro, 2009), those two levels in our framework are not claimed to provide "ontological descriptions of reality" (Geels, 2002), but they are developed as analytical concepts, which can guide us to analyse and understand the intricately evolving dynamics of the emergence of regional industrial ecosystems in real settings.

3. Methodology

In this paper, we employed a case study methodology to empirically assess how industrial symbiosis initiatives can contribute to the emergence of regional industrial ecosystems for sustainability transitions of LIPS. Case study methodology is commonly used to answer “how” questions by focusing on understandings of the dynamics and processes in particular settings (Eisenhardt, 1989) and it provides a solid foundation for constructing “context-dependent knowledge” (Flyvbjerg, 2006), while studying complex and contemporary research objects (Yin, 2014) like industrial ecosystems. While designing, analysing and interpreting our case study, we have used our conceptual framework to improve the explanatory power of the study (Dubois and Gadde, 2002) and to represent the merits of our conceptualisation when applied to a real setting.

3.1. Case selection and design

The empirical setting of the case study was chosen to be Catalonia from Spain, which has not been a focus for related research studies despite its diverse and rich industrial production culture and routines embedded in a long industrial tradition. The region was one the early adopters of British industrialisation model in the nineteenth century. Manufacturing sector has been a main employing sector in the region; for example, it employed 21 per cent of the total Catalan workforce in 1860, 47 per cent in 1930, and 18.4 per cent in 2014, despite the general de-industrialisation trend and global crisis (Domenech and Ramos, 2016).

In Catalonia, development of agglomerated industries was first promoted by the industrial development policy of the 1960s. Since then, LIPS has been the most salient form of developing industrial areas and the economic reality of the region, especially since 1980s (Incasòl, 2007). Industrial activity, in general, represents almost 20 per cent of GDP in the region. There are more than 40 LIPS, including almost 9000 industrial establishments, generating turnover of more than 45 billion Euros, contributing to an estimated 10 per cent of the region's GDP (Hernández et al., 2005). The region has been relatively active in sustainability-oriented initiatives because its rapid industrial development has surpassed the available land for further development. The intensity and diversity in geographically agglomerated industries have provided a proper ground for potential exchange synergies between industrial actors, which may create industrial ecosystems in the region.

We followed an embedded case study design with multiple units of analysis (Yin, 2014) – that is, various industrial symbiosis initiatives – to understand how these initiatives contributed to the emergence of regional industrial ecosystems. After a review of the literature, internet and research reports, we selected eight industrial symbiosis initiatives from the region, which have addressed sustainability transitions of LIPS in the region through their objectives and activities. Seven of these initiatives were completed, while the other is still on-going. The selected set of initiatives covers an 18-year time span, from 1999 to 2017. Temporal distribution of initiatives, together with their names, start and end years, are illustrated in Fig. 2 below.

After identifying these eight initiatives, we conducted interviewees and collected available secondary data from the interviewees and from online sources to develop an integrated set of interpretations (Yin, 2014) drawing upon our conceptual framework.

3.2. Data and insight gathering

This study is based on two different sources of empirical material, considering *triangulation* of the data and insights (Yin, 2014; Creswell and Clark, 2007) to enhance the credibility of our research results while securing an in-depth understanding (Denzin and Lincoln, 2005).

Firstly, secondary data related to industrial ecosystem development in Catalonia was used as a source of evidence to trace the related industrial development in the region. Collected secondary data includes comprehensive reports from governmental organisations, interim and final reports of selected local experiments, press

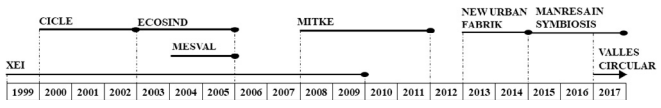

Fig. 2. Temporal distribution of eight industrial symbiosis initiatives under analysis from Catalonia over 18 years.

releases, presentations, posters, articles, news and blogs published in the mass media or in community newspapers. All the secondary data was selected considering their source and scope (Hox and Boeije, 2005), their trustworthiness and their relevance to our research question. Secondary data inventory is given in Appendix A.

Secondly, semi-structured interviews were conducted with the most relevant actors in relation to the selected industrial symbiosis experiments from the region. We started our interviews with key informants who were involved in design and implementation of the initial experiments; during our interviews with them, we identified more key informants using the snowball technique (Lincoln and Guba, 1985; Heckathorn, 2002) for other selected experiments. Finally, from May 2017 until October 2017, we conducted eight interviews with nine interviewees. All interviewees were involved in design and implementation of the selected experiments with key roles, such as manager, coordinator, expert, and principal architect. Thus, they were able to provide us with the holistic background, design, implementation and follow-up situation of the experiments. The interviews lasted between 35 and 90 minutes. All interviews were recorded after obtaining the consent of the interviewees. Follow-up enquiries were conducted by e-mail or telephone and further secondary documents were collected from the interviewees as well for the sake of triangulation. The interviewees are listed in Appendix B.

Here we recognise that although the relatively high number of industrial symbiosis initiatives were included in the study, more initiatives may have pictured a more robust regional perspective. Yet, we never claimed to present a set of regional truths and have instead looked for ways to understand the regional niche development processes, which may help further regional policy development or inspire other regional development agents. Moreover, more interviewees from each initiative could have provided more insights as input for our interpretation and discussion. Still, the selected interviewees were selected in a way that all of them had key roles for selected initiatives and had extensive knowledge about the details of its development. Also, triangulation of data and insight sources have added more trustworthiness to our empirical study.

Regarding the design of semi-structured interviews, we had a priori framing of the underlying interview questions (Creswell, 2009), encompassing the underpinning conceptual elements of our framework. We formulated the questions to examine: (i) the background of the interviewee; (ii) general information about the routines of industrial production systems in the region (that is, the industrial actors and industrial composition/specialisation of the region, related regulations in the region, infrastructure, regional interest in sustainability); (iii) detailed information about the related initiative (that is, the expectations and visions of the actors, the achieved results and unexpected outcomes, if and how the initiative was in relation to other similar initiatives in the region, network building activities, the involved actors and their level of involvement, challenges and success factors encountered during the development of the initiative, learning-oriented activities and learning outcomes for different actors); and finally (iv) general information about the region in regard to other similar initiatives and other relevant actors based on the experience and the knowledge of the interviewee.

Moreover, we have tailored the questions in language that would be understandable by the interviewees (Meyer and Ward, 2014). Still, interviewees were are also permitted to explain beyond the answers to the drafted questions in order to gather more insights without concrete constraints. It is also crucial to note that those interviews alternated between retrospective and prospective reflections (*see generally* Schultze and Avital, 2011) of the interviewees. More specifically, most of the interviewees firstly shared with us their past experiences and ideas – that is, retrospective reflections (Eisenhardt and Graebner, 2007) – about the specific local experiments because seven of eight experiments were already completed (see Fig. 2), and also there were prospective reflections from those interviewees evolving during the interviews when they started envisioning ideal conditions for regional industrial ecosystem development based on their past experiences and shared those ideas with us. It is worth pointing out that we were aware of potential recall bias, which may be due to retrospective distortion (Miles, 1979). However, in this paper, we hold a sustainability transitions perspective with an evolutionary approach, which requires an analysis of various events distributed over a considerable time-span (Farla et al., 2012) and this makes it necessary to gather and analyse retrospective data and insights. In order to avoid this potential bias due to retrospective reflections for completed industrial symbiosis experiments, we shared the semi-structured interview questions with the interviewees in advance of the interviews, and during the interviews we gave them enough time to reflect and think before answering (Hassan, 2005). Furthermore, using secondary data considering triangulation also enabled us to scrutinise reflections and insights of the interviewees by means of multiple sources of evidence (Gioia et al., 2010) in order to allay the potential recall bias concerns.

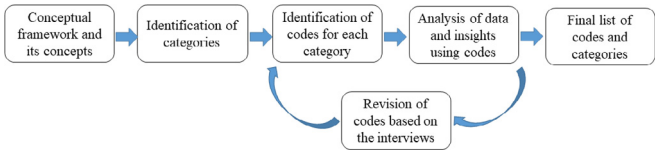

Fig. 3. Identification of codes and categories. Source: Authors' own elaboration.

3.3. Data and insight analysis and interpretation

In this step, we analysed the data and insights by means of codes and categories, and then interpreted the relationship among them through explanation building (Yin, 2014) to answer our research question. Firstly, we identified categories and codes based on the underpinning concepts of our conceptual framework; that is, the three niche internal processes that are articulations of expectations and visions, social network building and learning activities. Then, we further revised the coding scheme while analysing the data and insights, which led to the final list of codes and categories, as illustrated in Fig. 3.

Once the codes and categories were iteratively identified, we completed coding data and insights and allocated them to the relevant categories for each local industrial symbiosis experiment. We used the analytic technique of *'explanation building'*, which is a type of pattern matching (Yin, 2014), to observe the patterns and interpret the relationship among the codes in light of our conceptual framework to explain how each local industrial symbiosis experiment and its outcomes influenced three internal niche processes and how these processes can collectively contribute to regional industrial ecosystem niche building for sustainability transitions of LIPS in Catalonia.

In the following section, we present how the emergence of regional industrial ecosystems can be understood by analysing the identified prominent local industrial symbiosis experiments from the region and by assessing their interlinkage and aggregating contribution to an emerging regional network of actors through coupled expectations and visions and shared cognitive, formal and normative rules.

4. Results and discussions

This section is structured based on the conceptual foundations of

our framework to theoretically strengthen the understanding of regional industrial ecosystems' niche emerging dynamics. We start by describing the identified industrial symbiosis experiments that were implemented in Catalonia over the past two decades or so and analytically represent how those experiments have been interlinked. In Section 4.2, we present our assessment on the identified experiments' influence on regional niche building processes, which are the articulation of expectations and visions, social networking and learning activities. Subsequently, in Section 4.3, we discuss how those processes conduced towards the emergence of regional industrial ecosystems niche, and then represent our overall empirical assessment through operationalisation of our conceptual framework.

4.1. Local industrial symbiosis experiments level

In the region, industrial ecology and industrial symbiosis started to be discussed through the end 1990s at the academic level with efforts of some academicians from Universitat Autonoma de Barcelona (UAB) and Universitat Politècnica de Catalunya (UPC), Universitat de Girona (UdG) and Universitat Rovira i Virgili (URV) as the first bricks on the regional niche building wall. The first few experiments were initiated by academia in collaboration with related governmental organisations, followed by various other experiments.

In this paper, we analysed the local industrial symbiosis experiments level through a selected set of eight industrial symbiosis experiments covering a period of 18 years starting from 1999 and coming up till 2017. Table 1 gives an overview of each experiment with its name, dates, objective, initiator and related important actors and their roles.

The local experiments level in Catalonia showed characteristics of both top-down and bottom-up development characteristics, in both cases aiming to establish connections between academia, governmental organisations and industry. Data and insights revealed that those connections resulted in fruitful interactions that led to considerable linkages between local experiments.

XEI, as the first experiment, was created and initiated by actors from the academia in the region, which had leading roles as niche players. The same players from these universities and research institutes also had direct roles in terms of designing, lobbying and networking for the creation of CICLE, ECOSIND, and MESVAL experiments, although these three were initiated by governmental organisations through regional or international funding. Another experiment, MITKE was also started by a regional governmental organisation and was linked to another experiment, ECOSIND, through which MITKE coordinators from Catalonia had learnt ways of starting such experiments in terms of fundraising and international partnering. Although Manresa in Symbiosis was triggered and implemented by a private niche player, it had the support of governmental organisations and it drew upon previously gained knowledge in Manresa through the MESVAL experiment. Finally, Vallès Circular, the recently started and on-going experiment, is a county-based circular economy initiative that has been developed based on the knowledge of the actors and experience of the region coming from previous experiments, such as XEI, CICLE, ECOSIND and MESVAL.

Analytical illustration of these linkages between niche experiments is presented below in Fig. 4. Only New Urban Fabrik experiment is missing in this figure as this was an early-phase experiment and differs from others because it was not implemented. It was included in this paper to reflect the importance of power issue in sustainability transitions, which is discussed later in Section 4.2.1. Those interlinkages between the experiments show clues of emerging regional industrial ecosystem niche level in the region. We further elaborate on this in the next section through analysis of local experiments' contribution to three niche building processes.

4.2. Experiments' influence on regional niche building processes

Data and insights showed that each industrial symbiosis experiment contributed, to some extent, to regional niche building processes. Table 2 summarises the changing characteristics of niche processes in each experiment and is further explained through our following discussions on each niche process separately.

Table 1
Overview of analysed industrial symbiosis projects.

Experiment and dates	Objective	Initiator	Important actors
XEI 1999–2009	To build a thematic network of industrial ecology, aiming to involve academia, industry and policy-makers.	UAB, UPC, UdG and URV	Financially supported by Department of Universities, Research and Information Society (DURSI) of the Government of Catalonia at that time.
CICLE 2000–2002	To identify the concrete possibilities of applying industrial ecology in Catalonia focusing on leather and paper industries.	UPC	Financially supported by Waste Agency of Catalonia.
ECOSIND 2003–2006	To foster sustainable development of industrial production systems based on industrial ecology principles for Catalonia and other partner regions from Italy and Greece.	Ministry of Environment of Government of Catalonia as consortium leader	Designed by XEI members (mainly by UAB and UPC); funded by Interreg Programme of European Commission.
MESVAL 2004–2006	To build a new industrial ecology network between technological centres, chambers of commerce, and the universities from Catalonia, Tuscany (Italy) and Peloponnesus (Greece).	Coordinated by UPC.	Funded by ECOSIND budget as a sub-project.
MITKE 2008–2011	To retrofit existing business and industrial areas and transforming them into sustainable spaces in the partner regions.	Catalan Land Institute (Incasòl) as a consortium partner	Funded by Interreg Programme of European Commission; consortium leader as Sprilur which is LIPS Development Agency of Basque Country in Spain
New Urban Fabrik 2013–2014	To evaluate the feasibility of transforming Torrent Estadella (old LIPS) into an eco-industrial park.	Barcelona City Council	Prepared by Eduard Balcells Architecture, a private architecture company
Manresa in Symbiosis 2015–2017	To implement the first applied industrial symbiosis project in Catalonia to maximize efficiency in the use of available resources.	The municipality of Manresa and Waste Agency of Catalonia	Run by Simbiosy, a regional private consultancy company as the project consultant; supported and facilitated by Bages Consortium of Waste Management and Department of Territory and Sustainability of Regional Government of Catalonia.
Vallès Circular 2017–ongoing	To promote circular economy by building networks in the territory in order to take advantage of new ways of industrial production and also consumption.	The Vallès Occidental County Council	Supported by Government of Catalonia and the Barcelona City Council.

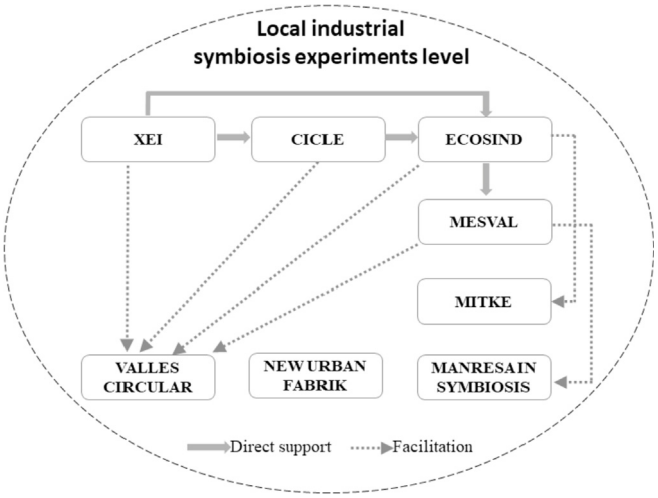

Fig. 4. Interlinkages between local industrial symbiosis experiments.

4.2.1. Articulation of expectations and visions

Even before the first local industrial symbiosis experiment, XEI, there had already been an established common ground about the need for sustainable development in the region. However, introducing industrial ecology as a new concept to the academic environment in Catalonia and as a new policy and development tool to the region was a difficult task for the creators and coordinators of the XEI. There was no vision among different actors in the region about what industrial ecology actually meant and how it could address sustainability problematic related to industrial production in the region. In this vein, the co-creator and member of XEI stated:

> *"It was not easy to start industrial ecology in Catalonia. We were trying to inform several regional actors why industrial ecology was important and how it was different than other sustainable development actions … But it was very difficult to convince them … For example, if the industry doesn't see any immediate economic profit, they normally do not get involved. And the mentality of the governmental institutions was not really open to new concepts."*

Since XEI was initiated in 1999, a sequence of industrial symbiosis experiments has been implemented and a regional understanding of industrial ecology has been established, although those experiments were conducted through varying expectations and visions and resulted in different achievement levels.

Relatively large-scale experiments, in terms of a bigger budget, a higher number of partners and longer duration like ECOSIND and MITKE, were initiated by the regional governmental organisations, which had positive and high expectations from the beginning that were not easy to achieve. In the ECOSIND case, for example, once the experiment was started it was challenging to create a common understanding even within the Ministry of Environment of the Catalan Government and to engage the industry in the experiment due to their lack of experience in similar initiatives. The outcomes of the experiment demonstrated the importance of having *a common vision and expectation* among the involved actors. Based on his

Table 2
Overview of internal niche processes for each experiment.

Experiment	Expectations and visions	Social network building	Learning
XEI	Positive and high-level expectations on network building through a knowledge exchange platform. No common vision of what industrial ecology meant.	A thematic network of regional actors including researchers, universities, governmental organisations and industry. Involvement in related international academic societies.	Facilitation of knowledge and experience exchange through events. Learning outcomes for industrial actors and governmental actors that led to cultivation for CICLE and ECOSIND.
CICLE	Positive and medium-level expectations to uncover the potential of industrial ecology in the region.	Network building activities for recycling bodies and industrial actors.	Second-order learning for industries and recycling bodies. Learning outcome for Waste Agency of Catalonia, which was a supporter of ECOSIND.
ECOSIND	Positive and high-level expectations to establish a new regional industrial symbiosis strategy. Difficulty in having common expectations among international partners of the project. Blurred vision about the new and relatively radical practice – that is, industrial symbiosis – for regional governmental organisations and the industry.	A consortium of international partners directly leading to cross-national networking between Spain, Italy and Greece. Loose network among related regional actors such as the Union of Catalan Industrial Estates (UPIC), Catalan Land Institute (Incasòl) and the industry.	Knowledge transfer to governmental organisations and the industry through events. Cultivation for MESVAL through direct funding. Cultivation for MITKE initiative through knowledge sharing with Incasòl. Failed second-order learning for the industry.
MESVAL	Positive and medium-level expectations for a new industrial ecology network in the region with a vision to create a regional waste recovery strategy.	Initiating a cross-regional and cross-national network of technological centres, chamber of commerce and universities of three regions from Spain, Italy and Greece.	Learning within the cross-regional network through knowledge exchange events. Learning for local actors in Manresa, which then facilitated Manresa in Symbiosis.
MITKE	Positive and high-level expectations for retrofitting existing regional industrial areas and transforming them into sustainable spaces. Common vision among international partners for creating region-tailored solutions. Lack of regional consciousness of "industrial symbiosis".	Cross-regional and cross-national networking between 11 partners including regional development agencies, business networks and land developers and research centres from Basque Country, Catalonia, and regions of seven other countries. A pan-European platform for retrofitting existing LIPS.	Knowledge sharing and co-creation based on best-practices among international partners. Second-order learning outcomes for Incasòl in terms of planning a follow-up project and, more importantly, an institutional change.
New Urban Fabrik	Neutral and medium-level expectations on potential transformation of an old LIPS, into an eco-industrial park. Interrupted and changed expectations due to change in power actors.	No network building activity except the established relations between the actors in Barcelona City Council and the consultancy team.	Ineffective first-order learning for the governmental organisation; that is, no outcome from the experiment.
Manresa in Symbiosis	Positive and high-level expectations to realise real symbiotic exchanges and become a success demonstration story for future related experiments. Lack of territorial vision despite gained previous knowledge in MESVAL.	Good communication with sensible local and regional actors through network building. Lobbying activities for bringing protection and support to start, implement and follow-up the initiative.	First-order learning for the industry and governmental organisations on how to launch such experiments. Mining out previous knowledge in Manresa gained through previous experiments, such as MESVAL. Second-order learning for the industry by real symbiotic exchanges.
Vallès Circular	Positive and high-level expectations and vision for promoting circular economy in Vallès Occidental County to become a reference circular economy territory that will serve as a branding instrument.	Network building experiment by its objectives. An agreement signed by 30 entities, including municipalities, universities, research centres, business organisations, and industry.	Regional learning through dissemination activities and events in the network.

experience, the experiment coordinator noted, with regret:

> *"If I started ECOSIND now, as the public servant that I am, I would try to put all people in charge from all Departments on the same table and start the project together … Now I know the methodology. First thing is to put all the Departments with the same vision and try to achieve a governance model in order to go in the same direction. Another step is to integrate industry in this initiative. We already have a lot of experience here in Catalonia combining private and public sector with the same visions … We have experience and frameworks to achieve this."*

On the other side, the data and insights related to the MITKE experiment revealed that there was a lack of regional consciousness of "industrial symbiosis". In the experiment, neither industrial symbiosis nor eco-industrial park terminology was used in terms of its *vision,* although they were among its core expectations. As the project development coordinator of Incasòl stated:

> *"We did not call it industrial symbiosis in the project, although we were with it all the time now we see it … For us, it was about the fact of the collaboration between LIPS or the companies. Industrial symbiosis, now we see it, was an ideal that we were trying to get to."*

Unlike those experiments, CICLE, designed by XEI core members, was the first local experiment to facilitate real symbiotic exchanges between industrial actors. Its vision was to learn the concrete possibilities of applying industrial ecology in Catalonia. Among the other analysed experiments, only one – Manresa in Symbiosis – had a similar vision regarding facilitation of real symbiotic exchanges, but on a smaller scale; namely, in Manresa. The local actors in the city already had knowledge background of what an industrial ecosystem would mean by means of another experiment, MESVAL. However, Manresa in Symbiosis, despite the local previous knowledge and familiarity gained through MESVAL, still faced with difficulties to convince especially the industry to get involved in the network of exchanges.

Among the set of analysed experiments, The New Urban Fabrik was an interesting example reminding the issues of power. The vision and expectations of the Barcelona City Council changed after the party in power changed and this led to the failure of the initiative and interrupted its implementation. Indeed, as Truffer and Coenen (2012) stated, "sustainability transitions are by their very nature political projects" and transition processes might change based on the change in interests of specific power actors or on the change of power actors themselves, as was the case for this experiment. The principal architect of the experiment explained this as:

> *"… Then the political government changed … When we went to the new responsible for the urban design and they said the project was still interesting, but the new City Council was more focused on social housing building. Our project was not prioritised. In the end, it was a more like a research proposal and, at a certain moment, there had been a will to realise it. Of course, a real application would require a policy support …"*

The last experiment, Vallès Circular, is a territorial circular economy initiative and is protected by governmental organisations through articulated expectations and visions from previous experiments, such as XEI, CICLE, ECOSIND and MESVAL. Industrial symbiosis is covered in its vision in relation to the creation of a public–private collaboration ecosystem and the recognition of companies and entities that act as agents of change. This implies a vision shift in the region. The circular economy, as a bigger umbrella concept for industrial ecology, is becoming a promising and more popular policy tool for the regional industrial development. This may be due to its clear emphasis on 'economy' although the core emphasis is on the resource scarcity same as industrial symbiosis. One of our interviewees, UAB professor, co-creator and member of Vallès Circular, explained this as follows:

> *"Now, the circular economy concept has more power. At this moment the symbiotic relations, or the idea, philosophy behind the symbiotic relations are included in circular economy development here in Catalonia."*

4.2.2. Social network building

The results showed that the network building has been a crucial activity for the analysed experiments, except the New Urban Fabrik experiment, which only established relations between the actors in Barcelona City Council and the consultancy team. Regional network building was started with XEI experiment, which facilitated a thematic network of industrial ecology composed of researchers, universities, the industry, and governmental organisations. The network worked continuously to include more members to raise regional awareness. Furthermore, co-creators of XEI from academia were also members of International Society for Industrial Ecology (ISIE) and as such, they acted as knowledge bridges between the region and ISIE.

Network building activities were not limited only to the regional actors but also were achieved at the cross-regional and cross-international level in the experiments that were implemented by international consortiums; that is, ECOSIND, MESVAL and MITKE. Those experiments, by their visions and expectations more related to planning and strategy making, established links between universities, governmental and non-governmental organisations and, to some extent, the industry. Thus, the industrial symbiosis network, based on the symbiotic exchanges, did not emerge and there was a minimal involvement from the regional industrial actors in those experiments.

On the other hand, applied industrial ecology-oriented experiments like CICLE and Manresa in Symbiosis revealed the crucial role of the industry and facilitated concrete relationships between regional actors and the industry. CICLE had positive results in terms of realising some pilot symbiotic exchanges between industrial actors and it enabled information exchange between recycling bodies and the industry. Trust was the common issue in both experiments and it was difficult to convince industrial actors to share information and become involved in the initiatives. The project team of Manresa in Symbiosis worked individually with various industries to identify potential synergies that would motivate the industry's willingness to participate. The coordinator of the project underlined that:

> *"… firstly we identified the most sensible actors from the region to realise this project. Then we worked as activators to start it …"*

The results of Manresa in Symbiosis showed that in only a year and a half, 27 companies have participated, 50 businessmen and technicians have been involved and eight synergies, four of which are in implementation, have been identified. Although the official contract has ended, the project coordinator said:

> *"An industrial symbiosis project never ends … It is a continuous process …"*

In line with this, the project team continued lobbying and networking to have further support from the governmental organisations to ensure the continuation of the experiment. The Waste Agency of Catalonia continues to financially contribute to the promotion of industrial symbiosis in Manresa.

Finally, Vallès Circular was initiated in 2017 through the efforts of County Council to bring together actors from earlier niche experiments such as XEI, CICLE, ECOSIND and MESVAL. The agreement includes 11 of 23 local municipalities from the County, as well as other regional and local actors like Department of Territory and Sustainability from the Government of Catalonia, Barcelona City Council, Waste Management Agency of Vallès Occidental, business organisations, chambers of commerce, universities, and industry.

4.2.3. Learning activities

We distinguished learning outcomes from all experiments, except the New Urban Fabrik experiment, which was interrupted and not implemented due to change in power actors, as explained before. Starting with the XEI experiment, the thematic network creators and members organised various communication events, including meetings, workshops, forums, conferences, and seminars for knowledge exchange within the network and for bringing in new network members. The actors from governmental organisations who became directly involved in these learning events mainly had technical responsibilities in their home organisations, but they still acted as learning facilitators for other institutional actors who had more political power to initiate new experiments. Furthermore, co-creators of XEI from academia were also members of the International Society for Industrial Ecology (ISIE) and, as such, they acted as knowledge bridges between the region and ISIE. There was reciprocal learning as these academicians were sharing what they learnt from ISIE based on international experiences with the regional actors and they were also explaining the existing situation in Catalonia to the ISIE.

The CICLE experiment was a learning outcome of XEI as it was initiated through the funding from Waste Agency of Catalonia, which had gained relevant knowledge from XEI communication events. CICLE, with its vision towards applied industrial ecology in the region, managed to activate industries and recycling bodies by means of facilitating their involvement in pilot symbiotic exchanges. Thus, it was one of the few experiments that have provided a second-order learning outcome for the industry through real implementations.

ECOSIND was initiated after almost three years of preparation by XEI members together with the Ministry of Environment of the Catalan Government. Knowledge dissemination and learning activities from XEI, and also raising awareness achieved by the CICLE Project, were the main triggers for starting this experiment. By means of communication events, ECOSIND helped other regional actors to learn, especially from its Italian partners that had already been active in implementing industrial symbiosis projects. They learnt that collaboration with the industry was key to achieving good results from such experiments. However, there was a limited interest from the Catalan industry in ECOSIND due to missing exemplary successful industrial symbiosis cases in the region. As also stated by the UAB professor who was the co-creator of XEI and an expert in ECOSIND:

> *"A small set of regional demonstrative successful actions were what we needed. Not only one big industrial ecosystem experiment … We needed a critical mass of actions in different industrial sectors at different regional locations. Disseminating these small-scale but well-done examples through mass media could attract the industry."*

Although ECOSIND did not achieve a set of applied industrial ecology actions, it did lead to other regional projects. MESVAL was one of the sub-projects funded by the ECOSIND. The main beneficiary was Manresa city in Bages County. The MESVAL team not only evaluated and reported the industrial ecosystem development potential of Manresa but also built local awareness for local actors through the exchange of knowledge and expertise between international partners. Local actors in Manresa developed a local knowledge background for what an industrial ecosystem would mean and what to expect from such an experiment through learning.

This learning outcome later facilitated the Manresa in Symbiosis experiment. However, despite having a previous knowledge and familiarity with practices of industrial symbiosis, it was still difficult to convince the industry to get involved in the network of exchanges. Again, a small set of successful demonstrative industrial symbiosis exchanges were missing to attract the industry. In order to fulfill this gap, Manresa in Symbiosis experiment created second-order learning outcomes for local industry through practising physical and non-physical symbiotic exchanges between industrial actors.

Another second-order learning outcome from local industrial symbiosis experiments level was for a governmental organisation, Incasòl, which was motivated through ECOSIND for initiating a new experiment using similar funding mechanisms and designed MITKE experiment. This experiment served as a learning platform and provided mechanisms for the collection, exchange and transfer of knowledge using the potential of its crowded international consortium. At the communication events organised during MITKE, Incasòl had the opportunity to draw upon synergies between different regional actors while co-working with them to create a management model for LIPS. The organisation *learned* that such a management model would require government involvement in the whole process. Yet, Incasòl did not have any direct responsibilities or even possible roles in LIPS management, and in fact, it may have had a crucial role in promoting and facilitating industrial symbiosis in LIPS development. The head of the Environment Department of the instituion explained this as follows:

> *"… We are trying to incorporate the knowledge that has been acquired from MITKE … What we have learnt is that industrial symbiosis is within the LIPS management and it cannot be thought separately … Luckily, there has been a desire among all parties to promote some regulatory changes. In fact, we are now in a moment of change, that we should take advantage of the changes in urban planning law with respect to approval of a new law that we call the Law of Territory, so that Incasòl may have direct or indirect involvement in LIPS management."*

Moreover, Incasòl signed an agreement in 2008 with the local government of Camí dels Frares in Lleida for Camí dels Frares Industrial Park. After learning from the best practices from other member regions of MITKE project, Incasòl had the opportunity to implement its knowledge by conducting pilot work on integral management of services of this LIPS.

Finally, Vallès Circular stands as a learning outcome of XEI, CICLE, ECOSIND, and MESVAL experiments and implements regional learning by extending its agreement network and continuous knowledge dissemination and communications events.

4.3. Regional industrial ecosystems niche level

In our conceptual framework, this level is characterised by coupled expectations and visions; shared cognitive, formal and normative rules; and regional network of actors. Thus, discussions on this level are central to understand how industrial symbiosis initiatives can contribute to the emergence of regional industrial ecosystems for sustainability transitions of LIPS.

Thus far, we have analysed the local industrial symbiosis experiments and presented their influence on each regional niche

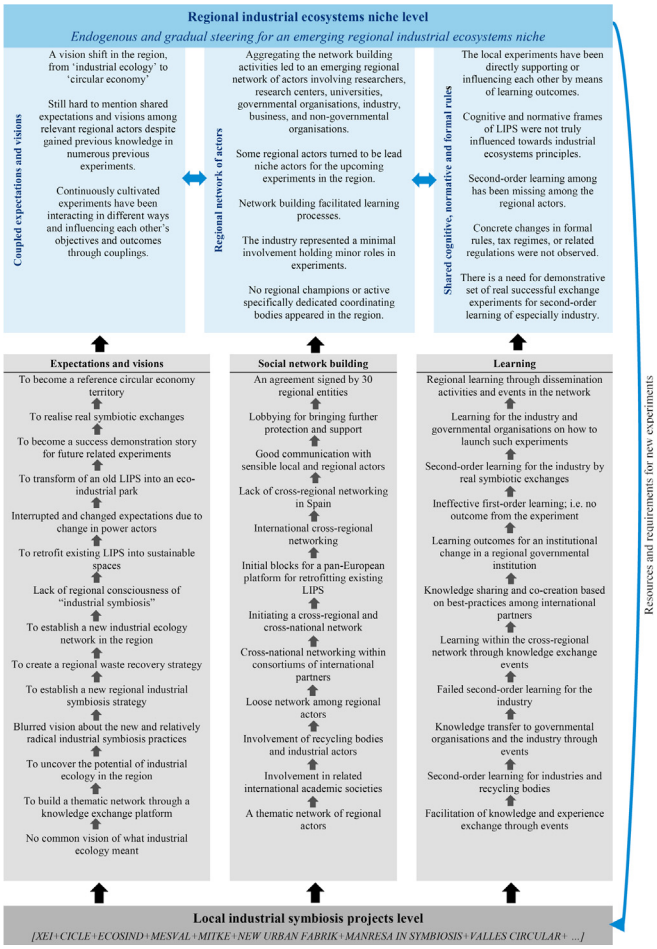

Fig. 5. The emergence of regional industrial ecosystems niche in Catalonia.

building processes. We now synthesise the obtained results to discuss the aggregation of these processes, which shed light on empirical assessment of regional industrial ecosystems niche in Catalonia, as illustrated in Fig. 5.

Empirical data and insights from the region provided clues to observe a regional endogenous and gradual steering for emerging regional industrial ecosystems through regional networking, which demonstrated a collective representation (*see also* Schot and Geels, 2008 for further reading on collective representation) involving various regional actors: regional and local governmental organisations, researchers, universities, private consultancy companies, regional development agencies, and industry. The built networks as the outcome of experiments varied in structure for each experiment, in terms of involved actors, and in dynamics, in terms of different collaboration mechanisms. Considering those networks, it can be concluded that a regional network of actors has been emerging in Catalonia.

Based on characteristics and results of local industrial symbiosis experiments, it is still hard to mention about shared expectations and visions among relevant regional actors. Nevertheless, continuously cultivated experiments have been interacting in different ways and influencing each other's objectives and outcomes through couplings. Network building can be pictured as a common expectation and vision among the analysed experiments and it facilitated learning processes which afterwards conveyed expectations and visions to regional actors. Those actors later turned out to be niche actors for the upcoming experiments in the region. In other words, the local experiments have been directly supporting or influencing each other by means of network building and learning outcomes.

A crucial shortcoming of most experiments was the minimal involvement of the industry. Cognitive and normative frames of LIPS actors were not truly aligned into industrial ecosystem principles. Moreover, we have not observed concrete changes in formal rules such as tax regime, environmental regulations, or market mechanisms that could facilitate changes in cognitive and normative frames of the LIPS. Niche experiments have not yet totally fitted into the existing industrial production routines and have mostly provided first-order learning outcomes for the industry. For transitions to occur, there is still a need to change the production routines; this could be achieved by second-order learning through real implementations, as also suggested by the SNM studies (*e.g.* Schot and Geels, 2008; Boon et al., 2014). There is still a need for a demonstrative set of real successful exchange experiments in the region. In these concerns, regional champions or coordinating bodies may have been helpful also in line with previous empirical findings from industrial ecology literature (*see generally* Hewes and Lyons, 2008; Domenech and Davies, 2011) but we have not identified any of them in the region based on the collected data and insights for this paper.

Another remark from the results is related to lack of cross-regional networking in Spain. It was only in MITKE experiment that two regions from Spain collaborated. If learning processes in Catalonia are aggregated and cross-regionally transferred, the industrial production routines at other autonomous regions in Spain may gradually change into more circular ways. Experiences and knowledge of other regions may contribute to further niche development and stabilisation in Catalonia as well.

Overall, it can be stated that the outcomes of continuously cultivated local niche experiments in Catalonia have contributed to three internal niche processes. However, there is still a way to go for regional industrial ecosystem niche building. While social network building processes have led to a promising emerging community, more industrial actors still need to be involved in the regional network. On the other hand, learning processes of the local experiments have provided important learning outcomes for different actors, which then directly supported or facilitated new experiments. Yet, second-order learning is still missing, especially for the industrial actors. The results of this study pointed to the required conditions that would better encourage the industry for real symbiotic exchanges, which could influence their cognitive and normative rules that form the basis for future sustainability transitions of LIPS. Moreover, second-order learning at the instituional level was observed only in one governmental organisation, which after the experiment (MITKE) has been trying to change the underlying rules of the existing problematic situation related to formal rules.

In brief, if a broader regional network, including the industry, with more second-order learning outcomes, can be achieved in the region, then it will be possible to talk about a regional industrial ecosystems niche with coupled expectations and visions towards a common direction for sustainability transitions of LIPS. Finally, our case study revealed that the emergence of regional industrial ecosystems niche does not exclusively depend on articulation of expectations and visions, network building or learning activities, but eventually the dynamic interaction between all three niche processes.

5. Conclusion

In this paper, we aimed to understand how industrial symbiosis initiatives can contribute to the emergence of regional industrial ecosystems for sustainability transitions of LIPS. To do so, firstly we attempted to enlarge the visionary window of the industrial ecology research by building on SNM framework and its concepts.

Integrating industrial ecology literature and SNM, we developed a framework that provides a conceptual foundation for analysing and understanding regional industrial ecosystem development by focusing on the interaction of two heuristic and analytical levels – that is, the local industrial symbiosis experiments level and the regional industrial ecosystems niche level – linked through three analytical niche processes. The developed framework provides grounds for a structured and diversified analysis of individual industrial symbiosis initiatives and their aggregating contribution to the emergence dynamics of regional industrial ecosystems.

Our empirical study, with data and insights from Catalonia, demonstrated how a set of local industrial symbiosis experiments can be analysed to understand the emergence of regional industrial ecosystems using our conceptual framework. The results showed that continuously cultivated and interlinked industrial symbiosis initiatives from the region have been gradually adding up to an emerging regional industrial ecosystems niche. However, it is not yet accurate to speak of a broad emerged community with articulated expectations and visions and shared cognitive, formal and normative rules. In this vein, continuity of local industrial symbiosis experiments is crucial to keep the momentum going, as also proposed by the SNM studies (*see generally* Raven, 2005; Schot and Geels, 2008), to involve more industrial actors in the regional network; to develop more real symbiotic exchanges for supporting further second-order learning outcomes; to assign regional coordinators with an industrial ecology vision; to create deeper linkages between experiments; and to inform more actors in the region about what has been achieved so far and the necessary future steps. If emerging regional network provides support and protection for new experiments, which will continuously contribute to regional niche building processes, a regional culture change can be realised to achieve sustainability transition of LIPS employing closed industrial production loops.

Our theory-based approach in this paper is not to test or expand the SNM framework. Instead, it should be seen as an endeavour to link industrial ecology to innovation studies and to bring in issues from ST field of innovation studies into the industrial ecology literature through synthesising a conceptual framework. Our framework advances the richness of the industrial ecology field through using different concepts (niche experiments, niche building, articulation of expectations and visions, first-order and second-order learning, emerging community, etc.) and, more importantly, making different lines of interpretations (local industrial symbiosis initiatives as niche experiments gradually aggregating into regional industrial ecosystems niche). While distinguishing different levels of analysis and conceptualising their interactions through proposed processes, we did not aim to provide the representation of reality in ontological accounts; instead, we generated analytical and heuristic concepts that could guide us to analyse and understand the intricately evolving dynamics of potential emergence of regional industrial ecosystems in real settings.

Therefore, our empirical study not only addressed our research question but also served to explore the plausibility of our conceptual framework rather than expanding it. Adopting a case study strategy, we represented the merits of our conceptual approach and provided an analytical narrative on emerging regional industrial ecosystems in the selected region covering an 18-year period. Our narrative has been guided by the main concepts of our framework, which both enabled us to draw an analytical illustration (see Fig. 5 in Section 4.3) and facilitated the interpretive explanations for understanding the individual industrial symbiosis experiments, the interplay between them, and their aggregating contribution to the emerging regional network of actors through coupled expectations and visions and shared cognitive, formal and normative rules.

In this paper, we have conferred theoretical, methodological and empirical contributions. Firstly, we developed a conceptual framework that provides a conceptual structuration of two interconnected heuristic and analytical levels. It enables the analysis of separate but gradually adding up industrial symbiosis experiments and their contribution to the emergence of regional industrial ecosystems through three analytical niche building processes for sustainability transitions of industrial production systems. Secondly, we differ from most case studies in industrial ecology literature in that we focused on a set of local industrial symbiosis experiments. We focused on each experiment as a separate unit of analysis and then combined and synthesised their results to understand their aggregating influence. As for empirical contributions, we provided new understandings based on new data and insights from the Catalonia region, which has never been analysed in industrial ecology literature. Moreover, the empirical study from Catalonia enabled the illustration of theoretical linkages between the concepts of our framework in a real setting, which may help to analyse other relevant contexts in future studies with a refined or the same conceptual approach as ours.

Considering practical and policy implications, the developed conceptual framework has been used in this paper as an analytical lens for ex-post evaluation of industrial ecosystem development in a region, but it can also be extended as a prescriptive management tool for regional actors from Catalonia, as well as other regions holding an interest in initiating or sustaining industrial symbiosis initiatives. We argue if new experiments can be designed from the beginning considering the internal niche building processes using our framework prescriptively as a management tool, then their contribution to regional industrial ecosystems niche can be stronger (*see also* Weber et al., 1999; Raven, 2006; Schot and Geels, 2008 for parallel suggestions on the applicability of the SNM framework). Moreover, this paper also contributes to better understanding of the emergence of regional industrial ecosystems, which strongly relates to the decisions and actions of relevant actors involving industrial organisations of all sizes, governmental and non-governmental organisations, entrepreneurs, universities and research institutes, local champions, managing/coordinating bodies, and the local community.

Finally, we offer some further research opportunities. Our conceptual framework can be further tailored and used as an ex-post analytical framework for analysing other empirical cases from the industrial ecology field. Moreover, future studies can seek to analyse socio-technical transitions of industrial production systems through industrial ecology practices. This may require analysis of multi-regime dynamics building also on the multi-level perspective (*see generally* Geels, 2002; Rip and Kemp, 1998), which indeed needs to be expanded in the ST field, as other ST scholars have also recommended (*e.g.* Schot and Kanger, 2018; Raven, 2007).

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Appendix A. Secondary data inventory

Data type	Quantity	Original data purpose	Original data audience
Governmental communication reports	9 reports with 835 pages in total	To promote economic activity in Catalonia analysing industrial sectors and their progress and to evaluate potential of industrial symbiosis and circular economy	Regional and local governmental organisations, industries
	– The power of circular economy in the Barcelona Metropolitan Area, Àrea Metropolitana de Barcelona, 2016 – Economic activity sectors' style guide, Institut Català del Sòl, 2017 – Corporate associative activity in economic activity sectors, Diputació de Barcelona, 2016 – Mapping of the industrial associative networks in the Barcelona Metropolitan Area, Àrea Metropolitana de Barcelona, 2016 – Catalonia Ecodesign Catalogue, Government of Catalonia, 2016 – Industrial Strategy of Catalonia: Programmes for the Seven Strategic Industrial Sectors, Government of Catalonia, 2015 –2009 Communication Report, Institut Català del Sòl, 2009 – The new industry: The core sector of Catalan economy, Government of Catalonia, 2009 – Map of Local Industrial Production Systems in Catalonia, Government of Catalonia, 2005		
Interim and final reports of the initiatives	9 reports with 403 pages in total	To monitor initiatives' progress and disseminate information and knowledge	Partners, clients of initiatives, industries, NGOs, local community, universities and research centres, other local stakeholders
	– Good Practice in the Management and Development of Business Areas and Industrial Parks: Benchmark Findings from the Mitke Project, 2009 – XEI, Project Results Report, 2002 – Ecosind, Project Summary Information, 2006 – Ecosind, Recommendation Guide for Planification and Management of Industrials Zones Using Industrial Ecology: Industrial Ecology and Circular Economy, 2006 – Ecosind, Recommendation Guide for Planification and Management of Industrials Zones Using Industrial Ecology: South Europe Industrial Zones' Current Situation and Problems, 2006 – Ecosind, Recommendation Guide for Planification and Management of Industrials Zones Using Industrial Ecology: Ecosind Recommendations, 2006 – Ecosind, Recommendation Guide for Planification and Management of Industrials Zones Using Industrial Ecology: Experiences and Techniques Files, 2006Mitke, Managing the Industrial Territories in the Knowledge Era, Project Summary Document, 2011 – Mitke, Managing the Industrial Territories in the Knowledge Era, Project Fiche, 2013		
Local news	5 news with 27 pages in total	To disseminate information and knowledge about regional industrial ecosystem development	Industries, local community and other local stakeholders
	– Eco-circular: The industrial symbiosis in Manresa could yield annual savings of approximately 1.35 million euros, 2017 – iResiduo, Manresa in Symbiosis; Circular economy would yield annual savings of up to 1.35 million euros, 2017 – La Vanguardia, Catalonia launches a record of industrial parks to attract investors, 2017 – Món Sostenible, Green economy and circular economy in Catalonia, 2017 – Blog Terraqui, Public and private support to industrial symbiosis: the implementation of circular economy, 2015		
Press releases, presentations and posters	22 documents with 237 pages in total	To disseminate interim and final results of the initiatives	Clients of initiatives, industries, NGOs, local community, other local stakeholders
	– Project presentation, Manresa in Symbiosis: Implementation of an industrial symbiosis Project in Manresa, 2016 – Project poster, Manresa in Symbiosis: Results of the pilot industrial symbiosis project in Catalonia, 2016 – Workshop presentation, 13th European Week of Regions and Cities: Promoting green and circular economy in Catalonia, 2015 – Interregional seminar presentation, Mitke, 2011 – Mitke Newsletter 1, 2009 – Mitke Newsletter 2, 2009 – Mitke Newsletter 3, 2009 – Mitke Newsletter 4, 2010 – Mitke Newsletter 5, 2010 – Mitke Newsletter 6, 2011 – Mitke Newsletter 8, 2011 – Project final conference presentation, Ecosind: The inter-regional cooperation III C, The RFOS and the Environment, 2006 – Project presentation, Ecosind: Industrial ecosystem, a strategy for the sustainable development of industrial activities, 2006 – Project presentation, Ecosind: Strategic and integrated governance system of industrial areas, 2006 – Project presentation, Ecosind: Demonstration projects of industrial ecology, 2005 – Project final presentation, Mesval: Final Mesval Results, 2006 – Project poster, Mesval, 2005 – Press release, Mesval, 2005 – Project general presentation, XEI: Industrial ecology in Catalonia, 2002 – Project poster, XEI, 2002 – Project presentation, Cycle: Industrial ecology in paper and leather industry, 2002 – Project detailed presentation, Cycle: Industrial ecology in paper and leather industry, 2002		
Articles	3 articles with 44 pages in total	To study industrial symbiosis opportunities and to analyse LIPS in Catalonia	Academic community
	– Towards a closed cycle of matter in Teneria, Jornada AQEIC, 2002, 31–44, Puig, R.; Cervantes, G.; Rius, A.; Marti, M.; Soler, J.; Olalla, S. – Industrial Colonies in Catalonia, Catalan Historical Review, 4, 201, 101–120, Serra Rosa – The Catalan industry, Treballs de la Societat Catalana de Geografia, 1986, 105–118, Pujadas i Rúbies, Romà		

Appendix B. List of interviewees

Organisation name	The position of the interviewee
Universidad de Guanajuato	Professor at Universitat Politècnica de Catalunya from 1991 till 2008. Co-creator and member of *XEI* Expert in *CICLE* Coordinator in *ECOSIND* Coordinator in *MESVAL*
Universidad Autonoma de Barcelona, The Institute of Environmental Science and Technology	Head researcher of the research group on sustainability and environmental protection. Co-creator and member of *XEI* Expert on industrial ecology. Expert in *ECOSIND* *Expert in MESVAL* Co-creator and member of *Vallès Circular*
The Government of Catalonia. Secretariat for Housing and Urban Improvement. Department of Governance, Public Administrations and Housing	Chief Officer of European Programmes. Director of *ECOSIND*
Incasòl, a public company of the Government of Catalonia which is attached to the Department of Regional Policy responsible for Development of land for economic activities	Head of Environmental Department. Project coordinator of *MITKE* Project Development Coordinator Project Expert in *MITKE*
Simbiosy, a private key player for industrial symbiosis in Catalonia linking municipalities, LIPS and other industrial actors	Founder and Director of the company Founder and Director of the company Manager and coordinator of various industrial ecosystem initiatives in Catalonia including *Manresa in Symbiosis*
Eduard Balcells Architecture, a private architecture company	Director of the company and principal architect of an industrial ecosystem initiative, *The New Urban Fabric*
The Vallès Occidental County Council, public body to coordinate policies and the provision of services to the public, especially of collaboration and support in Vallès area of Catalonia	Head of Entrepreneurship and Business Department Local coordinator of *Vallès Circular*

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