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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.

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.

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'elaborazione 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.
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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 & Gallapoulos, 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 & Gallapoulos, 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 & Gallapoulos, 1989) and industrial ecology practices held by industrial ecosystems can bring a transition into circular industrial production routines (Chertow, 2000; Felicio, 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 & Huisinigh, 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 & Gallapoulos, 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 argue 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 & Mouzakis, 2009; Baas & Huisin, 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 & Mouzakis, 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 & Gallapoulos, 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 identification², (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; Felicio, 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 interviews 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 systems³ development into local industrial ecosystem⁴ 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 transitional 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 projects⁵ 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 analysis 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 ongoing, 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 levels⁶.

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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