School of Civil and Mechanical Engineering

Industrial Symbiosis – Additional learnings from 40 years of Industrial Symbiosis development

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.'

Signature: Aja Maria Wen

Date: 12/04/2018

Abstract

Industrial Symbiosis (IS) describes a collaborative industrial system in which companies utilise each other's waste, by-products and utility resources for mutual gains. Despite increasing awareness of sustainability issues worldwide, such as resource scarcity, pollution and ongoing environmental degradation, the development of IS and eco-parks programs has been slow, though research has been conducted to support their ongoing development.

An initial literature review to this study has shown, that previous research presents a general overview of IS programs, their development models and factors influencing their development. Though the empirical evidence on these topics is extensive, the literature lacks a comparative assessment and review of the IS development process. This research addresses this gap by providing a comparative examination of major IS projects, an investigation of influential IS development factors and additional cognitive contributing factors.

This thesis provides a categorisation of IS activities and common operational challenges and a classification of three funding models: private, public and co-funded. Insights are presented on the effects of individual factors on the IS process and cognitive elements addressing organisational and human behaviour change towards sustainability management. Four development models were identified, including their key influential IS development factors and management options.

It is concluded that no single element is responsible as an initiation mechanism of an IS program nor that IS development is inflexible in its nature. In order to support IS development, a guiding framework is essential, including governmental incentives like regional development, legislation, and social and operational management elements.

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List of Abbreviations

€	Euro
A$	Australian Dollar
ACCI	Australian Chamber of Commerce and Industry
APEFIS	Act to Promote Environmental Friendly Industrial Structure
ARC	Australian Research Council
BCPC	Burnside Cleaner Production Centre
BCSD-GM	Business Council for Sustainable Development Gulf of Mexico
BCSD UK	Business Council for Sustainable Development United Kingdom
BCSD US	Business Council for Sustainable Development United Stated
BHP	Broken Hill Proprietary Company Limited
BHPB	BHP Billiton
BMBF	German acronym for German Federal Ministry of Education and Research
BP	British Petroleum
BPS	By-Product Synergy
BQMS	French acronym for Quebec Secondary Materials Exchange
BRIQ	French acronym for Quebec Industrial Waste Exchange
BS	Bilateral Symbiosis
CBD	Central Business District
CCIWA	Chamber of Commerce and Industry of Western Australia
CECP	Centre of Excellence in Cleaner Production
CP	Cleaner Production
CRC	Cooperative Research Centre
CSR	Corporate Social Responsibility
CSRP	Centre for Sustainable Resource Processing
CTTÉI	Centre de transfert technologique en écologie industrielle
DBU	German acronym for German Environment Foundation
DfE	Design for the Environment
DMITRE	Department of Manufacturing, Innovation, Trade and Recourses
e.g.	exempli gratia, *Latin* (for example)
EE	Eco-efficiency
EEC	Eco-efficiency centre
EEFS	Environmental Education for Sustainability

EIFSG	Eco-innovation feasibility study grant
EIIG	Eco-innovation infrastructure grant
EIP	Eco-industrial park
EIS	Economic Impact Study
EMS	Environmental Management System
EPA	Environmental Protection Agency
EPA	Environmental Protection Authority
est.	established
Etc.	et cetera
EU	European Union
FEC	Financial-Economic Crisis
FSM	Facilitating Structures Model
GFC	Global Financial Crisis
GHG	Green House Gas
GST	Goods and Services Tax
i.e.	id est, *Latin* (that is)
IA	Industrial area
IE	Industrial Ecology
Incl.	inclusive
INES	Dutch acronym for the industrial ecology project in the Rotterdam industrial area
IOA	Input-Output Analysis
IS	Industrial Symbiosis (Industrial Synergy)
ISO	International Organization for Standardization (based on the Greek word *isos*)
IUWA	German acronym for Institute of Eco-Industrial Analyses
KDC	Kawerau District Council
KIA	Kwinana Industrial Area
KIC	Kwinana Industrial Council
KICOX	Korea Industrial Complex Corporation
LCA	Life Cycle Analysis
M	Million
METI	Ministry of Economy, Trade and Industry
MFA	Material Flow Analysis

MoE	Ministry of Environment
NDRC	National Development and Reform Commission
NISP	National Industrial Symbiosis Programme
NSW	New South Wales
NZTE	New Zealand Trade and Enterprise
PCSD	Presidents Council for Sustainable Development
PP	Pollution Prevention
R&D	Research and Development
R&DB	Research and Development into Business
RDAWEP	Regional Development Australia – Whyalla and Eyre Peninsula
RiVu	Rietvelden/Vutter
ROI	Return of Investment
RRS	Regional Resource Synergies
SA	South Australia
SEPA	State Environmental Protection Administration
SKM	Sinclair Knight Merz
SLO	Social Licence to Operate
TBL	Triple bottom line
TUR	Toxics Use Reduction
UK	United Kingdom
UNU	United Nations University
US	United States
USG	Upper Spencer Gulf
vs.	versus
WA SIG	Western Australian Sustainable Industry Group
WA	Western Australia
WBCSD	World Business Council for Sustainable Development
WTC	Western Trade Coast
WTCIC	Western Trade Coast Industrial Committee
ZEF	Zero Emissions Forum
ZERI	Zero Emissions Research Initiative

Chapter 1. Introduction

1.1. Background

Industrial Symbiosis (IS) describes a collaborative industrial system in which companies utilise each other's waste, by-products and utility resources. With regards to the waste management hierarchy (Bakshi & Fiksel 2003), IS fosters material reuse, recycling and energy recovery. Hence, IS assists the conservation of virgin resources by converting one industry's waste to another industry's resource. The result of this substitution are economic, environmental and social benefits for businesses and society. The amplitude of these benefits underlines the value of IS in supporting sustainable industrial development.

Sustainable development has already become a goal of industrial development in the 21st century and more environmentally friendly production models have been developed, given the increasing awareness of finite resource levels, climate change and environmental degradation and the importance in securing resources for future generations. In particular, increasing efforts are being made by industry to reduce the consumption of water and non-renewable resources like fossil fuels, natural gas and coal. Alongside this development, new technologies and innovative management concepts have been developed to achieve reductions in emission generation and waste management. These concepts include 'Design for Sustainability', 'Eco-Efficient Manufacturing' and 'Industrial Ecology' (IE) (Bakshi & Fiksel 2003).

The concept of IS falls under the category of IE, which addresses closed loop production. Specifically, the theory of IE seeks optimal material utilisation within an industrial system, including the re-use of waste products, and aims for the creation of an industrial eco-system. Like natural eco-systems, industrial eco-systems can display cases of 'symbiosis'; where two or more entities gain mutual benefits by sharing waste or other important resources. In an industrial system, this is called 'Industrial Symbiosis'.

The concepts of IE and IS are gaining importance due to the fact that natural resources become scarce. Therefore, developing industrial eco-systems and symbioses is important as a means to support sustainable development. In

order to increase the number of symbiotic interfirm co-operations, a solid understanding on how IS evolves and develops is necessary (Rosano & Schianetz 2014).

Early studies by Gertler (1995), Lowe and Evans (1995), Lowe et al. (1996), Schwarz and Steininger (1997), Ehrenfeld and Gertler (1997), Côté & Cohen-Rosenthal (1998), Chertow (1998), Chertow (2000), Sterr (2000) and Mirata (2003) showed that the establishment of IS can follow different evolutionary paths due to a range of factors influencing their initiation and development. In 2004 Mirata argues, that symbiotic links are established if the right mix of factors (technical, informational, political, economic and organisational) is present for all involved parties. Though, further research has been proposed to investigate the drivers of IS formation (Mathews & Tan 2011).

For example, Doménech and Davies (2011) call for additional research to better understand the role played by different mechanisms to build social structures (trust and embeddedness). They see the need to identify different phases in co-operation, which can lead to effective IS development. Yu et al. (2011) propose to investigate:

- "*Who are the actors?*
- *What are the positions or roles that actors play?*
- *What are the boundary rules to specify which actors enter or leave positions?*
- *What actions can actors take in given positions, and how are actions linked to outcomes?*
- *What costs and benefits do actors incur when they take actions?*
- *What are the drivers and barriers?"*

Boons et al. (2011) conceptualize IS as a regional industrial and social system. They see the need to further investigate:

- *"How is institutional capacity built in these systems and what are its effects on the system?*
- *Is institutional capacity linked to phases of IS development?*
- *What influences institutional capacity building process?"*

Chertow and Ehrenfeld (2012) draw on biological, ecological, organizational, and systems theory, they present a discontinuous three- stage model of IS. They pose further research questions including:

- *"Why most IS systems do not develop far beyond the initial stakeholders?*
- *How 'explicit recognition of the IS' affects outcomes?*
- *How are coordinating entities formed and what are their characteristics?"*

Boons et al. (2014) investigate the role of policy in IS development. They highlight that 'policy is dynamic' and suggest to further investigate the following research questions:

- *"How do actors in industrial parks translate national, regional and local policy interventions into their practices?*
- *How is experiential knowledge from these practices translated by local, regional and national policy makers into adaptive policy changes?*
- *How does the wider institutional context impact upon the policy translation process?*
- *In what way does the policy translation process of IS and CE relate to other policy processes?*
- *How does the concept of IS cross national borders to become translated into other nations' policy programs?"*

All these questions are important to advance the knowledge on IS development. However, they also highlight that IS development factors and processes require identification and analysis. Therefore, the literature review of this thesis (Chapter 3) reviews the research progress on IE/IS theory and concepts in more detail including IS drivers and barriers, and evolutionary path. It has shown that various IS evolved and their progress has been studied to understand their individual development. Researchers have identified overarching development models of IS (Paquin & Howard-Grenville 2012) and formulated evolutionary processes and development stages (Baas & Boons 2004; Doménech & Davies 2011; Chertow & Ehrenfeld 2012). Though, studies

focus primarily on case studies (Yu et al. 2013) describing the IS development and factors influencing their development.

The literature review highlights, that the current research has addressed singular elements of IS management success (e.g. champion, facilitators) but:

- does not examine IS project management holistically including initiation mechanisms, funding and organisational features influencing IS development and
- further research is required to draw conclusions on best practice in IS project management, and
- the factors influencing IS initiation and development have yet not been approached and discussed holistically.

At present the IS literature provides a general overview of IS programs, their development models and factors influencing their development. Though the empirical evidence on these topics is extensive, the literature lacks a comparative assessment and review of the IS development process. This research addresses this gap by:

- providing a comparative examination of major IS projects,
- investigating what influence IS initiation and development, including organisational features and funding structures,
- reviewing additional social, management and local contributing factors that have not been collectively acknowledged in detail in the literature to date, and by
- defining IS development scenarios and by reviewing factors relevant for specific scenarios.

1.2. Project aim

The main objective of this research is to enhance the understanding on IS development models to assist ongoing and future IS developments. In addition, this research aims to provide further insides into the development mechanisms of IS. Therefore, this study focuses on identifying factors influencing IS initiation and development, and to illustrate the effects these factors have. Identifying varying aspects in the IS initiation and development

is important and will assist to identify shifts in system models and operational frameworks. With regards to the research objectives, the following three research questions are examined by this research:

1. What are the IS development models?
2. What influences these development models?
3. What is needed to adjust the IS development processes?

1.3. Scope and limitations

The research presented in this thesis reviews international IS programs of the following countries: Denmark, Australia, South Korea, United Kingdom, Netherlands, Germany, Austria, United States, Canada, New Zealand, Japan and China. The selection is based on the availability of literature.

The investigation draws on various forms of data, including published literature, international case studies, publicly available governmental data, and interviews with stakeholders. As a result, the evidence base for the reviews presented in this thesis is relatively broad and from a variety of disciplines and fields of knowledge. Also, the style (qualitative vs. quantitative assessment), terminology (i.e. IS vs. Regional Resource Synergies or champions vs. project champions), and format (paper/thesis structures) used in the literature is rather heterogeneous, which makes direct comparisons of the presented case studies difficult. A final potential limitation of the findings are language barriers, since research might be conducted in one language, published in another and is likely to be translated and interpreted by researchers into a third language.

Industrial Symbiosis in this thesis is defined as ‘interfirm exchanges of industrial waste products for a mutual economic, environmental and social benefit, regardless of their physical state (solid, gaseous or liquid)’ (Gertler 1995).

1.4. Chapter outline

The following Chapter 2, offers a brief description of the research methodology employed in this study. Chapter 3 presents a comprehensive literature review on the topic of IS in order to provide the theoretical background for the research. It outlines the concept, application, and tools of IE, defines the

concept and emergence of IS, and provides an overview of the various definitions of IS in the research literature. This section further describes the development of IS, the different initiation phases of self-organised, facilitated, and planned IS, formalised development models as well as the influencing factors of IS initiation and development. The chapter closes by summarising the conclusions from the literature review.

Chapter 4 presents a review of international IS programs, including projects in Denmark, Australia, South Korea, United Kingdom, Netherlands, Germany, Austria, United States, Canada, New Zealand, Japan, and China. It outlines the motivation behind each project initiation, the structure of these diverse programs as well as highlights the differences in approaches and regional conditions. The review also discusses the three different models of IS programs: self-organised, planned, and facilitated programs.

Chapter 5 outlines the various factors influencing the development of IS programs. It begins with investigating drivers, barriers, enabling mechanisms and success elements in IS development. This is followed by an investigation of various factors and their impact on IS development at different management levels. Further, research in IS development and IS facilitation is discussed and models of IS development and initiation are categorised. Project participants are introduced, their recruitment process and roles explained. The term ‘champion’ and its application is discussed. The attributes and skills of champions are described as well as their activities in fostering interfirm collaboration in IS development. A review of previous research on funding mechanisms and different funding models is also provided

Chapter 6 discusses cognitive factors influencing behaviour change for sustainable development. It focusses on the factors of behaviour change and the influence of peer pressure on individuals, firms and countries in relation to sustainable development. Influences on the behaviour of managers are investigated. The relationship between behaviour change and IS is analysed and the overall benefits of IS to sustainable development is discussed.

Chapter 7 brings findings of this thesis together and presents IS development models and an examination of major IS projects. Based on the examination

key influential IS development factors for each of the IS development models are identified and management considerations proposed.

The final section of this thesis, Chapter 8, presents concluding comments on the research presented. It provides recommendations for IS facilitation and highlights the importance of understanding regional characteristics and historic industrial developments in order to evaluate the potential for IS development.

Chapter 2. Methodology

This Chapter describes methodology framework followed to produce this thesis. Outlined are also the research methods used to address the three research questions investigated.

The initial research questions, which lead to this research project were: 'how does IS start', 'what does it take', 'what are the funding and organisational factors'. To provide a theoretical background on the development theories of Industrial Ecology (IE) and Industrial Symbiosis (IS) an extensive literature review was conducted. This was followed by a comprehensive literature review of IS case studies and publications focussing on initiation phases and development models of IS development. This initial literature review provided an insight into the terminology used in publications concerning IS initiation and development. Key words identified included 'Drivers' and 'Barriers', such as costs and regulations (see Table 3.1, page 24). Then published data were examined on motivational factors to participate in IS and facilitating structures.

The reviewed literature was then used to examined and evaluated factors influencing IS development and associated initiation processes over the past 40 years, which then assisted with the formation of the research objectives of this study. For this purpose, a narrative research method was used, focusing on theoretical, primary and secondary data. In addition to academic publications, additional sources including archival records, government documents, and industrial reports were also sourced. To assist the literature review process, a systematic keyword search was performed in the following databases: *Elsevier, Emerald, Google Scholar, SAGE Publications, ScienceDirect,* Sustainability Science abstracts *(ProQuest)* and *Wiley Online Library.* Key search terms included 'Industrial Symbiosis', 'Industrial Ecology', 'Development', 'Initiation', 'Evolution', 'Drivers', 'Barriers', 'Funding' and 'Financial Assistance' and 'Political Factors'. The selected key words assisted to narrow the search down the publications to allow for a specific review of aspects related to the initiation/evolution and development of IS. The research questions were then re-evaluated and different research methods were applied to provide a comprehensive investigation analysis. An outline of the research design is depicted in Figure 2.1 (page 11).

Firstly, a meta-synthesis of several international IS case studies and national strategies for sustainable industrial development was conducted, to address the first research question on IS development mechanisms. The examination included published data from IS developments in Denmark, Australia, South Korea, United Kingdom, Netherlands, Germany, Austria, United States, Canada, New Zealand, Japan and China. Selection of the case studies was based on information identified during the initial comprehensive literature review. The analysis of the selected IS programs focused on the identification of key factors in the initiation process and similarities/differences in the IS development, funding and management structures. The key factors such as champions, peer pressure, principal agent, organisational culture, licence to operate, behavioural change, sustainable development and change agent have been further investigated in responding second research question (Figure 2.1). Whilst IS programs have been running for over 40 years, published literature available on IS development largely dates back only 20 years. However, this research has focussed on 40 years of IS development and research and has had to utilise a significant amount of informal and qualitative research materials in order to uncover the early years of IS development which had not been previously published.

The second research question focused on factors influencing IS development. A formal and systematic review process was applied, addressing and evaluating each factor individually. A complementary key word search was also conducted of the IS literature and sustainability management literature, to include additional social factors effecting IS development. Search terms included, '(Green) Champions', 'Peer Pressure', Principal Agent', 'Culture', 'License to Operate', 'Behaviour Change', 'Sustainable Development' and 'Change Agent'. The analysis of the influencing factors aimed to identify the effects of the individual factors on the IS development process and to highlight specific additional influencing factors requiring further examination, ultimately leading to the formation of the third research question. Behavioural change has been found to be a key influencing factor, which was further analysed in order to influence successful industrial symbiosis development.

The final part of the study addresses research question three, which is concerned with fine tuning the identified models of IS development. A systematic review approach was also taken, with additional primary and secondary data sourced. The study reviewed theories of behaviour change including ‘Social Cognitive Theory’, theories of ‘Reasoned Action’ and ‘Planned Behaviour’ as well as consumer behaviour. The analysis focussed on identifying elements and strategies moving individual and organisational behaviour towards sustainable industrial production and enhanced sustainability management.

The academic and research value of this study lies primarily in the comprehensive analysis of international case studies and in-depth review of influential IS development factors which will assist the development of future IS. Also, the identification and analysis of specific factors and their influence on a specific development model will contribute to better understand IS development mechanisms, may assist to make recommendations on organisational frameworks to foster future IS developments.

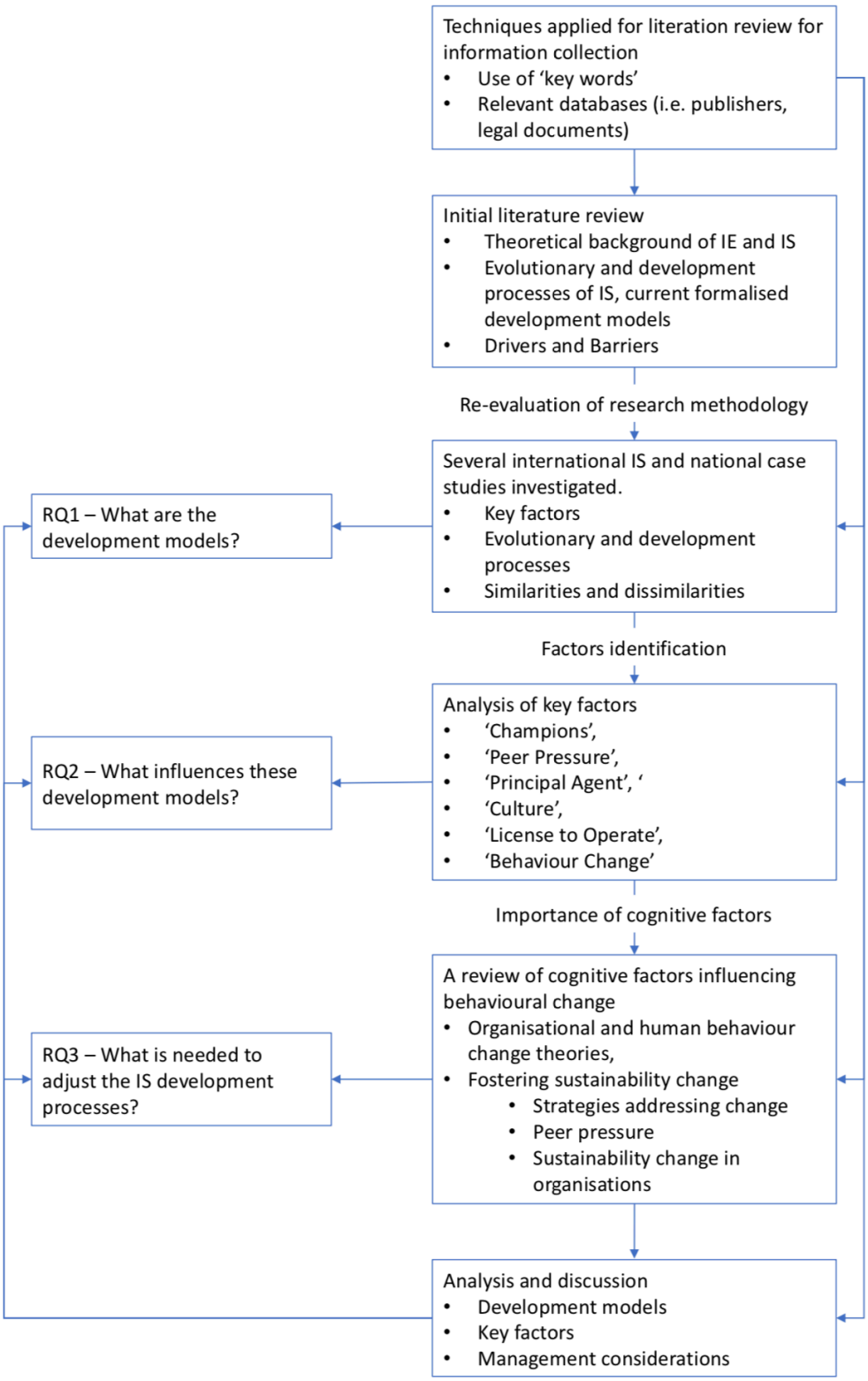

FIGURE 2.1: METHODOLOGY FRAMEWORK

Chapter 3. Literature review

Based on the research objectives this Chapter focused on reviewing the current literature available on Industrial Ecology (IE) and Industrial Symbiosis (IS) evolution theories, development models and factors influencing IS development and initiation processes.

3.1. Industrial Ecology

3.1.1. Concept

Industrial Ecology describes the optimal material utilisation within an industrial eco-system (Jelinski et al. 1992). The concept of IE was first recognised by a wider audience in 1989 with the publications by Frosch and Gallopoulos (1989) and Ayres (1989), even though the idea of IE was known before the 1960s (Erkman 1997). Cases depicted by Multhauf (1967) show that industrial by-product utilisation and innovation were pioneered by the chemical industry. In the 1990s, the theory and application of IE was studied in depth and policy frameworks investigated to assist further implementation of IE (Frosch 1992; Tibbs 1993; Lowe & Evans 1995; Garner & Keoleian 1995; Gertler & Ehrenfeld 1996; Ehrenfeld & Gertler 1997; Erkman 1997; Esty & Porter 1998).

Erkman (1997) published a historic review of IE, writing about the early developments in Kalundborg, Belgium and Japan. He further depicted the propagation of the concept of IS since full recognition of the concept in 1989. Frosch and Gallopolous termed the concept of IE in 1989. Recognising that waste and by-product exchanges already exist in practice, they highlighted the necessity to further develop recycling incentives in order to sustain human and industrial development. The idea is based on Ayres view of industrial metabolism, which he presented in 1988 (Frosch 1992). Ayres and Simonis (1994) describe industrial metabolism as an *"integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes*".

Frosch and Gallopolous (1989) describe IE as the optimisation of energy and materials, which are consumed in industrial production processes and called for a transformation of industrial activities. They did not give an exact definition

when coining the term; therefore, some additional views on the meaning of IE are noted below.

> *"The idea of an industrial ecology is based upon a straightforward analogy with natural ecological systems. In nature an ecological system operates through a web of connections in which organisms live and consume each other and each other's waste. The system has evolved so that the characteristic of communities of living organisms seems to be that nothing that contains available energy or useful material will be lost. There will evolve some organism that will manage to make its living by dealing with any waste product that provides available energy or usable material. Ecologists talk of a food web: an interconnection of uses of both organisms and their wastes. In the industrial context we may think of this as being use of products and waste products. The system structure of a natural ecology and the structure of an industrial system, or an economic system, are extremely similar"*

(Frosch 1992)

> *"Industrial ecology is a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies. It is a concept in which an industrial system is viewed not in isolation from its Surrounding systems but in concert with them. Industrial ecology seeks to optimize the total materials cycle from virgin material to finished material, to component, to product, to waste product, and to ultimate disposal."*

(Jelinski et al. 1992)

> *"Industrial ecology involves designing industrial infrastructures as if they were a series of interlocking manmade ecosystems interfacing with the natural global ecosystem. Industrial ecology takes the pattern of the natural environment as a model for solving environmental problems, creating a new paradigm for the industrial system in the process".*

(Tibbs 1993)

3.1.2. Application and tools of Industrial Ecology

The concept of IE can be applied to different system levels through a variety of methodologies and tools. System levels are generally defined as firm-, interfirm-, regional-, national- and global level (Lifset & Graedel 2002), Figure 3.1. Van Berkel et al. (1997) developed a structured framework to assist and guide IE efforts. The framework comprises of four specific tool types; inventory, improvement, prioritising and management tools. In addition to these, policies and governmental strategies are seen as supporting mechanisms for IE. The following application tools and system level approaches are characteristics of IE.

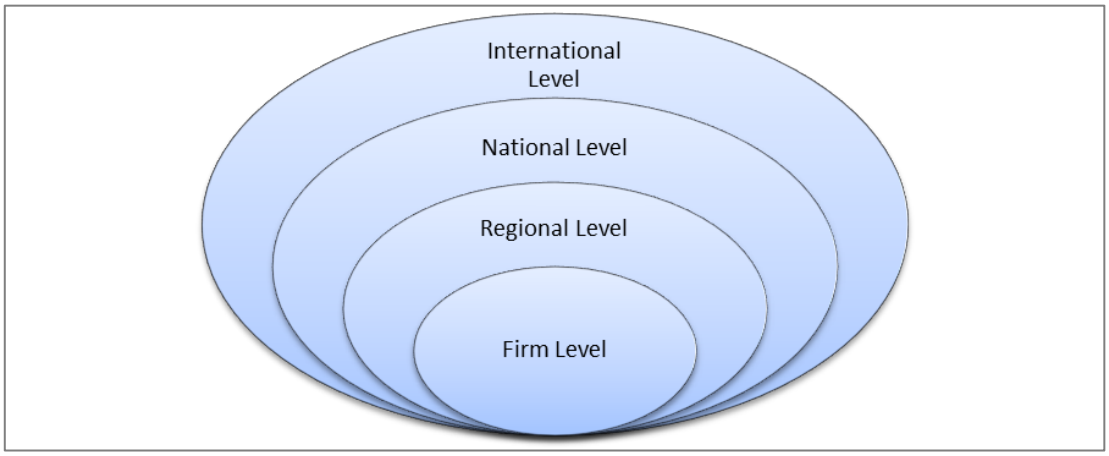

FIGURE 3.1: SYSTEM LEVELS
Based on Harris (2004) page 69

Cleaner Production initiatives combine a range of IE application tools such as waste minimisation, pollution prevention applications, toxic use reduction, and design for the environment (van Berkel et al. 1997). These applications are usually applied at firm level and focus not only on the reduction of pollution and emissions but also on adapting production processes. At interfirm level, Eco-Industrial Parks (EIP) and IS initiatives are used to foster industrial eco-systems (Chertow 2000). Rather than focussing on a single process or pollutant these applications consider all aspects of material intake and output of a company (Gertler 1995; Lowe 1997). The exchange of industrial by-products is not limited to an industrial area but can be applied regionally, and internationally.

Life Cycle Analysis (LCA) on the other hand traces a single process or product throughout the products entire lifetime including production and disposal

(Korhonen 2002). Material Flow Analysis (MFA) and Energy Accounting are tools tracing and assessing material flows and material stocks for a product or system (Fischer-Kowalski et al. 2011).

Industrial ecology at a national level can be applied through systematic policy development. For example, countries such as Japan, Germany, the Netherlands, Austria and China have implemented a legislative framework to reduce, reuse and recycle waste material; this concept is known as 'circular economy' (Heck & Birkenfeld 2006). Another national legislative approach is Extended Producer Responsibility that makes the producer of a product responsible for the product throughout its entire lifetime, including the product disposal. An example for this legislative approach is the German packaging ordinance and 'Green Dot' recycling program.

3.2. Industrial Symbiosis

3.2.1. Concept

As introduced previously, IS is an important methodology in IE. It is concerned with interfirm exchanges of industrial waste products for mutual economic, environmental and social benefit, regardless of their physical state (solid, gaseous or liquid) (Gertler 1995). In particular, it seeks to maximise the utilisation of industrial by-products and effluent, including waste heat and energy (Peck 1999).

While the concept of IE has been known since the early 1900s the theory of IS was first introduced in the early 1990s (Multhauf 1967; Knight 1990; Tibbs 1993; Gertler 1995). Historically, company-internal waste recycling and material recovery practices were primarily seen in the petrochemical industry (Multhauf 1967). Though these practices were never limited to the petrochemical industry, most industries did not pursue the utilisation of industrial production by-products in the same way. Some industrial waste by-products like fly ash have advanced and developed new markets naturally. These materials can be considered as 'traditional' waste exchange products (Swan et al. 1999), though they are still labelled as 'by-product' (Gertler 1995).

Schwarz et al. (1996) demonstrated that innovative utilisation of waste products is a 'natural behaviour' of corporate business operations in order to

save disposal costs and to gain extra revenue. Under the same notion, beneficial interfirm recycling collaborations (or according to Schwarz and Steininger (1997), recycling networks) have been established all over the world to provide both economic and environmental benefits (Schwarz et al. 1996).

3.2.2. Emergence

The concept of IS emerged in 1989 in the city of Kalundborg Denmark, when a group of local high school students designed a three-dimensional model of the city's industrial area (Branson 2011). Besides single firm buildings, the model also showed the extensive pipeline system spread across the industrial area, connecting multiple firms. At this point, a plant manager's wife, a biologist, recognised the model's resemblance to a biological symbiosis found in nature then coining the term 'Industrial Symbiosis' (Branson 2011).

The story was reported not just in the local newspaper but soon nationally and internationally (Branson 2011). In 1990 a reporter from the New York Times visited Kalundborg. After his article was published Kalundborg received much recognition worldwide (Knight 1990). In 1992 the concept of IS in Kalundborg was presented at a conference during the Earth Summit. Following the media exposure in 1990s, researchers became interested in the concept and started to study the IS at Kalundborg more closely (Sterr & Ott 2004).

3.2.3. Definitions

Industrial Symbiosis follows the principles of sustainable co-existence and is similar to natural symbiosis. In nature, 'symbiosis' means 'the living together of dissimilar organisms'. The concept was discovered by Anton de Bary, a German scientist, who identified the mutual co-existence between fungi and alga known as lichen (Ehrenfeld & Gertler 1997).

Ehrenfeld and Gertler (1997) cite the Encyclopaedia Britannica (1992, 14: 1034) which describes biological symbiosis as "*a close sustained living together of two species or kinds of organisms*". Since then the definition has been slightly changed to:

> "*any of several living arrangements between members of two different species, including mutualism, commensalism, and parasitism. Both*

positive (beneficial) and negative (unfavourable to harmful) associations are therefore included, and the members are called symbionts."

(Symbiosis 2013)

In the past 25 years different definitions of IS have emerged. Given the still evolving field of IS and different interpretations of its theory:

Kalundborg's IS was defined as:

> *"A co-operation between different industries by which the presence of each increases the viability of the other(s) and by which the demands of society for resource savings and environmental protection are considered."*

(Engberg 1993)

A less profound but straightforward description of the concept is depicted by Garner and Keoleian:

> *"…it is a process whereby a waste product in one industry is turned into a resource for use in one or more other industries."*

(Garner & Keoleian 1995)

However, Tibbs (1993) describes the IS at Kalundborg *"as a pioneering industrial eco-system (Frosch & Gallopoulos 1989), since symbiosis usually only refers to cooperation between two organisms"*.

Chertow (2000) defined IS with a more theoretical approach in saying:

> *"…industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products."*

(Chertow 2000)

Besides IS, other terms were used to describe the trade of by-products; Recycling Networks (Schwarz & Steininger 1997) and Regional Resource Synergies (RRS) (van Beers 2008b). Chertow's definition is now widely referenced (Kim 2009). She further developed her theory and defined IS as a

3-2 heuristic, meaning an IS has to consist of at least three companies sharing two different materials and where one company takes up one material and passes on another to a different company (Figure 3.2).

FIGURE 3.2: 3-2 HEURISTIC
Source: Chertow (2007), page13

Branson, however, argues that symbiosis entails inter-dependency of firms though their waste linkages and that the 2-1 heuristic (Figure 3.3) is the foundation of IS. Based on this statement the IS at Kalundborg is an "*accumulation of bilateral arrangements*" (Branson 2011).

Bilateral Symbiosis is described by Branson (2011) as follows:

> *"…a basic form of industrial symbiosis comprising a single relationship between two principals..."*

FIGURE 3.3: 2-1 HEURISTIC
Source: Branson (2011)

Schwarz and Steininger (1995) studied recycling networks in the early 1990s in Styria, Austria and the Ruhr Area in Germany. They defined such networks as *"consisting of various regional enterprises that are connected by at least one 'waste relationship'"*.

The term 'Regional Resource Synergies' was only used in Australia and Canada and incorporates *"a wider scope as it also includes the shared use of utility infrastructure and industries which are not located in close proximity"* with a regional 'perspective' not just a local intention (van Beers 2008b).

3.3. Industrial Symbiosis development

There are three overarching development models for IS: self-organised, facilitated and planned (Paquin & Howard-Grenville 2012). Self-organised IS programs are those which have evolved from interaction and interfirm co-operation of industry partners within the same industrial estate or region (Gertler 1995; Schwarz & Steininger 1997; Rosano & Schianetz 2014). Facilitated IS refers to an IS or EIP established through either a group or an individual person supporting the idea of IE under which influence industry voluntarily participates (Boons & Baas 1997; Heeres et al. 2004; van Beers et al. 2005; Hewes & Lyons 2008). Planned eco-industrial development or IS refers to the structured development of an EIP based on a strategy set out by a steering committee (e.g. regional planning agencies) (Eilering & Vermeulen 2004; Chertow 2007; Gibbs & Deutz 2007). Critical elements for the establishment of IS are the initiation phase, development model chosen and the factors influencing the development (Gertler 1995; Lowe & Evans 1995; Lowe et al. 1996; Schwarz & Steininger 1997; Ehrenfeld & Gertler 1997; Côté & Cohen-Rosenthal 1998; Chertow 1998; Chertow 2000; Sterr 2000; Mirata 2003).

3.3.1. Initiation phases of self-organised, facilitated and planned Industrial Symbiosis

Self-organised IS

The emergence of self-organised IS has been investigated based on the Kalundborg industrial area (Gertler 1995; Ehrenfeld & Gertler 1997), the Ruhr Area, Germany and the region of Styria, Austria (Schwarz & Steininger 1995). Case studies on these three areas have shown that the exchanges identified can be regarded as normal business operation between two businesses as the main incentive to establish the collaboration was economic gain (Gertler 1995; Schwarz & Steininger 1995). Describing the process more specifically, one company saves disposal costs whilst the other company reduces their costs for raw materials. Further it was shown that the technologies used to facilitate the trade were regarded as common and the type of by-product exchanged (e.g. fly ash) well established at the time (Gertler 1995; Schwarz & Steininger 1995).

By recognising that the trade of industrial by-products is not any different to other business transactions, exchange prerequisites are created under which IS can be developed (Gertler 1995; Schwarz & Steininger 1995). It can also be observed that IS can develop from a few bilateral exchanges initially (Lowe 1997; Branson 2011). In addition, self-organised IS can emerge spontaneously based on previously established interfirm collaborations which often are discovered by a facilitator outside the production system (someone external to the industrial area) (Chertow 2007).

Facilitated IS

Researchers also investigated the emergence of facilitated IS projects and have shown that there are several different approaches to facilitate IS (van Beers et al. 2007a; Hewes & Lyons 2008; Paquin & Howard-Grenville 2009). Facilitation emerges with the support of industry associations as seen in the Netherlands and Australia (Heeres et al. 2004; van Beers et al. 2007a), or facilitation proposed by consultants or government agencies (Hill & LLC 2001; Paquin & Howard-Grenville 2009). Common external (third) parties facilitating IS are commercial consultancy offices, university associate research centres and government associations (Boons & Baas 1997; Heeres et al. 2004; van Beers et al. 2005; Hewes & Lyons 2008). They act either as single entities or in collaboration, but they always work closely with their industry partners. Typically, IS can be facilitated by developing communication and trust within an industrial area (Lowe et al. 1996) or through analysis of material flows (Jelinski et al. 1992). Hewes and Lyons (2008) noted that individuals (called champions) can foster IS from within a network by building up communication channels and trust in the IS project.

Planned IS

Planned EIPs are often initiated by local and regional government agencies (Chertow 2007; Gibbs & Deutz 2007). These developments follow a certain plan and have a set agenda (Heeres et al. 2004). The literature identified two basic models of planned EIPs; brownfield development or greenfield development (Lambert & Boons 2002). ‘Brownfield development’ describes the retrofitting of an existing industrial estate, whereas ‘greenfield development’ characterises the establishment of a new industrial area.

3.3.2. Formalised development models

In 2000, Chertow described three evolutionary development models, which involve pre-existing synergies or networking or the presence of a large industrial plant. To capture the individual steps involved in IS development, researches have aimed to formalise these stages and models have been developed by Baas and Boons (2004), Doménech and Davies (2011) and Chertow and Ehrenfeld (2012).

Baas and Boons (2004) describe the evolutionary model of IE with regards to decision making processes, based on the finding of the INES project in Rotterdam (Netherlands). In their approach, they describe the following three phases[1]:

1. Regional efficiency
2. Regional learning
3. Sustainable industrial district

In the initial phase (regional efficiency), autonomous decision-making leads to interfirm material exchanges resulting in higher efficiency across the region. The next phase is based on 'regional learning', which means mutual benefits of the interfirm collaboration are recognised amongst stakeholders and further developed by exchanging knowledge or the introduction of other stakeholders. In the final phase, the stakeholder's decisions are based on a common vision for sustainable development for the region.

In comparison, Doménech and Davies (2011) describe the evolution of IS through three separate phases:

1. Emergence
2. Probation
3. Development and expansion

In their model an IS network emerges from a change in manufacturing processes leading to innovative interfirm collaboration. In the probation phase, the collaboration has to prove itself by sustaining and developing trust among

[1]Baas and Boons (2004) describe an additional phase – selection, which would be the first phase in case of a new development (Greenfield)

stakeholders. The network transition in the last phase depends on the positive or negative effects of the probation phase, which could lead to a stronger, growing network.

Similarly, Chertow and Ehrenfeld (2012) describe the IS evolution process in three stages:

1. Sprouting
2. Uncovering
3. Embeddedness and institutionalisation

Sprouting describes the initial material exchanges which develop based on market conditions and business decisions – often called a recycling network. The second stage involves an "uncovering' effect" (Chertow 2007). The process is described as the discovery and publication of existing symbiotic linkages in an industrial area. Through this process industry partners, the local community and other parties are made aware of the existing linkages. The last stage describes the development, or embedding, of the system and may include an institutionalisation of the network for a more formal platform of collaboration.

3.3.3. Influencing factors of initiation and development

The development of IS is influenced by many factors (Gertler 1995; Mirata 2004; Kurup 2007; Corder 2008; Giurco et al. 2011). These include the following elements: economic and legislative incentives, the necessity of institutional or private links, the presence of a facilitator or broker (also called a champion), awareness of the concept of IS/IE, interest in business development (opportunisms) and project funding (Gertler 1995; Ehrenfeld & Gertler 1997).

Since the initial research project by Gertler in 1995, researchers have branched off to investigate specific elements responsible for IS development including research on drivers and barriers (Peck 1999; Young 2000; Harris 2004), enabling mechanisms (Harris 2008) and trigger events (van Beers et al. 2007a). Researchers have also investigated reasons and motivations behind symbiotic exchanges (Chertow 2007), the role of governmental policy

(Lehtoranta et al. 2011; Costa et al. 2010; Wenting et al. 2014; Veleva et al. 2015), identified success factors (Heeres et al. 2004; van Beers et al. 2007b; Park et al. 2008) and other influencing factors such as willingness to co-operate, dependence on social ties and market forces (Gibbs 2003; Chertow et al. 2008; Chertow & Ehrenfeld 2012).

It was noted that *"the development and operational characteristics of IS networks are dependent on the presence of the right mix of various factors"* (Mirata 2004). The statement is supported by studies conducted by other researchers (Gibbs 2003; Peck 1999; Young 2000; Harris 2004; van Beers & van Berkel 2007; Chertow 2007; Park et al. 2008; Chertow & Ehrenfeld 2012). They all agree on the flowing overarching classification of major factors influencing IS including technical, political, economic, informational and organisational factors.

Whereas the technical, political, economic and informational factors seem to be more transparent, organisational factors cover a range of latent sub factors. This category opens up into social science as it is concerned with motivational factors, decision processes and interactions between human individuals and firms (Uzzi 1996; Uzzi 1997; Côté & Cohen-Rosenthal 1998; Edward Cohen-Rosenthal 2000; Andrews 1999; Andrews 2001; Korhonen 2004; Petty et al. 2004; Boons & Baas 1997; Baas & Boons 2004; Baas & Huisingh 2008). Especially of concern are stakeholder processes as highlighted by Schwarz and Steininger (1997), who argue that 'human relations' can act as a barrier to cooperation. Another relevant sub section of social science is Corporate Social Responsibility (CSR), which has also been investigated in respect to IE (Korhonen 2002; Korhonen 2003; Allenby 1999; Boons & Roome 2001). Despite these research advances, computer simulation focussing on agent based modelling suggest that additional research on agent behaviours and decision-making processes is required (Bichraoui et al. 2013). Yu et al. (2013) also supported previous findings on the importance of social factors. They show that the research focus has changed over time, including additional diverse factors like organizational management and regional development.

A compilation of factors identified by Gertler (1995), Peck (1999), Young (2000) and Harris (2004) is depicted in Table 3.1 (page 24). The table shows an overarching classification of major influencing factors and relating drivers and barriers. Based on earlier research (Lifset & Graedel 2002; Côté & Hall 1995) it is noted that influencing factors are present at all system levels (Harris 2004).

An investigation into three Dutch and three US EIP programs highlighted the importance of two success factors: active participation of stakeholders and the presence of an entrepreneurs' association (Heeres et al. 2004). Van Beers et al. (2007b) identified the following three 'success factors' for IS development: proven technology, convincing business case, and licence to operate. They further argued that these three elements, in conjunction with the mutual benefits gained through the interfirm cooperation (financial, environmental and social), would also balance associated project costs and risks.

TABLE 3.1: IS ASPECTS, DRIVERS AND BARRIERS
(Based on Gertler (1995) Peck (1999), Young (2000) and Harris (2004))

Category	Drivers	Barriers
Economic	profit, high utility prices, landfill tax	ROI, low utility costs, capital, low taxes and subsidisation
Political (legislation)	taxes, environmental legislation, regional development	classification of waste, transport regulations, taxation, jurisdictional differences and poor/inconsistent regulation, long approval processes for new regulations, environmental liability
Technical	large quantities	small/large quantities, quality, supply security, back-up solutions, lack of handling facilities, geographic (space problems, distance)
Informational	past projects, sustainability awareness	unawareness of benefits, ease of disposal, lack of education
Organisational	environmental managers and management systems, company image, public concern over the environment	lack of organisation among stakeholders, short term view, conceptual-corporate culture (corporate practices), trust, mind-set core business focus, management time, nature of business

A different approach in investigating influencing factors is to review IS developments on the basis of trigger events (van Beers & van Berkel 2007). Triggers include the presence of a champion, new pollution targets or studies identifying potential synergy opportunities. Further research acknowledges the impact of global factors on business decisions and their impact on the drivers and barriers (Harris 2004).

3.4. Conclusions from the literature review

Industrial Ecology is a new concept in sustainability management for the 21st century. Researchers and engineers have found various tools to assist with the transition to an industrial ecosystem including IS, LCA and Cleaner Production (Section 3.1.2).

Though IS developments in Kalundborg were initiated over 40 years ago, most research has been published over the past 20 years. Reviewing the published research, the IS concept is well established though it is interesting to note that the definition and scope of IS is still being developed. Definition arguments include the minimum number of exchanges and type of industry participants as well as the scope in terms of geographic proximity. To illustrate the difference in scope and to demonstrate the overall complexity of IS systems, diagrams of the IS programs of Kalundborg and Kwinana are depicted below (Figure 3.4 and 3.5).

Regardless of discussions on heuristic and proximity, researchers have shown that there are three main models of IS (self-organised, facilitated and planned) and that the establishment of IS can follow different evolutionary paths due to a range of factors influencing their initiation and development. Concerning the research questions on how IS is implemented and what the influencing factors are, Mirata (2004) argues that symbiotic links are established if the right mix of (technical, informational, political, economic and organisational) factors are present for all involved parties. The IS literature highlights the importance of three factors (as barriers, drivers, triggers) in IS development. However, past research has focused primarily on case studies (Yu et al. 2013) describing the development and influencing factors of individual IS/EIP rather than a comparative examination on all-important social factors. The literature review

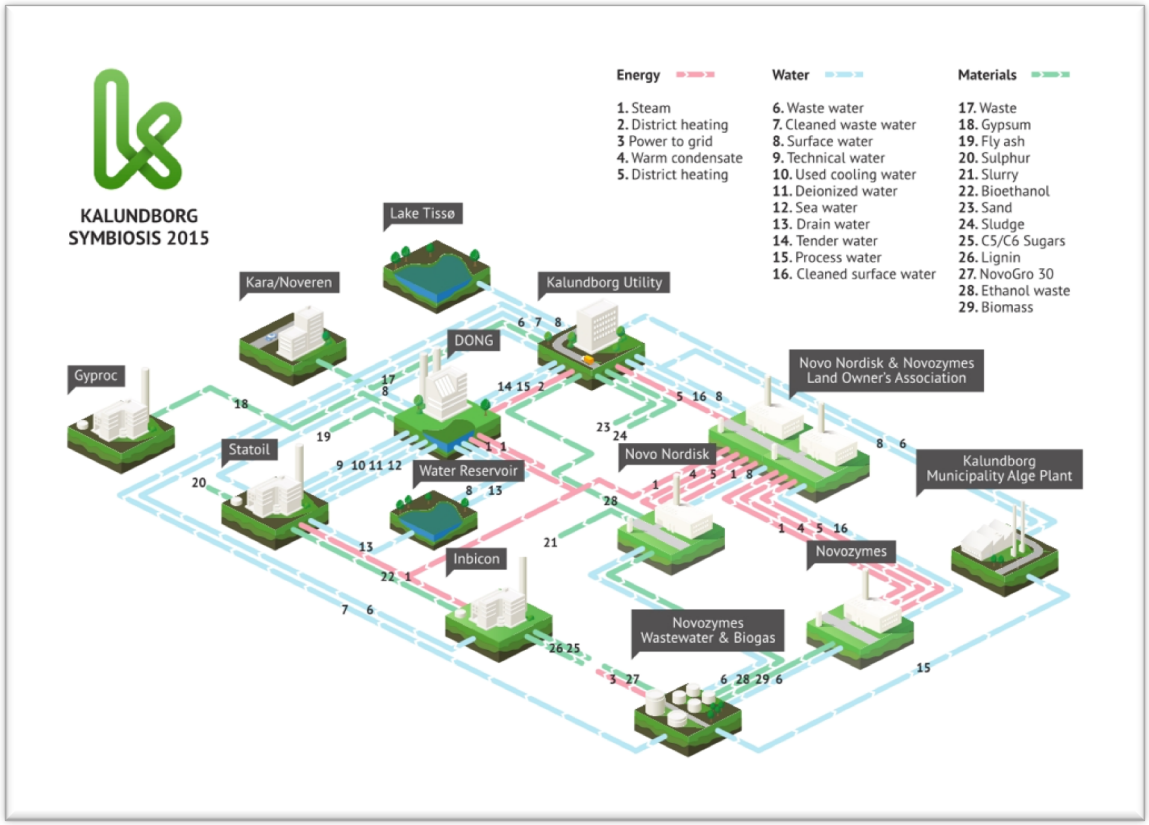

FIGURE 3.4: INDUSTRIAL SYMBIOSIS IN KALUNDBORG
Source: http://www.symbiosecenter.dk/wp-content/uploads/2016/06/Kalundborg-Symbiosis-Diagram.jpg 07/08/2016

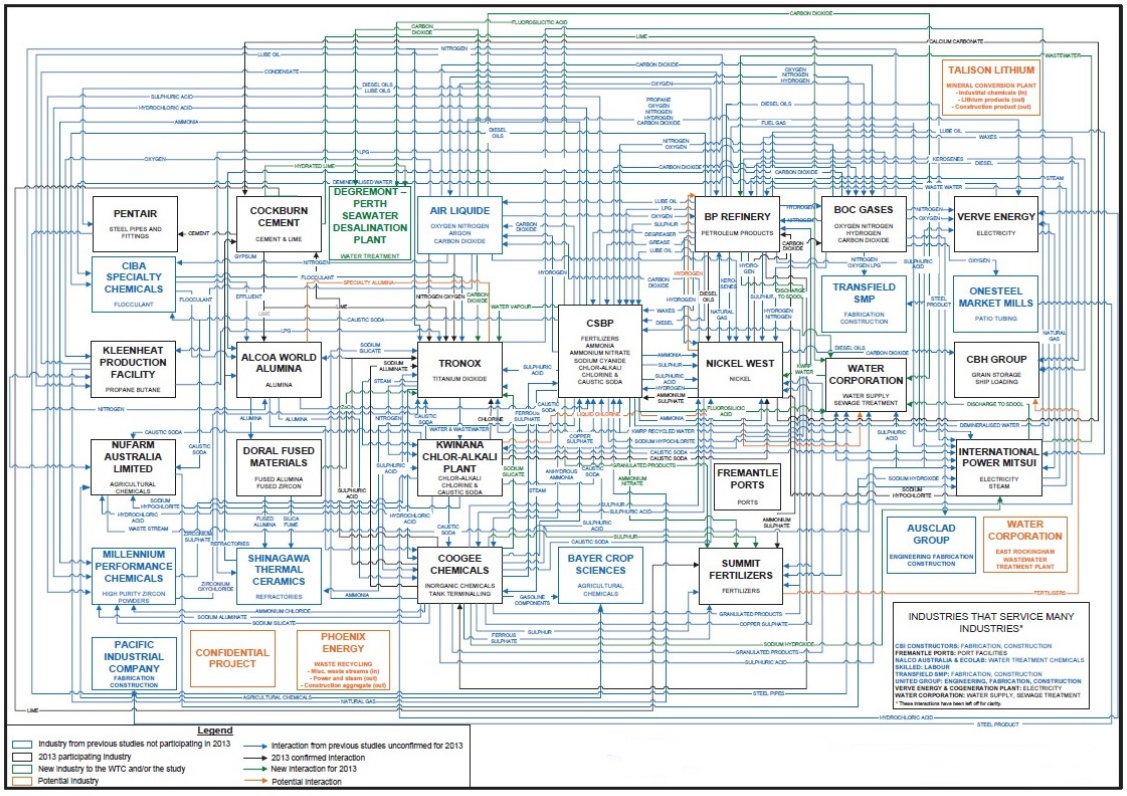

FIGURE 3.5: INDUSTRIAL SYMBIOSIS IN KWINANA
Source: SKM (2013)

has shown increased, IS related, research interest in organisational theory, highlighting the importance of project management in IS development. However, the previous research has addressed singular elements of IS management success (e.g. Champion, facilitators) but does not examine IS project management holistically including initiation mechanisms, funding and organisational features influencing IS development and further research is required to draw conclusions on best practice in IS project management. As a result, the factors influencing IS initiation and development have not yet been approached and discussed holistically.

The literature review highlights, that the previous research has addressed singular elements of IS management success (e.g. champion, facilitators) but does not examine IS project management holistically including initiation mechanisms, funding and organisational features influencing IS development and further research is required to draw conclusions on best practice in IS project management. As a result, the factors influencing IS initiation and development have not yet been approached and discussed holistically.

At present the IS literature provides a general overview of IS programs, their development models and factors influencing their development. Though the empirical evidence on these topics is extensive, the literature lacks a comparative assessment and review of the IS development process. The present research aims to address this gap by analysing different models and operational frameworks that exist in international case studies of IS and by investigating what influence the different factors have on IS initiation and funding. This study involves a comparative examination of major IS projects and reviews additional social, management and local contributing factors that have not been collectively acknowledged in detail in the literature to date.

Chapter 4. International review of Industrial Symbiosis projects

In the past 40 years, Industrial Symbiosis (IS) projects have been established and studied around the world (Chapter 3). The following international review depicts IS projects in various countries and their development. The selection of IS programs is based on the availability of literature; the following outline, based on countries, was chosen due multiple IS projects in the same country or country specific sustainable development strategies. The aim of the review is to address the first research question on how IS projects are initiated, and what assists and influences their development whilst also providing insight into the organisational frameworks of current international IS programs.

4.1. Denmark

The IS in Kalundborg, Denmark is one of the oldest and most published IS projects in the world. Its structure was initially studied by Holger Engberg from the Stern School of Business (New York) (Gertler 1995). Other early research on the IS development in Kalundborg was conducted by Tibbs (1993) and Gertler (1995), Ehrenfeld and Gertler (1997).

Tibbs looked at Kalundborg from the Industrial Ecology (IE) side, viewing it as a 'literal example' of an industrial ecosystem (as did Garner and Keoleian 1995). Gertler studied its system in depth, describing all interfirm collaborations up to 1993 and providing an outline of the systems development (Gertler 1995). Chertow further investigated the theory, structure and model of Kalundborg IS (Chertow 2000; Chertow 2004; Chertow 2007).

The early publications on Kalundborg such as Knight (1990), Tibbs (1993) and Gertler (1995) are inconsistent on when the IS started. This can be explained by the early stage of research and the still emerging definition of IS (Section 3.2.3). One can argue that the foundation for the IS program in Kalundborg was made by the first bilateral arrangement between the City of Kalundborg and Statoil (then Esso) 1961, which enabled the establishment of the oil refinery[2]. Eleven years later, the first industrial by-product exchange was implemented, which concerned the flare gas exchange between the refinery and Gyproc. By 1973, the IS system comprised of Statoil, Gyproc, Dong

[2] http://www.symbiosis.dk/en/evolution, accessed 1/8/2013

Energy (then the Asnæs Plant) and the local municipality. Figure 4.1 shows a timeline depicting the year synergies were initiated in Kalundborg. Though the numbers of symbiotic linkages increased steadily, few synergies were developed between 1970 and 1980. By 1981 seven independent synergies were implemented between eight entities and by 2010 it increased to 30 synergies between 16 entities.

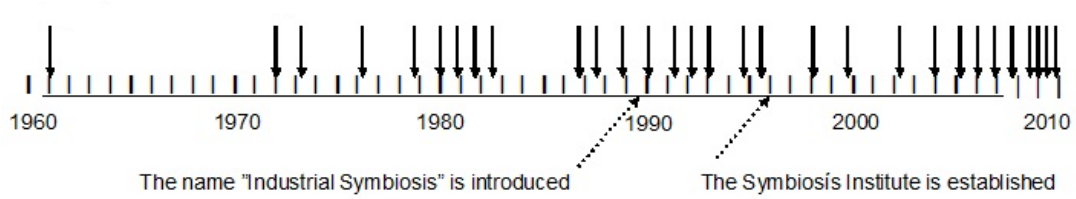

FIGURE 4.1: CHRONOLOGICAL DEVELOPMENTS OF THE IS IN KALUNDBORG
Source: Adaptation Christensen (2012)

The symbiotic linkages at Kalundborg emerged without a 'master plan' and even without knowledge of the new emerging concept of IE (Gertler 1995; Ehrenfeld & Gertler 1997). Ehrenfeld and Gertler (1997) state that the simultaneous appearance of 'positive technical and economic factors' made the linkages feasible together with the increased water scarcity being experienced.

The costs of each project were shared among the project participants, though the individual share depended on the benefits gained thorough the exchange and was negotiated between the parties (Gertler 1995; Tibbs 1993).

For the first 35 years the symbiotic development in Kalundborg has been deemed 'self-organised' (Chertow 2007). There was no overarching project or management team to specifically identify possible symbiotic exchanges in order to develop triple bottom line benefits. Every linkage was a single project, which was negotiated, planned, and executed between the participating parties alone (Gertler 1995). In the 1980s city officials initiated communication with industry experts to develop the 'Environmental Club' (Hewes & Lyons 2008) before the Symbiosis Institute was founded in 1996 (Christensen 2012).

Researchers further mentioned the following factors, which influenced the development of the Kalundborg IS. Gertler (1995), Hewes and Lyons (2008) have revealed that the passion and ambition of individuals were key elements

of Kalundborg's success; *"the right people being in the right place"* (Jacobsen 2005). For example, the personality of Valdemar Christensen (former production manager at Asnæs Power Plant) is highlighted to have had a strong influence on the IS developments in in Kalundborg and the Ukraine. Hewes and Lyons (2008) reported that his dedication enabled communication and information exchange on personal trust basis. The fact that the managers of the IS 'project' lived in the community provided them with additional regional knowledge such as the conditions of the natural environment and community objectives. In his thesis, Gertler (1995) has depicted decisions of managers that highlight preferential cleaner production initiatives (even though they regard future change in environmental legislation).

Concerning the technical feasibility of symbiotic linkages it should be noted that technologies applied in Kalundborg were common and well tested (Gertler 1995). An example is the steam exchange between the municipality of Kalundborg and the power station for central heating purposes (Gertler 1995). It is known that central heating was a Roman innovation, whereas general heat and steam exchanges have their origin in industrialisation. Since then transfer technologies for gases, fluids, and energy have been well studied and are a fundamental part of modern industrial processes.

Governmental regulations influenced IS developments in Kalundborg. Prior to legislative changes heat and steam exchanges with the power station were legally prohibited due to the defined purpose of the power station to produce electricity only (Gertler 1995). Drivers for synergy development in particular were the decreases in discharge limits required for waste water to the nearby fjord and ongoing air pollution requirement.

Community resistance to industry practices drove alternative waste disposal solutions such as the diversion of thermal and organic polluted water away from the fjord and cleaner air incentives. This community involvement and industry's foresight to adapt environmentally friendly technologies on their own initiative is an indication for the awareness of the impacts of industry on the natural environment and the need for a healthy ecosystem.

4.2. Australia

In the past decades three IS projects have been implemented in Australia. These projects targeted ore and minerals processing industries in Kwinana (Western Australia, WA), Gladstone (Queensland, QLD), and the Upper Spencer Gulf (USG) region (South Australia, SA). The main contributors to the Australian IS literature were the Sustainable Engineering Group (SEG)[3], Sustainable Minerals Institute at the University of Queensland and members of the Cooperative Research Centre for Sustainable Resource Processing (CSRP). Further bilateral symbiotic linkages were also investigated in New South Wales (NSW) with a focus on manufacturing waste recycling opportunities (Branson 2011).

The large-scale research project involving the Kwinana Industrial Area (KIA) and Gladstone Industrial Area (GIA) was initiated from different sustainable industrial production incentives in Australia and the set-up of the IS program and recruitment of industry stakeholders took two to three years (Michael 2013). Sustainable production incentives, for example, were advocated by Joe Herbertson in regards to the mining/minerals processing industry as well as the Chamber of Commerce and Industry of Western Australia (CCIWA) in conjunction with the KIC and the Centre of Excellence in Cleaner Production (CECP) pursued cleaner production incentives in the KIA. The CCIWA in collaboration with the KIC commissioned another Economic Impact Study (EIS), which included an input output analysis building on the initial EIS from 1990. Based on the results of the two economic impact studies in the KIA (1990 and 2002) and conversations with Joe Herbertson, industry stakeholders in the KIA and GIA became interested in collaborative research on sustainable resource processing in industrial areas with large scale minerals processing plants such as the KIA and GIA. Despite enthusiasm and potential synergies, stakeholders realised the problem of time commitment and project related cost. In order to facilitate the necessary research and development (R&D) involved in an IS project, stakeholders applied for a state

[3] formally the Centre of Excellence in Cleaner Production (CECP)

(Centre of Excellence Programme) and national government grants (ARC - Australian Research Council) (Taylor 2002; van Beers et al. 2005).

An integrated research strategy (see Figure 4.2) was developed by the CECP (now the Sustainable Engineering Group, Curtin University) in consultation with KIC, its members and other industry bodies to assist IS development (van Beers et al. 2005). This strategy involved regional case studies and research on engineering, which were supported by the CSRP, while the studies on tools, technologies and enabling mechanisms were supported by the ARC.

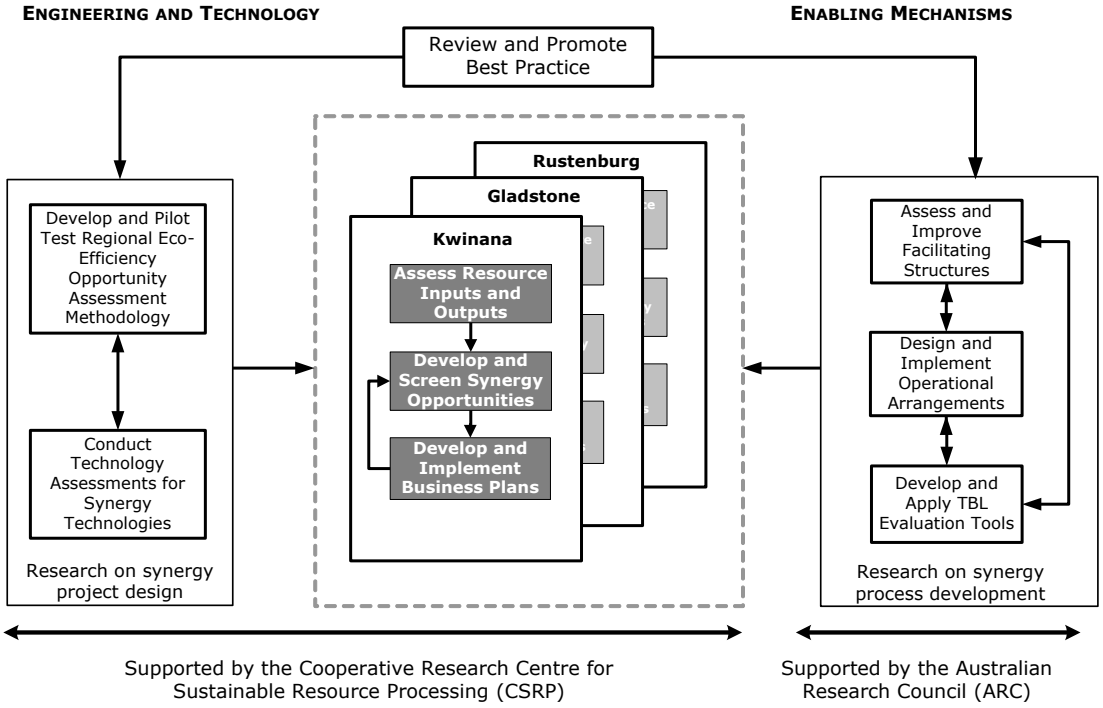

FIGURE 4.2: REGIONAL SYNERGIES RESEARCH STRATEGY
Source: van Beers et al. (2005)

The CSRP, a nationally funded Cooperative Research Centre (CRC), was established aiming to increase sustainability management and triple bottom line benefits in the Australian minerals industry by improving environmental conditions, company profits and community satisfaction for those living within the precinct of the industrial area. Funding for the CSRP was provided by industry participants and universities as well as the Commonwealth of Australia through its CRC program. Requirements of the CRC oblige the total stakeholder contribution to match Commonwealth funds dollar-for-dollar. The same contribution structure is applied by grants awarded by the ARC, which supported a study on 'enabling mechanisms' for symbioses.

The first synergetic links in the Kwinana Industrial Area (KIA) were discovered in 1990, when a report (Dames 1990) was submitted to the former Confederation of West Australian Industry (now Chamber of Commerce and Industry WA), outlining the economic impact of the KIA on wealth generation in the region. The study identified 27 already existing symbiotic linkages between 13 industries and highlighted further opportunities for both upstream and downstream integrations. Suggestions were made to improve the development of the KIA through strategic planning, for example the introduction of new industries, which may be beneficial for the existing companies or their waste/ production.

As a result of increased environmental pollution through heavy industry operations and community objections on the same matter, the Kwinana Industries Council (KIC) was established in 1991, mainly focussing on water and air quality monitoring at the time. The council is an incorporated business association and consists of major production companies and associated members of supporting industries and service (van Beers et al. 2005; KIC 2012). Pre-existing supply synergies as well as the communication network and interfirm cooperation of the KIC were essential conditions for further symbiotic developments.

In Gladstone a sustainability report and by-product mapping study, both released in 2001, showed potential for a sustainable industrial development in the GIA (Corder 2005). Also in the GIA, synergetic links among businesses already existed prior to the CSRP project (2004-2007), with five synergetic by-product exchanges in place (Corder 2005). Though additional synergy opportunities were identified during the CSRP project, the lack of new implemented synergies (Corder 2008) resulted in an increased focus on research towards motivational aspects and obstructions regarding by-product re-use options in the GIA. One of the key elements identified to positively support the development of synergetic linkages, is an enhanced network system (Corder 2008), which has been realised in 2008 with the establishment of the Gladstone Industrial Leadership Group (Golev et al. 2014).

In order to facilitate sustainable growth in the USG industrial region a symbiosis project was initiated by the SA Government – Office of Manufacturing; Department of Manufacturing, Innovation, Trade and Recourses (DMITRE) under its CleverGreenTM Eco-Innovation Programme. The program ran from 2011-2013 with the objective to increase the overall economic performance of SA while decreasing negative impacts of industrial operations on the environment and communities. It was designed to increase interfirm collaboration concerning energy, material, water efficiency projects and waste minimisation.

The USG project was fully funded under the Eco-innovation feasibility study grant (EIFSG) and therefore did not bear any actual costs for stakeholders. However, the recruitment process for project participants was particularly difficult (Michael 2013). The SEG was commissioned to conduct the USG IS project due to their extensive previous experience in IS in both Kwinana (WA) and Gladstone (QLD). Initially the focus of the project was on the industrial area of Whyalla only. However, the project scope was extended to the USG region as per suggestion of SEG, aiming for additional stakeholders and increasing the numbers of possible synergies effects.

The USG IS project kicked off at a workshop in Whyalla in March 2012 bringing together key stakeholders of the region. The project participants nominated preferred contacts within their organisations to liaise with each other and to provide information to the project team. By March 2013 the IS project identified 32 possible synergetic linkages between stakeholders (Rezaei 2013a). A second stage of this project is currently being discussed with the South Australian government to look at the potential development of the synergies determined in stage one.

An example of waste related IS research in Australia include Branson (2011) who investigated opportunities for bilateral symbioses (BS, see Section 3.2) in the manufacturing industry in NSW as an approach for sustainable development, which was both efficient and economical. The research concluded that the diversion of manufacturing waste form landfills, i.e. through IS, is a way to facilitate sustainable development and that possible market

opportunities are identified by interfirm collaboration. According to Branson, the crucial elements to promote interfirm recycling and IS opportunities involves governmental regulations as well as the connective infrastructure to support interfirm interactions (Branson 2011).

4.3. South Korea

The South Korean government has been promoting the application of environmental management systems (EMS), e.g. ISO 14001, since the 1995, by introducing the Act to Promote Environmentally Friendly Industrial Structure (APEFIS) (Park et al. 2008). The main source of research on IS developments in South Korea are published by Behera et al. (2012), Park et al. (2008) and Park (2011). In 2005, a strategy was formulated in order to facilitate IE principals in industrial areas. The strategy involved the development of Eco-Industrial Parks (EIP) and was called the “EIP master plan”. This action was taken to enhance productivity and resource efficiency in order to strengthen the economy. Another Korean incentive on sustainable development was the implementation of the ‘low carbon green growth strategy’. There the government attempts to change its economic growth from ‘quantitative’ to low carbon ‘qualitative’ to create a more sustainable economy. These two strategies mainly target South Korea’s heavy industry, which is highly dependent on energy availability and costs, consuming 38% of the country’s total energy supply. Therefore, the EIP master plan was to help achieve the proposed emission reductions by reducing the industrial energy intake on one side and decrease the production of greenhouse gas (GHG) emissions on the other side.

A key component of the master plan is a ‘research and development into business’ framework (R&DB). The framework applies a three-step strategy by exploring new linkages, reviewing the feasibility and the commercialisation/implementation of feasible exchanges at other locations. Furthermore, the plan connects government, industry, research and local communities to retrofit existing industrial areas to become EIPs.

The master plan evolved over a period of 15 years and is equally divided into three phases; pilot studies, revision and dissemination, and project review. The

project is comprised of a total of eight sample regions, of which five were started in 2005 as the initial case studies.

The EIP master plan program is managed by a federal governmental agency, the Korea Industrial Complex Corporation (KICOX). It delegates the management of the sample region to individual local EIP Centres, who are typically chosen by a local 'champion' (Section 5.1.3). A limited amount of public funding is available to support the EIP projects and a project proposal needs to be submitted and approved by the local EIP Centre and the KICOX in order to receive funds.

The industrial area based around the city of Ulsan was one of the initial case study areas. According to Behera et al. (2012), 13 exchanges have been successfully implemented and others are on the way, with a potential 40 proposed linkages.

4.4. United Kingdom

The United Kingdom (UK) has developed a unique approach in the application of IS. It funds the National Industrial Symbiosis Programme (NISP), which gives active support in the establishment of industrial waste exchanges on a national level. Early developments of NISP have been described by Mirata (2004) and Harris (2004), whereas Paquin and Howard-Grenville (2009; 2012) reviewed later progresses regarding concept and system application of NISP. The project was initially founded on the back of declining landfill capacity and availability in the London area.

The concept of industrial by-product exchanges was initially introduced to the UK during an IS project in Humberside by an oil company involved in a synergy project in Tampico, Mexico in the 1990s, led by the Business Council for Sustainable Development of the United States (BCSD US). As reported by Mirata (2004) and Harris (2004) NISP was instituted by the Business Council for Sustainable Development (BCSD UK), which was granted funding for the program in 2002. Both researchers reported earlier attempts of IS in the UK, which sparked the interest of symbiotic exchanges and the establishment of NISP. These included the extension of the IS programs outside of London to Humberside, Merseyside, West Midlands and the Forth Valley. The motives

behind the establishment of NISP were increasing awareness of environmental concerns such as highlighted by the Kyoto protocol and the foreside to assist industry to cope with increasing waste disposal costs and legislative requirements such as new environmental laws.

NISP is publicly funded and operates as a governmental consultant supporting symbiotic exchanges at a regional level. Its aim is to foster the identification and implementation of waste exchanges. Even though NISPs' consultation is free of charge, it does not provide project funding, which has to be provided by businesses themselves. A detailed description of NISPs' processes and procedures, as well as its development is provided by Paquin and Howard-Grenville (2012). NISP engages in three ways: conversation, connection and co-creation, which reflect back into pre-network development, early network development and later network development. As seen by the kind of its actions, NISP is a networking system identifying business opportunities. Participating companies provide data, which are continually assessed by NISP staff (Jensen et al. 2012). NISP also assist in the negotiation and business opportunity development for the waste material highlighted.

4.5. Netherlands

The Dutch were one of the first nations to integrate cleaner production and environmental management practices in the early 1990s. The researchers Baas and Boons were involved in projects around Rotterdam (Boons & Baas 1997), which is further described below. Other Dutch EIP attempts were analysed by Heeres et al. (2004).

The IS program around the Harbour and Industrial Complex of Rotterdam was initiated in 1994 by an industry association called Deltalinqs. The association was instituted as a result of previous attempts to address local environmental issues in the area. The initial IS program was known under the acronym INES; however, in 2003 the program merged into the 'Sustainable Rijnmond' and the 'Energy' program. A well outlined overview of the developments is given by Boons and Baas (1997). The program is now managed by members of the ROM-Rijnmond team, which consists of public, private representatives, as well as university academics.

In 1996 and 1998 two additional projects were initiated in the Netherlands, the Rietvelden/Vutter (RiVu) sustainable revitalisation project and the Moerdijk EIP project (Heeres et al. 2004). According to Heeres et al. (2004), these projects were financially supported through public and private funds during the project-planning phase. For the physical implementation of synergies individual firms were responsible, which also had to carry all project costs (Heeres et al. 2004). However, their study shows differences in the initiation and development structure between the Rijnmond and the other two EIP projects. The EIP programs in RiVu and Moerdijk displayed stronger government involvement during the project initiation and planning phases. In Moerdijk, the local governmental authorities also managed the project, whereas entrepreneurs supervised the RiVu and Rijnmond projects.

The focus of the Harbour and Industrial Complex of Rotterdam has been the combined management of water and waste water, residual heat and compressed air (Saikku 2006; CECP 2007). The low risks, cost-effectiveness and reduced pollution (noise and gaseous emission benefits) made it beneficial for companies within the Harbour to investigate symbiotic management of utility and services. Since 2000, companies share a compressed air system, which was extended in 2002. Industrial water management was targeted due to the high consumption of freshwater in the Harbour region, which can be substituted by industrial grade surface water. There is great potential for the utilisation of waste heat in the region as a substitution for fossil-fuelled power plants (Baas 2011).

4.6. Germany

In 1996, Germany implemented the Closed Substance Cycle and Waste Management Act in pursuit of a circular economy. Based on this policy development, several IS projects, ranging from planned EIP projects, retrofitting of existing industrial areas or recycling orientated networks are reported. Major contributors are Sterr and Ott (2004), who established the IS in and around Heidelberg and the Rhein-Neckar Triangle, and Schwarz et al. (1996) who investigated recycling networks in the Ruhr Area.

In 1996 researchers at the Institute of Eco-Industrial Analyses (IUWA) approached the city of Heidelberg for support of an IS project. The regional development agency identified the industrial area of 'Pfaffengrund' as a potential site for the project. The location was chosen due to an economic downturn in the industrial area in the mid-1990s, and 18 companies participated in the project. Financial support was granted by the DBU (German Environment Foundation); additionally, each project participant contributed approximately €5,000. From 1996 to 1998 a communication network was established, which was appreciated by companies as the information exchange provided the basis for the financial success the project and the satisfaction of the participating companies (Sterr 2000; Sterr & Ott 2004). The project focused on input-output matching, tender solutions, joint transportation and information coordination. The return on investment (ROI) was considered sufficient for businesses to continue in the identification of other waste exchanges.

The main researchers and facilitators of the Pfaffengrund project, Thomas Sterr and Thomas Ott realised, that the chosen location limited material exchanges quantitatively and did not guarantee supply security. Due to the success of the initial project, a second project on a larger area was initiated in 1997 and formally started in 1999. With three years of financial support from the BMBF (German Federal Ministry of Education and Research), the research team extended their focus area on the Rhein-Neckar region which stretches over 5,600 km^2 (including the industrial area of Pfaffengrund, about 3.5 km^2)[4,5]. The Rhein-Neckar region belongs to one of Germany's largest industrialised regions. The IUWA focussed their activities on waste based interfirm collaboration of small and medium sized enterprises (Sterr 2000).

Based on Schwarz's research in Austria (Section 4.7) a research team investigated regional recycling networks in the Ruhr Area in North Rhine-Westphalia. Analysing the development and structure of the recycling network,

[4] http://www.m-r-n.com/start/forschen-studieren/mrn-in-zahlen.html accessed 19/8/13
[5] http://www.heidelberg.de/servlet/PB/show/1191201/12_pdf_PfaffengrundAufEinenBlick2011.pdf accessed 19/8/13

the research shows a comprehensive network of interfirm exchanges across the region (Schwarz et al. 1996).

Between 1980 and 2000, Germany experienced a shift from heavy industrialised manufacturing to more medium size light industrialisation. Older industrial estates of all sizes were reutilised and retrofitted. As a result, obsolete industrial estates have been transformed into leisure parks for recreational purposes like the 'Landschaftspark Duisburg Nord'[6]. Other industrial estates have been renovated with the objective to operate 'self-sustainingly'. In most cases, the focus is on energy saving (e.g. photovoltaic systems, innovative-low energy buildings) and to use optimal infrastructure with regards to general services (e.g. broadband, mailing facilities, shared use of bore water)[7]. Another way of modern industrial estate design is displayed in the Industrial Area of Frankfurt-Höchst[8]. The industrial estate offers businesses a well-established infrastructure including pre-installed pipelines for gas or steam supply, which is suitable for a range of different industries. With regards to the above, in Germany the term 'Eco Park' needs to be viewed with care as it refers to a wide range of sustainable industrial park models.

4.7. Austria

After the concept of IS emerged, researchers questioned the uniqueness of Kalundborg (Schwarz & Steininger 1997), and research was conducted to evaluate if similar projects existed elsewhere, though not publicised. Therefore, Schwarz and Steininger (1997) investigated regional recycling networks in Styria, a province of Austria. The authors back traced material linkages between companies, starting at one company and following input and output trails to other businesses. This was repeated until reaching the boundaries of the region. Material inputs from the natural environment were excluded from the process. The network was quiet substantial with regards to the overall recycling activities.

As described by Schwarz and Steininger (1997) the network is driven on economic incentives, similar to those in Kalundborg. The system was

[6] http://www.landschaftspark.de/der-park/einfuehrung accessed 20/8/13
[7] http://www.ecopark.de/index.php?PHPSESSID=625d7e6295f8cf5f0afef1d7fb3e5e68 accessed 20/08/13
[8] http://www.industriepark-hoechst.com/index.htm accessed 20/08/13

established on collaborative symbiotic exchanges between two businesses, based on market conditions for materials, disposal costs and environmental regulations. However, due to the type of exchanges, synergies were known as 'business as usual' (Schwarz & Steininger 1997), as they were noted as the most cost-effective method of waste disposal. Even though no pipelines need to be build, the network relies heavily on transportation of materials across the region. Transport and administrative costs of each exchange are covered by the involved companies. Schwarz and Steininger (1997) further note that the firms within the recycling network were not aware of the system itself and therefore the full potential of the network was not utilised. Since their investigation and through further efforts of the research team the companies within the regional recycling network are now "aware" of the existing material exchange network and the potential for more development.

4.8. United States

Industrial Symbiosis concepts were adapted in the United States (US) after the Rio Conference in 1992. The US experienced both, private and public interest in sustainable development. In the year 1993, a group of executives established the Business Council for Sustainable Development – Gulf of Mexico (BCSD-GM), which focussed on the reutilisation of industrial by-products in the Gulf region. At the same time, the government supported the development of new industrial sites with the idea to plan new EIPs as well as to retrofit older industrial estates. In the 2000s, the BCSD US (Section 4.4) focussed on network development in existing industrial areas, aiming for the establishment of more by-product synergies (Kim 2009).

A pilot project was launched by the President's Council on Sustainable Development (PCSD) together with the US Environmental Protection Agency (EPA) in 1994 to foster sustainable development, to enhance productivity and to strengthen the economy of the chosen sites. The project framework comprehended the development of 14 EIPs in the US and one in Canada. A team of developers, local governments and regional planners compiled a 'genetic design concept' including requirements and conditions for the development of the EIPs (Lowe & Evans 1995). The planning, initial facilitation and administration of the individual US EIP were financed and managed by

the government, whereas the implementation costs had to be incurred by stakeholder involved in the exchange (Heeres et al. 2004). Only two projects were successfully implemented (Londonderry, NH US; Burnside, CA). It was therefore concluded, that the proposed concept failed. In their comparative study between three US and Dutch EIP projects, Heeres et al. (2004) describe the strong involvement of the government that resulted into strict development regulations and disinterest of private companies to participate in the program as main reasons for the failure of the US attempts.

The BCSD-GM fostered a successful IS project in Tampico between 1997 and 1999 by establishing a network of local industry stakeholders (Chertow 2000). Synergies were identified though input-output analyses. The BCSD-GM itself was funded through membership fees. Members further provided in-kind[9] (in-kind 2013) services as well as their experience (Mangan 1997). In 2002, the BCSD-GM was dissolved in order to found the BCSD US, with Andrew Mangan as the director. The group was similarly structured as the BCSD-GM and is anchor for new networks. The aim is to co-found sustainable development in American industrial areas like Chicago and Kansas City. The group focused on existing industrial areas and their potential for by-product synergies rather than establishing new EIPs (Kim 2009).

4.9. Canada

Canada is rich in natural resources, in particular oil, natural gas and oil sands, it is therefore, considered a prime location for industrial development. Recognition of the concept of circular economy and the need for businesses to adapt sustainable manufacturing processes has been promoted in Canada since 1990 (Côté & Hall 1995). Based on a literature review, six industrial clusters and four large industrial parks were identified in relation to EIP/IS development; most of them located in the provinces of Alberta and Ontario. These were either retrofitted industrial areas or new build EIPs. In 1999 the status of EIP projects in the US and Canada was investigated (Peck 1999). In his report Peck recognises the efforts made to promote EIP, but described them as “infantile”. Besides direct attempts to retrofit industrial estates,

[9] Means the payment in services instead of money

Markewitz (2011) shows the advancement of a regional recycling network towards IS in Québec.

The Burnside Industrial Park is one of the largest industrial areas in Canada, established in the 1970s. The industrial area hosts a mix of small and medium sized businesses as well as large industrial corporations (Peck 1999). In 1992, the Burnside industrial area became subject to an eco-industrial incentive (i.e. mapping of material flows) aiming to explore potential transformation of the estate into an industrial eco-system (Lambert & Boons 2002). Researchers at the Dalhousie University (Halifax) were leading the initiative. This was followed by the establishment of the Burnside Cleaner Production Centre (BCPC) as a hub of networking, information exchange and promotion. Though, it was in operation between 1995 and 1996 (Peck 1999) information on structure and finances is not available. Two years later a new centre (Eco-Efficiency Centre or EEC) was established by Dalhousie University and Nova Scotia Power Inc.[10]. It was a non-profit organisation, financially supported by local businesses and government agencies, directed through an advisory board (Adams 2011; Côté et al. 2006). The centre provided training and services with the objective to foster sustainable development in the region, through workshops and practice and acted as facilitator for IE projects. The centre was closed in 2012[11].

From 1998 to 1999 a By-Product Synergy (BPS) project was implemented in Alberta's Industrial Heartland (Chertow 2000). The Heartland, also called 'Upgrader Alley' is the hub of resource processing in Canada, closely located to sources of natural resources like Alberta's oil sand fields. The mix of industries, including hydrocarbon, chemical and minerals processing industries, and the size of the industrial area made it very attractive for BPSs. The project was proposed and facilitated by Applied Sustainability LLC, a consultancy firm (Young 2000). Other project participants were 15 public and private players, who contributed financially to the project. At the end of the

[10] http://www.supergreenme.com/DalhousieUniversitysEcoEfficiencyCentre, accessed26/08/2013
[11] http://www.dal.ca/faculty/management/schools_and_centres/eco-efficiency-centre.html, accessed 26/08/2013

project 25 symbiotic linages were identified, however, it is not reported to what extent these had been implemented.

Sustainable development approaches from the Canadian province of Québec are reported by researchers from the Centre de Transfert Technologique en Écologie Industrielle (CTTÉI) (Markewitz et al. 2012). Their research describes the advancement of a regional recycling network towards IS focussing on waste management. Similar to the recycling network in Styria (Austria) and the Ruhr-Area (Germany), a public provincial organisation provided an online platform where companies were encouraged to advertise waste and by-products or even to search for input material. The service is free of charge, though a subscription is required. The Quebec Secondary Materials Exchange (BQMS in French) platform was implemented by a governmental agency in 1993 to increase material recycling rates for various materials. On average, this platform enables ten waste exchanges per year. Since restructuring in 2005 the exchange platform is called Quebec Industrial Waste Exchange (BRIQ). As part of the reorganisation of the system an online database was created, which included an auto-matching function as well as manual search features. The research centre affiliated with the management and development of the exchange software, called CTTEI[12], proposed an IS project in one of the industrial area in the province in 2008. The project involved the Bécancour Industrial and Port Park and was supported by a provincial governmental program. However, Markewitz et al. (2012) does not give exact details on in-kind or financial support. Through further software adjustments, 39 symbiotic linkages were identified between twelve participants. Further IS projects were initiated by local development agencies. The system analysis and application of BRIQ's interactive web interface identified 285 possible synergies in the region Launaudière whereas 58 were discovered in the town of Rivière-du-Loup and 47 in the town of Shawinigan.

[12] French acronym – Centre for the Transfer of Technologies in Industrial Ecology, affiliated with the Sorel-Tracy College of General and Professional Education in Québec

4.10. New Zealand

The literature review identified only one IS project in New Zealand[13] in Kawerau. The town's industry is based on timber processing which includes the operation of five mills[14]. The project was initiated by the Kawerau District Council (KDC) and New Zealand Trade and Enterprise (NZTE) in 2010 with the aim to enhance regional development. Even though geothermal heat had been used in the industrial area of Kawerau since the 1950s, additional developments took place in the mid-2000s. The establishment of a new geothermal energy plant, providing electricity and steam to local businesses, was essential to secure sustainable development of the region and has had a positive effect on the community. For example, one of the major employers (Norske Skog Tasman) considered closing down its operations in New Zealand and moving to Australia. However, the company closure was prevented. Besides the financial crisis, the expansion of the geothermal field supported compliance with the green energy strategy of its parent company.

The project is managed by KDC with support from the NZTE and financed through public funds. Their activities focus on the development of interfirm collaboration for mutual benefits and the creation of a platform to foster communication. Initially only the largest employers were invited, later workshops were open for smaller firms as well. It is reported that the interest in IS and the opportunities it offers was that great, that people had to be turned down from attending the workshops. Through personal communication (Cammell 2013) it was identified that none of the KDC staff involved had any prior experience in a symbiosis project and also did not seek support from an external experienced facilitator, due to cost restraints.

4.11. Japan

Japan is a pioneer in the application of IE. Japanese IS was initially studied by Belgian ecologist Gunter Pauli (Gertler 1995). Reflecting on the past 50 years, Japan has a versatile mix of ecological initiatives. Their ecological efforts have been reported in great detail by Gertler (1995), Erkman (1997), Côté et al. (1998), Peck (1999), Chertow (2000, 2004), Van Berkel el al. (2009a,b) and

[13] http://embracechange.co.nz/, accessed 17/04/2013
[14] http://www.kawerau.org.nz/history accessed 04/07/2014

Ohnishi et al. (2012). However, the Japanese examples of IS largely focus on waste materials, including domestic and industrial emissions in order to establish a circular economy.

In the late 1960s the Japanese government ordered an investigation of its industrial system to reduce industrial environmental impact, making it the first county to strategically put measures in place to encourage resource efficiency in industrial areas (Erkman 1997). In the 1990s, waste reduction initiatives took off. In 1994, the Zero Emissions Research Initiative (ZERI) was founded on the conception by Pauli that waste products can be reutilised as input material for another company maximising revenue for both parties involved (Gertler 1995).

Even though ZERI is based in Japan, the network operates worldwide, bringing together researchers and their ideas for future sustainable manufacturing. ZERI in collaboration with the United Nations University (UNU) initiated the Zero Emissions Forum (ZEF)[15] in 1999. The ZEF aims to mitigate between industry and research, providing a platform for collaboration, research and outreach (Kuehr 2007).

Following the idea of ‘zero emissions’ Japan's Ministry of International Trade and Industry (currently the Ministry of Economy, Trade and Industry, or METI) and the former Ministry of Health and Welfare (later transferred to the Ministry of Environment, MoE) instituted the ‘Eco-town Project’ in 1997 (van Berkel et al. 2009). Reasons behind this scheme were diminishing landfill capacities and industrial economic enhancement. Van Berkel et al. (2009) investigated the scheme in detail with regards to IS. As the Eco-Town concept differs from IS in its geographical orientation, van Berkel et al. (2009) entitle it ‘urban symbiosis’.

The Eco-town project is a top-down[16] approach, legally embedded in the Japanese legislative framework (The Basic Law for Establishing a Recycling-Based Society (2002), The Waste Management Law (2003) and The Law for

[15] http://archive.ias.unu.edu/sub_page.aspx?catID=5&ddlID=468 accessed 28/06/2014
[16] “denoting a system of government or management in which actions and policies are initiated at the highest level; hierarchical” (top-down 2013)

Promotion of Effective Utilisation of Resources (2001)). In this program, local governments, either on a municipality or on a prefectural level, function as main facilitators for project development. They liaise with industry, local community/groups and R&D facilities, to develop individual project plans for each target region, which may contain organisational mechanisms and technical components. Projects are approved and partly funded by MoE and METI. Further supplementary funding was received from local authorities. By 2006, 26 Eco-Towns, with unique development plans, were spread across Japan, divided up into target areas (metropolitan [6], cities [10], regional areas [6], islands [2] and port/industrial area [2]) (van Berkel et al. 2009).

The metropolitan area of Kawasaki was one target area in the Eco-Town Project. An investigation of its symbiotic linkages was made in 2006-2007 identifying 17 physical exchanges between ten firms (van Berkel et al. 2009). However, the authors note that only seven exchanges were classified as IS.

4.12. China

China adapted the concept of circular economy based on examples from Germany and Japan. The concept was manifested in the Chinese national legislation with the implementation of the Cleaner Production Promotion Law in 2003 (Geng & Doberstein 2008). To support the new law and to increase awareness of concept applications Cleaner Production Centres were established on national, sectoral and local levels. According to Geng and Doverstein (2008), the amendment of the Chinese national environmental legislation concerning pollution and controls on solid waste disposal further encouraged industry to participate in the EIP program. In 2008 further legislation was introduced to foster waste exchanges and the utilisation of by-products (Yu et al. 2011).

The first EIP project in China was initiated and managed by the State Environmental Protection Administration (SEPA) in Guigang in 2000 (Chiu & Yong 2004). Further EIP were planned and initiated by the SEPA, the National Development & Reform Commission (NDRC) under its ‘low-carbon’ program or through private initiatives (Yuan et al. 2006; Geng et al. 2012; Shi, Tian & Chen 2012a). As most EIPs are centrally planned through governmental

agencies, a high development rate of EIPs can be noted since 2000. An exact number of total developed EIPs is difficult to determine, as published research data are inconsistent. However, according to Shi et al. (2012) EIP activities focus on 60 industrial areas. Despite an already high development rate Shi et al. (2012) and Yu et al. (2011) note that more active participation of industry participants and governmental financial assistance for projects initiation would boost further EIP development. Zhu et al. (2007) and Dong et al. (2011) highlight the Chinese potential in IS development along with reductions in GHG emission and raw material utilisation.

4.13. Summary

This chapter reviewed case studies of IS programs from ten different countries. Reviewing these programs provided a better overview of international IS projects developed and understanding on the initiation mechanisms, project governance, organisational and funding structures. The review addresses the first research question on factors initiating IS development. It was also observed that other factors such as stakeholders and their objectives, champions, local factors and overall program objectives play an important role in the development of each individual IS program. The findings of this review also highlight the importance of IS organisational frameworks and behavioural change agents in supporting IS and sustainable industrial production.

4.13.1. Classifying Industrial Symbiosis activities

A summary of development and operational aspects of some of the IS cases discussed in this Chapter are depicted in Table 4.1. Though excluding IS programs from Japan and China due to their unique regulatory basis, the table allows for a better illustration of key differences and similarities of the development strategies, assists to classify the IS activities and highlights operational challenges. Concerning evolutionary processes Table 4.1 illustrates that five out of eleven IS projects started on a self-organised basis and then transitioned into a facilitated structure. Further it shows that, most of the long term IS programs are developed by a third party and not by the industrial stakeholders themselves. The facilitation approach is predominantly

TABLE 4.1: SUMMARY OF COMMON INDUSTRIAL SYMBIOSIS STRUCTURES

Location	Evolution	Start	Governance	Organisation	Champion	Funding	Source
Denmark, Kalundborg	self-organised	1961	self-governed	open	yes	private	Gertler (1995)
Australia, Kwinana	facilitated	2003	facilitated	research project with formal agreements	yes	public/ private	Van Beers et al. (2005)
Australia, USG	government initiated	2012	facilitated	open	yes	public	Rosano (2013)
South Korea, Ulsan	government initiated	2005	facilitated	government organised project	not specified	public/ private	Behera et al. (2012)
UK, Humberside	self-organised	2002	facilitated	open	not specified	public/ private	Mirata (2003)
Netherlands, Rotterdam	self-organised	1994	facilitated	research project with formal agreements	not specified	public/ private	Heeres et al. (2004)
Germany, Pfaffengrund	facilitated	1996	facilitated	research project with formal agreements	yes	public/ private	Sterr and Ott (2000)
Austria, Syria	self-organised	-	Self-governed	open	-	private	Schwarz and Steininger (1997)
US, Devens	government initiated	1999	facilitated	open	yes	public	Deutz et al (2008)
Canada, Burnside	facilitated	1992	facilitated	university/open	yes	public/ private	Peck (1999) Adams (2011) Côté et al. (2006)
New Zealand, Kawerau	self-organised	2010	facilitated	open	not specified	private	web/ personal com

'open' without formal agreements between stakeholders in place regarding key performance indicators for the program development. The table further shows that a large number of programs are supported by a project champion, which supports previous research on the importance of their role in the IS development process.

Table 4.1 presents a summary on the founding structures of major international IS programs. Despite the differences in each IS approach, the examples discussed support previous findings in regards to the general classification of common development models (self-organised, facilitated, planned). However, it was found that the applied model can change into another form over time. For example, an IS can start off self-organised and change into a facilitated IS at a later development stage as seen in the development of the IS at Kwinana (Section 4.2).

The same classification can also be applied to funding models. As shown by the Table 4.1, some projects are funded by industry partners solely (e.g. Kalundborg), whereas others are co-funded through public and private funds (e.g. Kwinana, Pfaffengrund) or even fully public funding as in the case of the IS facilitation study in the USG, South Australia. Though most programs are co-funded with public monies, the depicted funding structures differ vastly from each other. A possible explanation could be country specific regulations and policies addressing sustainable development, in the countries reviewed.

4.13.2. Common operational challenges

The above analysis has shown that the development of IS programs varies. Regional characteristics differ as well as the industries present. This, in combination with local legislative frameworks, creates a unique environment in which IS projects are typically founded. These aspects are unique to each country/region and have a strong impact on business practices, internal processes and the IS objectives sought.

In addition, key operational elements differ such as the project management and organisational structures. This review also noted many common factors in IS initiation and development. These include stakeholders, project champions and funding as well as policy and economic influences, project management

styles and IS facilitation. Managing these elements can be a challenge (Section 3.3) and addressing these factors appropriately is crucial for successful IS development. For example, stakeholders are a critical element in IS. However not only what drives them is important, but all factors influencing their decision-making processes are important. Some stakeholders become so-called ‘champions’, a key element driving IS (Section 3.3.1). The next Chapter investigates these management/organisational behavioural elements to shed light on their effects on IS project initiation and development.

Chapter 5. Factors influencing Industrial Symbiosis development

Chapter 4 highlighted the different approaches to Industrial Symbiosis (IS) and elements influencing their development. Common elements in an IS program are the stakeholders and their objectives, champions, local factors influencing project related funding, operational management structures and overall program objectives. Chapter 5 aims to address the second research question by analysing these factors and examining the stakeholder processes to give insight into the project management elements of IS initiation and development.

5.1. Potential stakeholders

Stakeholders are an integral part of IS. Chapter 4 identified that stakeholder groups consist of a combination of industrial and commercial firms, public entities and organisations, and governmental agencies. The cooperation of stakeholders is essential to an IS program and a strong communication network is considered a driver for IS development (Gertler 1997); as are champions (Hewes & Lyons 2008). However, researchers have pointed out that stakeholder processes can have a negative effect on IS outcomes (Schwarz and Steininger 1997).

The following paragraphs investigate the objectives and motivation of five specific stakeholders with regards to why they would participate in an IS program. These five stakeholders are private businesses, universities and governmental agencies, facilitators and individuals. They were selected due to their foremost involvement in the establishment of by-product exchanges. The local community as a stakeholder is considered in Section 5.9 under the title of Social Licence to Operate.

5.1.1. Stakeholder objectives and motivation

Stakeholders in IS projects are motivated by objectives and participate with intent. Throughout their participation, stakeholders focus on their objective and drive the project towards a specific target. Within an IS program objectives may need to be defined and the individual objectives of the stakeholders managed to ensure overall stakeholder satisfaction.

Private businesses

The main objective of a business is to make profits (Gibbs & Deutz 2005; CECP 2007). In order to operate and make profits a business is motivated to comply with governmental legislation and to obtain the relevant legal and social licences. With the aim of maintaining operational and Social Licences to Operate (SLO), business invest in cleaner production activities, plant upgrades and other sustainability management projects. Chapter 4 highlighted that local resource scarcity is another motivational factor.

Overall businesses are motivated to sustain their business operations by cost reductions, higher production efficiency and increasing market share. They respond to legislative and community pressure as well as to changing environmental conditions such as drought.

University

Universities seek to extend current knowledge through research and development, and to educate and pass on this knowledge. Amongst other things, the success of a university is measured by the sum of its research output – typically scientific journal publications. They are often involved in IS research to investigate and publicize the sustainability benefits associated with IS programs. University research groups have the objective to collect data and experiences, assisting with technology development and support. Their motivation is to test theories and implement new practices, increase knowledge and to pass on it on. In particular, IS examination provides an opportunity for universities to facilitate and promote more sustainable industrial production. This has been the case in Western Australia (Curtin University), Queensland (University of Queensland), Canada (Dalhousie University), Japan (United Nations University), and China (publication only-Shandong University), where universities have all spent many years researching and collaborating with local IS programs and publishing the benefits of IS in sustainable industrial production.

Government

Governmental agencies are motivated to participate in IS projects with the aim of supporting regional development and to gain (international) recognition for research and development conducted in the country. As highlighted by the

ARC linkage project in Western Australia (WA) (Section 4.2), governmental objectives include the development of innovative technologies, resource development and sustainability which will help reduce industrial emissions and other negative environmental impacts associated with industrial production (e.g. waste reduction).

Facilitator

Facilitators are an important factor in IS programs steering their development. Chapter 4 summarised facilitated IS programs and identified different facilitators; hired by the industrial partners (e.g. consultants or research groups), or employees of public and private businesses. The facilitator's objectives and motivation factors vary depending on the facilitator and their affiliation.

Hired facilitators bound by a contractual agreement are obligated to address the overarching project objectives. However, stakeholders and their interactive networks (also called peers) differ for individual IS program or project and thus influence the facilitators. Due to this influence, objectives can shift towards network development, such as in the case of NISP (Section 4.4), rather than a focus on the identification and implementation of actual synergies.

The motivational factors can also vary between project facilitators and their different affiliations. Facilitators can be motivated by revenue also. This might be the case particularly when project management is the main business of the company. Individuals volunteering to champion an IS program can be driven by achieving sustainable outcomes, economic, environmental and social benefits as in the case of Kalundborg, Kwinana and USG (Section 4.1 and 4.2).

Individual

The smallest agents in IS development are individual participants (Andrews 2001). The neoclassical view of individuals is that they are self-interested decision makers (Andrews 2001), whereas the modern view describes humans as self-learning actors (Vermeulen 2006). In an IS program individuals act rarely on their own behalf but on their employers. Individuals are influenced by their culture and society they grew up in and similar influences shape company policies and directions (Andrews 2001; Korhonen 2004). Not

necessarily does the firm's opinion on a subject match the beliefs of the employee. This problem is known as the 'principal-agent problem' and can occur in all organisations across all institutional levels (e.g. principal = company, agent = manager) (Faucheux & Nicolaï 1998; Reinhardt 1999; Andrews 2001; Ciliberti et al. 2011; Vermeulen 2006).

The principal-agent problem is not the only difficulty influencing human decision-making. Another problem is the inter-human cooperation, the so called 'prisoner's dilemma' (Schwarz & Steininger 1997; Andrews 2001; Baas 2007; Vilana & Rodríguez-Monroy 2010) where two humans will not necessarily collaborate for a mutual benefit if they sense the prospect of possible individual benefits that are more considerable.

This can be a challenge in IS development when the sustainability and waste management outcomes of an IS project are thwarted by individual(s) who are more interested in company financial performance (and associated employee benefits), and have the financial control to prevent or inhibit IS exchanges or development. These 'gatekeepers' can be considered a barrier to successful IS development. However, individuals are also known to positively influence or trigger IS as so-called champions (van Beers & van Berkel 2007; Hewes & Lyons 2008), which are discussed in more detail in Section 5.2.

5.1.2. Commitment and responsibility

With regard to the principal-agent problem, the level of commitment to sustainability can also differ between employer and employee. Particular managers are concerned with securing core business operations as their principal duty is to the company financial objectives. Therefore, additional IS related responsibilities may not be sufficiently recognised to be valuable and important across all employee groups and may not be included in employee focus and action in work plans. As shown by Hewes and Lyons (2008) individuals (champions) and their personalities play an important role in the successful development of IS.

To accomplish IS project objectives, clear definitions and appointment of responsibilities are important. Employee responsibilities might not be well defined within a business and the introduction of additional responsibilities may

or may not be emphasised by the employer depending on their personal commitment to the sustainability activities. However, employees having a clear set of directions and or performance indicators in terms of IS outcomes, can significantly assist the organisation in both managing and achieving the IS outcomes sought.

A review of roles and responsibilities of participants is further discussed with regard to project management in Section 5.4.2.

5.1.3. Stakeholder groups

Stakeholder groups in IS programs include a variety of parties including manufacturing or resource processing businesses, governmental agencies, research groups and consultancy firms. The set-up of stakeholder groups can depend on the network model (self-organised, planned or facilitated). Businesses that are part of a self-organised IS, such as the IS in Kalundborg, develop symbiotic exchanges by themselves. However, they might interact with governmental agencies or consultants (commercial or academic) depending on the nature of the exchange, which might require external consultation in regards to licences, regulations or technical queries. Facilitated IS programs are initiated by governmental agencies (e.g. Kwinana, USG), research groups (e.g. Burnside) and industrial associations (e.g. Rotterdam) whereas planned EIP are predominantly developed by governmental agencies (e.g. EIP program in the US) or developers (e.g. Frankfurt-Höchst). However, regardless of the development model industry stakeholders and their activities are the focus of IS and their participation is vital for any IS. The initiators of these programs are often required to find industry partners willing to participate in such projects, as industrial businesses are not necessarily involved from the start.

5.1.3.1. Group and industry network set-up

Reviewing the developments of the IS in Kalundborg (Gertler 1995) and recycling networks in Styria, Ruhr-Area (Schwarz & Steininger 1997) and Quebec (Markewitz et al. 2012), it can be argued that, in an self-organised system, by-product exchanges are a result of stakeholder interaction in recycling exchange platforms and market forces (business as usual). In planned EIPs (US, Japan, South Korea) governmental agencies target specific

regional or industrial areas and contact the local industries in order to create sustainable change. Facilitated IS projects usually create stakeholder interest through workshops (Mangan 1997; Côté & Cohen-Rosenthal 1998; Peck 1999; Young 2000; Sterr & Ott 2004; Paquin & Howard-Grenville 2012).

Though, in some cases specific companies who are interested in the IS project are contacted directly prior to the workshops before the project discussions begin (Cammell 2013; Michael 2013). Initially NISP advertised its services via mailing and phone campaigns to create awareness and to attract a large number of possible participants, to build their recycling system (Cammell 2013). Through personal communication (Sterr 2013; Michael 2013) it was identified that the recruitment process is demanding. Sterr noted private companies in Germany have limited interest in IS research and academic collaboration. A similar experience was reported from the USG project, noting that it took a lot of time and effort to convince businesses of the value in symbiotic exchanges in the USG region (Michaels 2013).

5.1.3.2. Initiators

In the case of Kalundborg, it is reported that plant managers (e.g. Jørgen Christensen, Valdemar Christensen) were heavily involved in the establishment of individual symbiotic links (Gertler 1995). Driving forces in establishing the two projects in Pfaffengrund and Burnside were Thomas Sterr and Raymond Côté who organised funding and recruited participants. Individuals such as Sterr and Côté are called ‘champions’ (see Section 5.2). Andrew Mangan is another champion of IS, strongly influencing the EIP programs in the US and Canada (Mackenzie 2002). Mangan’s activities in different organisations led to the research question: Are individuals the driving force in IS project development? Through personal communication (Neville 2013) it was revealed, that the establishment of the CRC project in Kwinana and Gladstone was further enhanced by efforts of Joe Herbertson who put substantial effort into the set-up of the Centre for Sustainable Resource Processing (CSRP) which enabled further studies, also on by-product exchanges. Without his efforts these further studies may not have been initiated.

It has been reported that Valdemar Christensen in Kalundborg, was very committed to sustainability management, even though in his role as manager his decisions were based on a business cases (Gertler 1995). Herbertson[17] became interested in sustainability and saw the potential in the Australian minerals sector to adapt sustainability principals, which inspired him to develop the IS research project at Kwinana (Herbertson 2013). Mackenzie (2002) describes Andrew Mangan as a key figure in IS development in the US (Section 4.8) and having a *"deep affinity for the natural environment"*. It is assumed, that other champions, such as Raymond Côté and Thomas Sterr, also have an interest in and strongly support sustainable development, e.g. through their choice of occupation in the field of Industrial Ecology (IE). Industrial organisations are interested in the application of IS with regards to production efficiency, cleaner production, eco-efficiency and waste. With the development of EIPs, agencies have to strengthen regional development (e.g. economic growth, employment, cleaner environment) co-operation also. NISP and the Japanese Eco-Town programs aimed to drive sustainable development and to reduce waste to landfill across their operating sectors. This flow on effect helped to initiate the IS programs in the UK and Japan that they are now famous for.

5.1.3.3. Industry stakeholders and their objectives for participation

A study of the drivers and barriers of IS in the Forth Valley (Scotland) identified economic incentives including potential revenue, reduction in disposal and transportation costs, cheaper secondary raw materials, cheaper utilities (water, heat) and higher production efficiency (Harris 2004). Businesses stated additional non-economic reasons for symbiotic exchanges such as environmental, social, legislative, organisational and technical factors (Harris 2004). As the aim of any business is to generate profits, it is assumed economic incentives are the main reason to participate in an IS project. This effect was observed in recycling networks in Styria and the IS in Kalundborg. Chapter 4 has shown that facilitated and planned EIPs receive financial assistance especially during the initiation phase and that this financial

[17] Former General Manager Research BHP Steel, and Director of the Central Research Laboratories in Newcastle

assistance was an essential part of the project's confirmed development and the commitment by industry participants.

5.2. Champions

In the wider context the term 'green champion' is used across different industries including the building industry (Bilec et al. 2009; Jiang & Tovey 2010), chemical industry (Tucker 2010), water works (André Taylor 2007; André Taylor 2008; André Taylor 2010; André Taylor et al. 2011), within the workspace (Holt & Ghobadian 2009; Price & Brodie 2001; Zibarras & Ballinger 2010) or directed at business management (Vickers & Cordey-Hayes 1999; Kurland & Zell 2011; Klinger et al. 1994). In relation to the IS literature Martin et al. (1996) and Peck (1999) were among the first to use the term 'champion'.

5.2.1. Definition

Within the IS literature the most common metaphors for the term 'green champion' are:

- "champion" (Peck 1999; Chertow 2007; Hewes & Lyons 2008: Ferrer et al. 2012; Doménech & Davies 2011 Chertow & Ehrenfeld 2012; Behera et al. 2012),
- "industry champion" (van Beers 2008a; van Beers 2008b; Harris 2008),
- "project champion" (Young 2000; Saikku 2006; Chertow 2007; Harris 2008).

In an open context, an even larger variety of metaphors is used to describe 'green champions'. These include project champion (Taylor 2007; Taylor 2008; Taylor et al. 2011; Bilec et al. 2009); internal green champion (Best & Thapa 2013); environmental champion (Burns & Carter 2010; Taylor et al. 2011; Best & Thapa 2013); green entrepreneurs (Holt 2010) and sustainability managers (Kurland & Zell 2011).

There is an inconsistency with regard to the usage of the term 'champion' within the IS and EIP literature. Young (2000) describes a project champion as a single *"local business executive who provides leadership in recruiting companies and promoting the project"*. Chertow (2007) uses the term without explaining the specific role except in regard to "whether it is the company itself

or an individual project champion (or champions) that drives the nascent symbioses" as does Bass (2007) who calls them "*actors of particular significance*".

The meanings of the terms industry champion and project champions are similar; a company or their representatives participating in an IS program on behalf of their company (van Beers 2008b; Harris 2008). Whereas in some cases companies participating are described as champions or anchor tenants (Saikku 2006; Harris 2008), others also refer to academics or governmental agencies (Peck 1999). The term 'champion' is also used to describe a IS project facilitator or EIP management, meaning a group or single person whose role it is to facilitate the project (Martin et al. 1996; Young 2000). According to Peck (1999), the President's Council on Sustainable Development (PCSD) acted as a champion driving the US EIP initiative in the 1990s at a senior level. Hewes and Lyons (2008) described 'individual champions', as a driving force in IS project development (Sakr et al. 2011; Doménech & Davies 2011; Behera et al. 2012; Paquin & Howard-Grenville 2012; Chertow & Ehrenfeld 2012; Ferrer et al. 2012). Sakr et al. (2011) stated, "*The champion(s) can be an individual, a group of individuals, or an institution"*.

Within the broader context (focussing on non IE and IS literature) the term 'green champion' was much clearer and described individuals as 'champions' (Richardson et al. 2009; Taylor et al. 2011; Bilec et al. 2009; Vickers & Cordey-Hayes 1999; Klinger et al. 1994; Holt & Ghobadian 2009).

The literature notes that any person can be a champion; staff members in an office, university students, council officers or company founders. With regard to IS, champions are typically company managers, managers of research divisions or staff responsible for sustainability or environmental management (van Beers 2008a).

5.2.2. Role and responsibilities

In accordance with the general definition of 'champions', their broad roles in the literature are to drive:

- sustainability (Drumwright 1994: Preston 2001; Richardson et al. 2009; Taylor et al. 2011; Holt 2010; Tucker 2010);
- change (Price & Brodie 2001; Taylor et al. 2011; Kurland & Zell 2011);
- innovation (Vickers & Cordey-Hayes 1999; Tucker 2010; Taylor et al. 2011; Best & Thapa 2013);
- communication (Preston 2001; Taylor et al. 2011);
- environmentally friendly workspace (Zibarras & Ballinger 2010).

Despite the different usages of the term 'champions' over the past 15 years, the role of a champion in an IS project is to promote symbiotic exchanges and to drive the IS project (Young 2000; Doménech & Davies 2011; Behera et al. 2012). The study of facilitation research has also became interested in the role of champions. Today champions are seen as networkers fostering cooperation and information exchange (Sakr et al. 2011), and building trust and developing social relationships among project participants (Ferrer et al. 2012; Behera et al. 2012; Hewes & Lyons 2008).

The IS literature has a general view on championing attributes. Adapted from Hewes and Lyons (2008), champions are visionary and inspiring individuals (Sakr et al. 2011; Ferrer et al. 2012), who believe in sustainability and passionately devoted to IS development. Champions in an IS project commonly have seniority in their firms and so have a level of 'empowerment'.

Champions are not just distinguished by their attributes alone but also by their skill set, which enables them to emphasise their character traits (Taylor et al. 2011). The literature identified technical and social management skills to be of importance to develop networking among stakeholders which might lead to symbiotic linkages (Ferrer et al. 2012). Though, technical skills might be negligible as technical personal be consulted during the process (Hewes & Lyons 2008,). However, interpersonal skills seem to be of high importance, as researchers highlighted the necessity of good communication skills (Gertler 1995; Ehrenfeld & Gertler 1997; Schwarz & Steininger 1997).

Generally champions focus their activities around the promotion, implementation and the support of a project (Klinger et al. 1994; Peattie & Hall 1994; Vickers & Cordey-Hayes 1999; Bilec et al. 2009; Holt & Ghobadian 2009;

Zibarras & Ballinger 2010; Taylor et al. 2011; Kurland & Zell 2011). They drive, facilitate and advance the project by encouraging the adoption of sustainable practices and reinforcing ecological values resulting from IS programs. Champions collaborate with other stakeholders and use their abilities and skills to influence and guide process developments and overcome resistances during the different project stages. Researchers (Behera et al. 2012; Chertow 2007;Harris 2004) agree that champions are the driving force in an IS project. Throughout the program they promote the concept of IS and educate the community. Champions campaign for participation and motivate stakeholders along the initiation of synergies (Ferrer et al. 2012; Behera et al. 2012; Young 2000). Among all activities the development of a communication network is the most important role of a Champion as depicted by Hewes and Lyons (2008).

5.3. Financial support for Industrial Symbiosis programs

Project funding was not an issue during the development of the IS in Kalundborg as each symbiotic exchange was financially viable on its own (Gertler 1995). Partners in Kalundborg's symbiotic exchanges shared the costs and revenues proportionally and provided in-kind contributions through staff participation and management. However, Kalundborg IS developed slowly over decades. Today IS projects usually have a shorter operational timeframe as they are often initiated by institutions outside the industrial park (Baas 2008; Markewitz et al. 2012; Rezaei 2013b). The reduced development time can put a strain on the project and therefore additional money to facilitate the program can assist to reduce this pressure. The literature and international review have revealed that the majority of EIPs and current IS programs are typically co-funded. Due to its importance, funding structures and their impact on the IS project development are discussed below.

5.3.1. Industrial Symbiosis funding structures

As Saikku (2006) reported, many EIP projects receive public funding. These include the IS programs in Kwinana (van Beers et al. 2007a), USG (Rezaei 2013b), Rio de Janeiro (Veiga et al. 2009), Ulsan (Park 2011), Devens (Hewes & Lyons 2008), Rotterdam harbour (Baas 2008), and NISP (Harris 2004). The importance of public funding is highlighted by researchers reporting limitations on EIP developments if public support is insufficient (Veiga et al. 2009; Ohnishi

et al. 2012). Furthermore, Schwarz and Steiniger (1997) argue that *"direct subsidies to numerous companies"* could increase the costs for project administration which might then result in possible negative impacts from external funding structures.

The case studies have shown that public funding schemes differ at international, national and county level. These include IS projects in Kwinana, USG, Ulsan, Humberside, Rotterdam, Pfaffengrund and Burnside. The monetary support varies in value and source (local or state government). However, these reports also show that IS developments are not only supported by regional or national governmental organisations, but may also receive financial support from participating companies. The funding structure of the relevant IS project depends on the project initiator(s) (being single or multiple industry partners or governmental organisations). It is one of the early steps in the development process of an IS program to think about means to fund the technical implementation and planning phases as well as the costs for administration of the project.

For developing countries, access to funding for IS development can be challenging. Referring to "Lowe", Chertow et al. (2004) states that processes and procedures of development banks usually consider IS development as high risk operations and do not support them. On the other hand, internationally funded IS projects may struggle to 'develop' away from their initial funding structure (Sakr et al. 2011) and might collapse if not continuously subsidised.

With regards to cleaner production initiatives Baas (2007) refers to Philippe Bergeron's "Driving cleaner production in Asia" report encouraging 'simple' wording to enable financial assistance from banks for potential IS project development.

The IS literature, to date, does not give a clear picture on how funding structures effect (reflect back on) IS project development or success or even on participants IS project outcome expectations. These elements are now discussed further.

5.3.2. Funding models

From the extensive literature review on international IS models investigated, it can be seen that there are typically three overarching types of funding models:

- privately funded;
- publicly funded;
- co-funded, a hybrid of public and private funding.

It can be argued that IS developments set up by industry stakeholders solely, start off 100% privately funded until their symbiotic exchanges have been noticed and publicised. Most 'bilateral' symbiotic exchanges are set up by private business partners without a third-party or governmental agencies. This is common business behaviour as seen in Kalundborg (Gertler 1995), the Ruhr-Area (Schwarz et al. 1996) and Styria (Schwarz & Steininger 1997). In this model business partners negotiate terms and conditions among themselves such as the price of the exchange product, possible pre-treatment, transportation and administrative costs (Schwarz et al. 1996). Industrial Symbiosis projects can also be 100% privately funded where a consultant or consultancy firm facilitates the program development (Mackenzie 2002).

With regard to public and co-funded programs, usually only the facilitation and administration of programs are financially supported as seen in Australia, the US and the Netherlands (Peck 1999; Heeres et al. 2004; van Beers 2007). The Kwinana Synergies Project in Western Australia was equally funded by industry partners and through a national government research grant. However, a 50/50 investment breakdown is not always seen. Different funding structures have been applied in Ulsan, Korea and the Japanese Eco-town programs. In Ulsan, project participants provide up to 25% of the project funding, whereas KICOX in South Korea (Section 4.3) put in up to 75%. However, businesses are often obligated to return 20-40% of the initial government funding upon successful implementation (commercialisation) of a synergy project (Behera et al. 2012). In Japan, 'software' and 'hardware' projects under the Eco-town program were funded by up to 50% by the National Ministry of Environment. Furthermore, individual projects were granted additional funding between 100-

7000 million JPY provided by METI plus subsidies from local authorities between 1-10% on METI investment (van Berkel et al. 2009).

The IS facilitation study of the USG in 2012 was fully funded by the state government of South Australia (Rezaei 2013b). Also, according to Heeres et al. (2004), the planning of the US EIP and the conception of the PCSD program, was financially supported by local, state and national governmental funds.

5.3.3. Impact of the funding structure

The success of Kalundborg IS and individual bilateral by-product exchanges elsewhere are indisputable. This success is based on a solid business case of each exchange and the stakeholder's belief in the feasibility of the symbiotic linkages and their predicted long-term benefits. As a result, managers make funds available to develop exchanges, either using internal funding mechanisms or loans. This business model reportedly worked for over 50 years in the Ruhr-Area in Germany (Schwarz et al. 1996) and indicates a natural acceptance (buy-in) of the model by stakeholders. However, a 'buy-in' situation has two facets; firstly, businesses or managers approve the concept and agree to participate in an IS program as a stakeholder and secondly, where businesses also provide funds to support the development program. Co-funded IS projects include the projects in Kwinana and Ulsan. Though, not all IS projects are strongly financially supported by industry or through in-kind services (Corder 2008; Markewitz et al. 2012). In particular the US EIP projects had low success rates (Heeres et al. 2004; Rezaei 2013a), even though their facilitation phases where fully publicly funded. On the other hand, NISP in the UK was very successful, though their funding approach was very different and followed a direct user pays model.

This indicates there is a correlation between the success of an IS project and the 'emotional' and 'financial' buy-in of its stakeholders. Northmore and Hart (2011) have discussed the sustainability of community-university partnerships, highlighting the importance of financial buy-in to a program to secure its long term success. In the US, it seems that initial public funding was not enough incentive to ensure the successful development of EIP programs.

Because of the strong commitment and inter-firm cooperation in Kalundborg its IS program has continued over four decades. If the stakeholders are not committed to an IS program or are not convinced of its advantages, they are less likely to provide funding and data to identify possible synergetic linkages. Also businesses usually prioritise their central business operations, rather than participate just in external affairs or ancillary IS activities (van Beers et al. 2009). Having confirmed and ongoing funding structures, including confirmed contractual commitments in place ensures all participants and stakeholders that the IS program is seen by all as a significant investment of money, time and manpower by participating stakeholders.

Funding structures are both a critical component in the establishment of the IS project. Whilst there are a wide variety of funding models for IS development across the world, there are three particular models that have been utilised consistently in IS development – IS programs that are 100% privately funded, 100% publicly funded and a 'co-funded' model which is a hybrid of both private and public funding. From the review presented, all major international IS programs suggest a strong link between funding access and availability and successful and ongoing IS development.

5.4. Local conceptual contributing factors

Industrial symbiosis programs face other organisational challenges during project development, particularly in regards to the management of stakeholder and project objectives. The following section investigates project objective, project management and individual company strategies and their impact on IS development.

5.4.1. Industrial Symbiosis project objectives

Project objectives may not be the same as individual or stakeholder objectives. They might be a sum of all stakeholder objectives or just a portion. The literature often talks about so called 'anchor tenants' – companies which bear the main/ largest number of possible exchange opportunities (Gibbs & Deutz 2007), either as the source or user of waste products. These companies can play a vital role in the development of an IS. The literature identified chemical processing plants such as refineries and power stations as potential anchor

tenants (Chapter 4). In Kalundborg, the power station was an anchor tenant, exchanging water and steam with neighbouring companies. However, as companies restructure, relocate or close down, linkages can disappear. On the other hand if an anchor tenant is not interested in participating in first place an IS might never develop. Therefore, considering the importance of single business as an anchor tenant to the network, the question arises as to the importance of particular incentives to motivate anchor tenants in order to potentially achieve the desired project objectives.

Another influencing factor to the project objective is the ambition of single firms or individuals. Whereas, commitment describes the dedication to a cause, ambition is a strong desire to act[18]. In comparison to a business participating but its staff not having the time to actively participate in the program, the company might miss out on opportunities. On the other hand, a business dedicated to the project and with a strong desire to gain 'in-house' benefits through the IS project objectives and through the IS network might have a stronger commitment to the success of the IS program and both directly and indirectly influence its staff towards the achievement of potential IS objectives.

5.4.2. Industrial Symbiosis project management

Chapter 4 has shown that most IS projects are facilitated, with a central communication point, project management and coordination. It is reported that without centralized communication or facilitation, IS can be difficult to establish (Markewitz et al. 2012). Businesses tend not to follow through with the establishment of an IS if left without support, as demonstrated by Heeres et al. (2004). Hewes and Lyons (2008) linked the success of IS development to individuals, their engagement and the project management style. Organised IS projects between multiple public and private stakeholders are based on stakeholder agreements (van Beers et al. 2005) and contain project objectives and management agreements. Further contracts may set out roles and responsibilities of stakeholders, including the management of funds, organisation and chair of meetings to facilitate communication and information exchange amongst stakeholders, in order to develop functional IS activities.

[18] http://www.oxforddictionaries.com accessed 28/10/2013

In Kalundborg, the project was managed mostly internally by company staff. Whereas in Kwinana, Ulsan and the US EIP approaches, the main IS programs management were carried out by third party organisations including universities, governmental agencies, non-profit organisations or hybrid[19] centres specially designed to foster IS.

Project management influences the development of an IS program, however the project structure and management are subject to several influences including culture, economy and environment. For example, the zero waste initiative in Japan was influenced by fast diminishing landfill space, which encouraged the government to act and change waste disposal practices. In Kalundborg and Kwinana, water or waste water exchanges were established to protect and preserve underground drinking water reservoirs and to secure industrial water supply for the future. Also, programs in Gladstone and Kwinana where particularly designed to target the local mineral processing industry, due to their dominance in size and economic impact in their industrial areas.

Research has highlighted that project management lead by individual facilitators with a strong interest in sustainable manufacturing are more successful than a project led by a governmental agency (Heeres et al. 2004: Hewes & Lyons 2008). However, individuals (including project staff and company representatives) have diverse preferences on management styles (Snyder & Wheelen 1981). This suggests stakeholders have perceptions (obligations) towards IS project management and preferences regarding management styles.

5.4.3. Individual company strategies

According to Harris (2004), company strategies can have an effect on business decisions in relation to IE. This influence can either be positive or negative (Esty & Porter 1998). In Kawerau, NZ the main manufacturer continued its operations there due to a local thermal energy source (Cammell 2013), which the Swedish owned company preferred to maintain based on its internal policies on cleaner production. Other companies follow similar approaches

[19] A mix of staff from different organisational bodies.

implementing environmental management systems (EMS) and require equal or comparable management systems from suppliers (Hutchinson 1996). Industrial Symbiosis development can be costly, time consuming and overall may not be the main business focus of participating companies. Staff reportedly have to balance normal business operations and additional tasks associated with synergy developments. Industrial Symbiosis development programs have to take note of the often competing financial objectives of IS projects and the need for due consideration of individual company business strategies.

5.5. Global economics

Global economics has an impact on government and private business decision making, affecting funding related decisions of businesses and governmental agencies (Ashford et al. 2012; Ayres 2006) and therefore can influence IS development. In prosperous economic climates, funds are more easily accessible to support projects not seen as essential for business operations, than in times of economic distress. Industrial Symbiosis projects are often categorised as sustainability related research projects and are amongst the first to experience cuts in funding during tough economic times.

The impact of changes in the global economic climate were observed in recent years as a result of the 'Global Financial Crisis' (GFC) 2007/2008 and earlier during the oil crisis in the 1970s (Geels 2013; Ashton 2009). During the GFC exports declined (Figure 5.1) resulting in a lower growth rates (Figure 5.2) and an increase in unemployment (Figure 5.3) as private companies reduced or even stopped new investments due to a lack of consumer and business confidence (OECD 2009a). Facing tough economic times, businesses focus on cost savings and production efficiency and if measures are failing, might cut back production hours, temporarily or even permanently cease production. Governments also shift their priorities based on the global economy. The Australian government created a financial assistance package to support businesses and the general public during the GFC (OECD 2009b). It provided an A$42 billion Nation Building and Jobs Plan[20] with the aim to stabilise the

[20] http://www.budget.gov.au/2008-09/content/uefo/html/part_2.htm accessed 25/09/2013

national economy. Even though the Australian banking system was not strongly influenced by the GFC (UNESCO 2012), the growth of industrial production in Australia decreased by 10% in 2009 (Figure 5.2), followed by a 4.6% increase in the next financial year (Resources & Economics 2011).

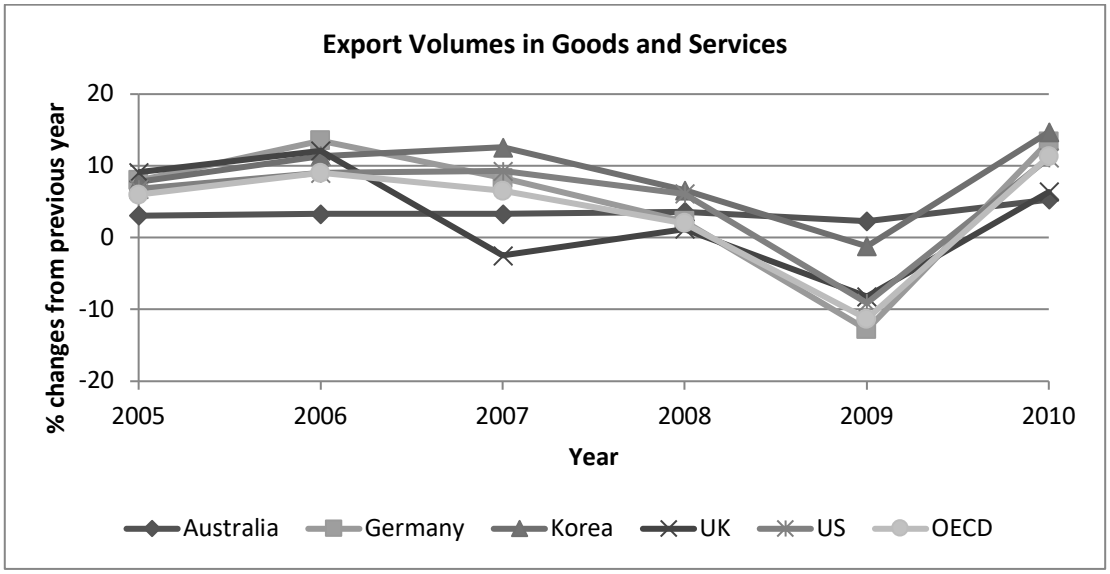

FIGURE 5.1: EXPORT VOLUMES IN GOODS AND SERVICES
Based on data retrieved from the OECD (2013)

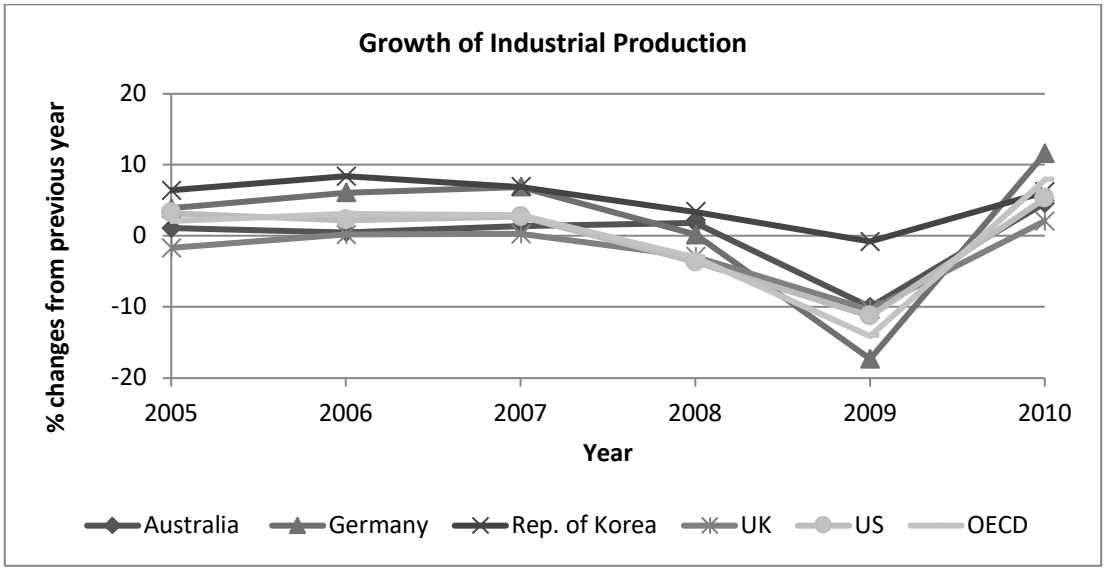

FIGURE 5.2: GROWTH OF INDUSTRIAL PRODUCTION
Based on data retrieved from the OECD (2013)

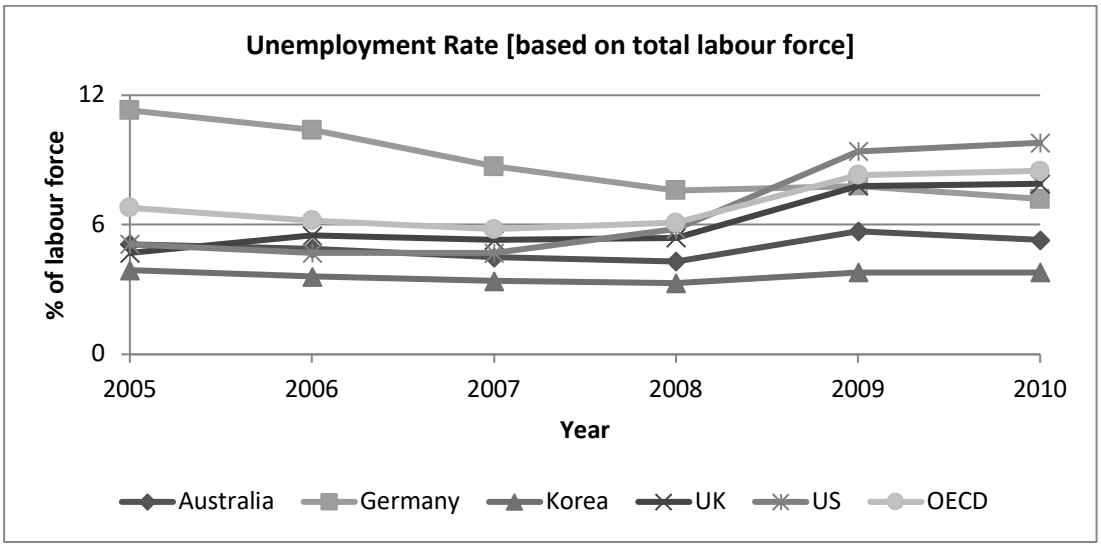

FIGURE 5.3: UNEMPLOYMENT RATE
Based on data retrieved from the OECD (2013)

An investigation of the effects of the GFC on sustainability transitions[21] by Markard et al. (2012) concluded that there is a 'window of opportunity' for sustainability transitions at an early stage (2008-2010). The author describes changes in sustainability activities based on the renewable energy sector showing less interest in climate change since the GFC. Markard et al. (2012) have shown that a financial-economic crisis (FEC) can also have a positive impact on sustainable development by encouraging firms to consider longer term sustainability and the potential financial benefits derived from enhanced sustainability management.

'Globalisation' has an effect on global economics and labour markets, as it impacts global markets structures and influences national and international manufacturing and resource sectors (Coe 2007; Kirkegaard 2007; Hamilton & Quinlan 2008). The expansion of the European Union (EU) in the 2000s is only one example of changing global trade patterns and how nations and businesses adjust (Ammon 2010; IfW 2002).

As highlighted in Chapter 4, IS and EIP projects are highly dependent on public and private funds, which are usually classified as research and development (R&D) funding. Therefore, a decline in R&D funds has an impact on the development of symbiotic exchanges. Corporate R&D funding is mainly based on company cash flow; a decline in cash flow results in less R&D funds and

[21] "Sustainability transitions are long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption."

businesses may focus on short-term, low risk project outcomes only (OECD 2009b).

5.6. Political influences

5.6.1. Policy developments

Developments in environmental policy and regulatory changes have a strong influence on IS. Therefore, regulations can be used as a tool to trigger/drive IS developments. Regulations regarding waste disposal practices and emissions have been seen to be effective tools triggering IS development. On the other hand, missing standards for disposal practices and emission controls can make it more difficult to establish symbiotic linkages (van Beers et al. 2009). The absence of legal encouragement on specific material reuse and recycling practices can create unclear and undefined legal grounds for by-product markets which results in low business confidence regarding by-product utilisation projects (van Beers et al. 2009). Researchers have categorised the aspects of previous studies on IS policy development as; 1) overviews of IS policy programs, 2) policy as a mechanism for stimulating IS, 3) evaluation of the impacts of policy and 4) lessons from practice (Jiao et al. 2014).

National and regional policies influence IS development and regional policies may differ from each other depending on state legislation. This was highlighted by the Australian cases and the regulatory differences between the two states of Western and South Australia (Section 4.2). Research by Jiao and Boons (2014) supports these findings and calls for additional studies to *"identify the sequence of events connecting policy process and industrial symbiosis practices"*.

For example, the definition of 'waste' is often the reason why businesses are not interested in waste exchanges (Costa et al. 2010). The definition is not consistent nationally or internationally and can vary at regional levels making it difficult to comply with waste versus by-product reuse regulations. Materials labelled as waste are legally bound for disposal or their recycling or reuse is limited and restricted by law. This often limits the potential for waste recycling and reuse in IS programs.

Changes in the regulatory framework influencing business practices can bring local managers together to consult with each other, which may result in an interfirm collaboration to tackle the new regulations collectively. This behaviour has been demonstrated in Kalundborg (Gertler & Ehrenfeld 1996), Kwinana (van Beers et al. 2005) and Japan (Gertler 1995).

It is important to highlight that regulatory changes affect the development of by-product markets as defined regulations (including pollution standards, material reuse quota) frame the marketing options. However, equally important are technology advances to support these regulatory changes and reuse standards as well as the knowledge transfer of new technologies.

5.6.2. Public funding for sustainable industrial development

Changes of governments have an influence on government income and expenditure (de Haan et al. 1996). Based on a governments direction public funds are allocated. However, governments on local level may have a different political colour than the corresponding national government and therefore budgets might vary strongly in objectives on national and regional level. In Australia two IS projects were co-funded by public funds, though there is a difference between the two. Whereas the ARC and CRC projects (see Section 4.2) involving the industrial areas of Kwinana and Gladstone were funded by industry and government, the feasibility study in USG region was solely funded by the South Australian (SA) government. This can be explained by the SA government's interest in sustainable development (Australia 2011). In the US, public funds were made available by the PCSD to support the development of EIPs. Governments committed to sustainable development may allocate further funding in by-product reuse incentives and renewable energies despite worldwide decline in public financial support of university research. As for the initiation of IS programs public funding has been an essential component in the establishment of a number of over 70% of the world's largest and most successful IS programs (see Table 4.1).

Furthermore, Andrews (1999) analysed the correlation between environmental problems, sustainability and regional planners, highlighting that regional developers can play a key role in IS development. The importance of regional developers is underlined by studies by Deutz et al. (2008) and Veleva et al.

(2015) who argue that extended or regional 'economic development objectives' should be a key focus in IS planning and development.

5.7. Specific characteristics of the industrial area

The development of IS over time depends on the typical development of the industrial area and/or region. The development of industrial areas is subject to global economics as businesses trade products and raw materials in national and international markets. Industrial Symbiosis development also depends on regional planners, economic conditions, the local regulatory framework and the social licence to operate afforded by the local community, which can function as either drivers or barriers.

In the literature it is mentioned the 'right mix' (Mirata 2004: Veiga et al. 2009) of industries is needed in order to find matching inputs and outputs. This is as true for the initiation as it is for the further development of an EIP or IS. Synergies might cease due to company closure, whereas new companies might bring the opportunity of further symbiotic linkages. A business closure usually has economic reasons; a business might relocate production to a more profitable location. Settlement of new businesses and industries in Western Australia is subject to regional and city planners who are responsible for industry zoning and operational approvals. This might well be the case in other areas/countries too. Companies choose their location according to their needs, and may require public or private port facilities, good road or train access or certain size of land or energy requirements. In an already developed industrial area with limited space, utilities and infrastructure, not every industry will be interested in establishing there.

5.8. Social and cultural characteristics involved in Industrial Symbiosis planning and development

Social and cultural characteristics are another sub category of organisational factors influencing IS. Investigations into the relationship between social science and economics, IE and IS (Section 3.3.3) have shown that public and private organisations consist of individuals. Their preferences and experience reflect back on an organisation's decision-making process through managers and senior staff. As individuals are affected by their cultural backdrop, culture

does have an effect on organisational structures (Andrews 2001; Korhonen 2004) such as business culture and strategies or political direction.
An important note is that a culture influences itself through the interaction and development of its social actors/peers (Ilieva 2008). This relates to education and knowledge spillover effects.

The differences in culture can be seen at regional and national level. For example, every country has different environmental legislation based on its historic development in industrialisation and environmental awareness such as community responses to the pollution of air, soil and waterways. It is further reported that organisational characteristics of industrial areas does vary depending on local industries and their agents (Baas 2011).

Embedded in culture are social codes of ethics, which influence the human desire for sustainability. Researchers have studied the role of ethics in IE; questioning its purpose and value (Allenby 1999; Boons & Roome 2001; Ehrenfeld 2007). Whereas Allenby (1999) recognised the affiliation of culture in IE, Boons & Roome (2001) and Ehrenfeld (2007) highlight the importance of social value systems in IE research. Reinhardt (1999) notes beyond compliance environmental behaviour may be motivated by personal ethics.

5.9. Social Licence to Operate for participating firms

In contrast to the legal license to operate, namely governmental approval for industry operations including regulations and standards, the Social Licence to Operate (SLO) refers to the social acceptance of industry practices by the community. Raised awareness of industry practices and knowledge on pollutants harmful impacts to the environment has increased worldwide since the 1950s, making local communities peers to local business (Blair 1992; Brüggemeier & Rommelspacher 1992) and hence possible stakeholders in an IS. Social Licence to Operate is important to business operations and especially to those businesses engaging in by-product exchanges and IS (SKM 2007; Chertow & Lombardi 2005). Therefore, positive publicity in the local community is desirable for businesses as strong public opinion on by-product reuse can hinder implementation resulting in unutilised material for disposal. As mentioned above, the researchers from CECP (van Beers et al. 2007a) highlight that SLO can act as a driver (Kurup 2007) or barrier (van

Beers 2008a) towards synergy development as seen in Kwinana. In addition, Faucheux and Nicolaï (1998) warned that societal pressure limits disposal options to end-of-pipe solutions, suggesting an inherent preference for waste recycling/reuse and the additional value gained from IS programs.

With regards to the Canadian mining sector, Prno and Slocombe (2012) explain the increased importance of SLO and highlight that it gives communities more authority based on their desire for co-determination and community benefits.

5.10. Corporate Social Responsibility goals of participants

Corporate Social Responsibility (CSR) is embedded in sustainable development (Ebner & Baumgartner 2006) and refers to a business's responsibilities towards society, including the environment. In the neoclassical view a company's only responsibility was to make profits (Friedman 1962). This objective changed in the 1950s with the start of the development of the definition of CSR (Carroll 1999; Ebner & Baumgartner 2006). The Commission of European Communities defined CSR as a *"concept, whereby companies integrate social and environmental concerns into their business operations and interactions with their stakeholders on a voluntary basis"* (Communities 2001).

Early research referred to 'social responsibility' (Carroll 1999). Discussing socioeconomics and socio-human responsibilities highlights the role of the social power of businesses (Davis 1960). Meaning, depending on their actions, business can influence governments and public opinion. Davis (1960) further refers to future developments and changes in management, noting, *"that avoidance of responsibilities as they develop will lead to loss of business power"*. Corporate Social Responsibility reporting increased since the 1990s, though the disclosure of data is depends on factors such as company size, industry group, country of head office and corporate culture (Adams et al. 1998; Adams 2002). Today, businesses voluntarily incorporate sustainable practices, reasoning increased awareness of sustainability and forestall changes in environmental regulation (Faucheux & Nicolaï 1998; Adams 2002).

Corporate Social Responsibility and reforms in data disclosure have also had an impact on IS. Reflecting on business ethics (Korhonen 2003), CSR

interconnects with SLO, social values (culture) and company policies. Corporate Social Responsibility reporting offers businesses a platform to reflect on the effects of their business have economically, socially and environmentally and to communicate them accordingly to the stakeholders including employees and the general public. Industrial symbiosis helps improve the potential outcomes from CSR with its focus on triple bottom line company performance.

5.11. Summary

The analysis of stakeholder groups and their processes highlights a variety of individual motivational factors and objectives. These objectives can influence the overall IS project objectives. Some stakeholders fulfil the role of champions driving the IS development and therefore the roles and responsibilities of individuals championing IS are also considered important. It was observed that champions use their personal attributes and skills to foster cooperation and information exchange, building trust and social relationships. Their willingness to 'question the status quo' seems to be a key feature. The analysis of the funding structures of IS programs identified three general funding models; private, public and co-funded and that there is a correlation between stakeholder processes and the funding structure. The importance of public funding in international IS development was noted and is considered a very important factor in both the successful initiation of IS programs and their ongoing development. Further highlighted was that the financial buy-in creates an emotion connection to the project, which keeps stakeholders interested in the project beyond its initiation. The impact of global economics on IS development influences the business decisions of globally operating companies. The effects of the political environment on public funding allocation was also discussed and links to IS development identified. Social norms, cultural factors and the influence of consumers and peers are also important factors, emphasising the role of SLO and CSR in IS planning and development. This Chapter has highlighted the value and importance of cognitive influences, often considered the 'human or softer elements' in business management and their significant potential impact on successful IS initiation and development.

Chapter 6. Cognitive factors influencing behaviour change for sustainable development

The previous Chapter highlighted the importance of cognitive factors in the IS development processes such as the supporting behaviour of stakeholders and champions, the relationships between IS motivation and objectives, personal attributes and employee skills. These factors highlight the value of the final (third) research question, on the human and organisational behaviour change factors influencing and fostering a move towards IS development. Reviewing these elements may identify further organisational strategies assisting IS project management and enhance sustainable industrial production.

The initial literature review had shown that within the IS context, behaviour and behavioural change has only been discussed with cursory reference to cognitive factors influencing and fostering IS and sustainability management.

6.1. Theoretical background organisational and human behaviour change

Factors influencing behavioural change can be categorised as social/psychological, physical and economic. They include values, norms that frame the human consciousness, a sense of justice/rightfulness, health and financial influences. Theories and models have been developed to investigate behavioural changes in individuals and organisations in order to understand, evaluate, predict and modify their behaviour. These theories include Social Cognitive Theory, Theories of Reasoned Action and Planned Behaviour. These theories are investigated in order to provide an enhanced understanding of the success factors influencing IS initiation and development.

Social Cognitive Theory investigates individual and organisational behaviour change (Bandura 1988; Bandura 2002). This theory includes the personal characteristics of champions, which was discussed in Section 5.1.3. According to this theory, the motivational drivers for champions are largely personal skills and self-belief in their efficacy to affect change (Bandura 1988). Bandura (2002) studied the influences of the cultural context, highlighting that managerial differences are often based on the cultural backdrop. The Theory of Reasoned Action examines human behaviours based on their intention to

perform a certain action. This behavioural intention is influenced by a person's attitude and subjective norms towards the action (Fishbein & Ajzen 1975). Personal attitudes are a reflection of a belief that actions have consequences and the evaluation of the values of the intended action; where personal norms are then influenced by the norm systems of individuals or groups (Ajzen & Fishbein 1980). The Theory of Planned Behaviour is a progression from the Theory of Reasoned Action. Picking up Bandura's view on self-efficacy affecting personal choices, Ajzen incorporates 'perceived behavioural control' as an additional element influencing behaviour change (Ajzen 1991).

Researchers have applied these theories in different areas such as health (e.g. smoking habits), criminology (e.g. theft) or social learning (e.g. personal perception) and also in regard to sustainable development (SD) (Ajzen & Fishbein 1980; Tonglet 1999; Bandura 1988, Jackson 2005). Sustainability behavioural research has included studies on attitudes towards climate change, recycling habits and consumer preferences for green products. The failure of business strategies to address environmental problems highlight barriers to SD including egoisms and denial, conditioning, wrong priorities set by public and private sector (short term thinking) and the shortage of public/private funding (Crocker & Lehmann 2013).

Consumer behaviour is also of interest in SD research as consumerism led increases in mass consumption are seen as fundamental obstructions to SD (Kahn 1995). Therefore, changes in consumer behaviour are also a necessity in facilitating SD. However, consumerism is very important as it supports firm profits and influences manufacturing strategies based on sales (Section 5.9). Investigations into consumer behaviour in Victoria, Australia, reviewed elements of the consumption process, concluding informational, organisational and financial factors as barriers to behavioural change as well as time constraints (Newton & Meyer 2011). The barriers identified match barriers experienced in IS (Table 3.1), which highlight that individual consumer behaviour is similar to the organisational behaviour in trying to maximise self-interest.

6.2. Fostering sustainability change

The following three sections aim to identify strategies and tools fostering suitability change in organisational management. Investigated strategies include social marketing strategies and frameworks that enable pro-environmental behaviour, the effects of Peer Pressure on human and organisational behaviour and changing organisation culture and values.

6.2.1. Strategies for fostering change

Strategies designed to move human behaviour towards SD need to address factors, which influence human attitudes. Studies have identified the creation of human concern for the environment or sustainable living as an important step towards SD behaviour change (Lorenzoni et al. 2007; Young et al. 2009; Newton & Meyer 2011). Creating this consciousness, human attitudes and values need to be altered, using the same tools which shaped consumerism initially (Muratovski 2013). Social marketing strategies are effective tools for behaviour change (Panter-Brick et al. 2006; Lorenzoni et al. 2007; Barr et al. 2011; Ashford et al. 2012) helping to address the different angles of behaviour change, motivating sustainable consumption and pro-environmentalism by changing consumption desires (Jackson 2005; Lucas et al. 2008).

Steg and Vlek (2009) offer a framework to enable pro-environmental behaviour through strategically planned incentives based on four steps; the identification, examination, design and evaluation of the behaviour change desired. Firstly, the behaviour to be changed needs to be identified, followed by an analysis of the elements underlining this behaviour. According to their findings, incentives are then selected/developed. It is highlighted that incentives often comprise of more than one strategy and that evaluating the success of the overall strategy is significant (Steg & Vlek 2009). Inducements to 'voluntarily' change consumption are increasingly noted in the media. These include incentives like the 'Earth Hour' and television appeals form local water authorities to use less water. Behaviour change can also be triggered through taxes and policies (Lucas et al. 2008). This is also in line with findings from the IS literature (Section 3.3.3) which identified taxes and legislation as strong drivers for businesses to engage in symbiotic by-product exchanges.

The consumer society as we know it today has its origin in the 17th century (Peck 2005) and researchers argue that our current consumer behaviour is the result of years of conditioning (Muratovski 2013). Starting 50 years ago, it was recognised that the structures of human living are unsustainable (Hotelling 1931). Researchers branched off into different areas, researching factors of behaviour change, consumer behaviour and the pro-environmental behaviour of individuals and organisations. Since the 1990s, the influences on SD have increasingly been studied (Ebner & Baumgartner 2006; Jovane et al. 2008).

Behaviour change can also be generated through 'peer pressure'. This term describes the influences of a group (peer group or peers) on a single unit (individual or company). Peer pressure can be applied to various social and communication issues including subjects such as smoking and fashion, with family and friends being common peers (Michell & West 1996). Peer pressure can also importantly be applied to foster sustainability and pro-environmental thinking at an individual and firm level (Stern et al. 1995; Luken & van Rompaey 2008).

6.2.2. Peer pressure and sustainability behaviour change

Peer pressure is an element of social pressure (Jackson 2005). In regards to SD, peer pressure develops with increasing public awareness of environmental issues and is described in relation to human learning. Individuals adapt to new objectives through cognitive processes (Seethaler & Rose 2004) and the interaction with their peers (Jackson 2005). However, the change to a new value system takes time as learning is based on peers relying on social norms which form/change slowly (Stern et al. 1995; Day 2007). It is reported that individuals are more willing to adapt to new norms when they are sure of their peers' support (Seethaler & Rose 2004). This fact is highly important for IS development as it supports assumptions 'short mental distance' and 'embeddedness' (Ashton & Bain 2012) which encourage the movement towards sustainability management.

Typical peers for companies are other businesses, though, pressure or monitoring can also be generated by trade or business associations (Luken & van Rompaey 2008). In general terms, peer pressure among companies is

typically created through competitive advantage which one business gains by 'greening' their operations (Peattie & Hall 1994). International research notes that peer pressure is a driver for the implementation of environmental management systems such as European Eco-Management and Audit Scheme (EMAS) or the ISO 14000 series (Vastag 2004). Frosch (1995) predicted that firms in the future will require their suppliers to adapt to standards from the ISO 14000 series which is increasingly the case today (Bansal & Bogner 2002). The competitive advantage associated with sustainability (green behaviour) has as a result been a significant factor in moving industrial production towards suitability outcomes and an interest in IS development.

In an industrial cluster peer pressure is seen to amplify competitive pressure and promote innovation (Porter 2000; del Río et al. 2010). International association such as the Organisation for Economic Co-operation and Development (OECD), United Nations or the World Trade Organisation encourage peer reviewing. The peer review process is described by Pagani (2002) as the *"systematic examination and assessment of the performance of a state by another state with the ultimate goal of helping the reviewed state to improve its policy making, adopt best practices and comply with established standards and principles"*. The OECD conducts environmental performance reviews of member countries, which enable evaluation of national policies on an international level and further pushing pro-environmental aspects on the OECD agenda (Lehtonen 2006). The OECD for many years has fostered an interest in IS and its promotion to industry. They note the value of peer review is extending the value of IS application in moving towards SD (OECD 2009a).

6.2.3. Sustainability change in organisations – culture and value systems

Reflecting on Chapter 5, culture and value systems are the basis of human decision making; and as a result cultural and social norms influence the decisions of managers and senior staff, and therefore, indirectly influence business decisions and environmental strategies. Managers are also influenced by the corporate environment such as time and cost constraints or external pro-environmental requirements. The following discussion

investigates behavioural change in relation to business management in order to gain a better understanding of the strategies and tools assisting managers, champions and facilitators to promote sustainability leadership and employee engagement in sustainability management.

Organisational change is concerned with behaviour change in business, their managers and practices. A company is made up of staff (including managers), their shared values, skills and styles, systems, structures and strategies (Lloyd & Phillips 1994). In the past two decades research findings have shown a growing emphasis on staff training as a way of influencing the human/employee ability to change (Balogun & Johnson 2005). The traditional management model is increasingly becoming obsolete and change based on human values and attitudes is suggested to be the new model of successful business development (Taylor 2011).

Researchers (Visser & Crane 2010) investigated motivations of so called 'sustainability managers' who actively support sustainable corporate development. Based on a selected set of characteristics, skills and approaches Visser and Crane (2010) characterised managers as 'experts', 'facilitators', 'catalysts' or 'activists'. An expert is described as a specialist providing technical expertise on a project or problem and is driven by the task ahead and the challenge. Facilitators focus on staff/group development and the transfer of knowledge and skills and find satisfaction in the success of others. A catalyst is distinguished by his/her ability to promote sustainability and to encourage sustainable practices at an organisational level. An activist displays social/environmental concern and justice, is described as a collaborative person seeking continued improvements in the workplace. Even though a manager can have a multiple skill sets, usually there is one dominant skill set influencing their sustainability management approach.

Although no explicit description of the position or role of 'sustainability managers' was given, Visser and Carne (2010) suggest their research results are transferable across all management levels. They highlight that SD can occur based on different personalities (values), management styles, motivation and skills. They further argue that companies increasingly recruit 'sustainability

managers', meaning staff with the specific skills and attributes outlined above in order to move the organisation forward on the sustainability focused management path.

Education is also a necessary tool in changing behaviour towards sustainability. Today environmental education for sustainability (EEFS) is part of the curriculum in many schools and universities (Tilbury 1995; Rosano & Biswas 2013). This new content in education influences students, our future managers; affecting their value systems and behaviour, giving them the knowledge to foster sustainability in their future workplaces. Environmental education emerged in the 1980s as part of increased awareness of environmental pollution and an increasing concern for the environment (Tilbury 1995). The concept of sustainability was firstly globally introduced to higher education organisations in the 1970s (Wright 2002). Sustainability as a subject on its own is still a new discipline (Cebrián et al. 2013). In Australia it was introduced in engineering education only about ten years (Rosano & Biswas 2013). With more EEFS in the curriculum graduates gradually bring more (basic) sustainability expertise into workplaces, assisting corporate sustainability and industrial development.

The behaviour change of managers can also be triggered from within an organisation as company policies and training programs have an effect on management style and decision making processes also. Typically, all employers, including managers and managing directors, are responsible for company policy development and action (Ogbonna & Harris 2001; Ogbonna & Eilkinson 2003). However, they further state that managers can be ambivalent about company (sustainability) strategies and sometimes their actions are more based on compliance toward internal policies or self-interest.

Therefore, leadership plays an important role in IS and SD. In an IS program facilitators and the company staff involved favour certain management styles. Understanding which management style is preferred by stakeholders can be of great assistance in IS project management. Facilitators can then adjust the project management strategy accordingly to engage stakeholders in the best possible way and enabling them to become key figures in sustainability

leadership. Research identified six leadership styles: directive, visionary, affiliative, democratic, pacesetting and coaching (Goleman 2000) and that managers engaging in a mixed management style, combining at least four out of the six, were more successful compared to managers with a rigid management style who focussed on only one style. This suggests both the value of leadership in setting the sustainability agenda, and in the important selection of the facilitator with well-rounded skills and a flexible management style to facilitate and develop the sustainability management change required.

Historically, companies and their managers operated under a command-control management structure (Lloyd & Phillips 1994). Management systems have had to increasingly adapt to modern work environment where 'emotional intelligence' is increasingly important in addition to technical and operational skills (Taylor 2011). It is common today that staff and particularly managers receive further training as part of their skill development on the job. Internal or external courses and workshops are provided focusing on technical expertise or soft skill development to enhance personal abilities on decision-making processes and management style. These training opportunities can significantly foster employer engagement in regards to sustainable production initiatives and their role in sustainability leadership. This is supported by many international case studies of IS which note the important role of facilitated discussion and workshops to manage and promote the sustainability outcomes sought by the individual IS programs (Rosano and Schianetz 2014).

6.3. Summary

This Chapter focused on some important cognitive elements in addressing organisational and human behaviour change towards sustainability management. This review has shown that individual consumer behaviour follows similar behavioural change principles to that in organisational behaviour. Strategies designed to change behaviour patterns need to address factors, which influence human attitudes such as personal values and norms and their intrinsic focus on SD. Peer pressure was identified as one way to address the behavioural change of individuals and groups. This is an important element to consider in an IS program where it can be effectively applied during meetings and in communications to influence both employee and

organisational change towards sustainable industrial production. In addition, the behavioural change was discussed with regards to managers and organisations. An increased organisational interest in managers that are able to support corporate sustainability, together with the personal attributes and management skills of these managers is also critically important.

Further insight into the role of cognitive factors and skills in supporting IS development has been discussed. Managers and champions play a key role in the initiation and development of IS. Strengthening their cognitive skills and influencing organisational values and norms around sustainable development, should assist the movement towards sustainable industrial production. Developing strategies and implementing procedures to foster sustainability change in organisations will assist in the movement from simple eco-efficiency and cleaner production focussed activities, towards the more strategic and holistic sustainability management focus of IS. The sustainable production system is also supported by increasing facilitation of sustainability outcomes through peer pressure, organisational sustainability leadership, employee sustainability engagement that further enhances the value of IS as a sustainability change agent.

Chapter 7. Analysis and discussion

Previous chapters introduced a theoretical background to IS, discussion on international IS case studies, major factors influencing the IS development process and important cognitive factors influencing behaviour change and commitment to IS development. In order to provide insight into the evolutionary and development processes of Industrial Symbiosis (IS) this chapter focuses on:

- defining IS development models,
- a comparative examination of major IS projects,
- identification of key influential IS development factors, and
- management considerations for IS development models.

7.1. Defining IS development models

The review of international IS developments presented in Chapter 4 is now used to assist the comparative examination of major IS projects. The study highlights differences as well as similarities between the IS development processes; specifically, in regards to the evolutionary phase, governance and organisational structure, project funding and use of project champions (see Table 4.1). Industrial Symbiosis activities are generally classified as self-organised, facilitated and planned development models (Section 3.2). However, Chapter 4 highlighted, that a development model is dynamic and can 'shift' and change into another model. Examining the evolutionary phase, industrial partners are often seen to initiate IS activities, however, most programs use external facilitators and third parties to provide structured program governance. Most IS developments follow an 'open' organisational structure, where no formal agreements have been made between stakeholders in regards to key performance indicators for the IS program development. However, there are IS programs where contractual agreements set boundaries and/or binding key performance indices. The review further shows that most IS developments are supported by a so called champion (Section 5.2) who drives the IS development forward. Industrial Symbiosis programs also differ in another organisational aspect, program funding. Chapter 4 identifies the funding structures for IS activities and highlights that a

large number of IS projects receive public subsidies. Table 4.1 highlights that IS development follows unique pathways. These pathways are based on a variety of factors which create a specific framework in which IS can develop. These pathways of IS development were presented in Table 4.1.

Table 7.1 colour codes Table 4.1 (Summary of common IS structures) and focuses on three key elements in the IS development process: ‘evolution’, ‘governance’ and ‘organisation’. In the ‘evolution’ column, IS which are ‘self-organised’ are highlighted in ‘orange’, IS set up through collaborative programs (facilitated) are highlighted in ‘yellow’ and IS initiated though governmental programs are highlighted in ‘blue’. The same classification has been used to classify the governance structure. Industrial Symbiosis programs that are ‘self-governed’ are highlighted in ‘orange’, whereas ‘facilitated’ IS programs are highlighted in ‘yellow’. The ‘organisation’ column refers to the organisational structure of the IS program and if formal agreements have been made between the stakeholders. Programs without formal agreements (‘open’) are highlighted in ‘orange’, ‘research programs with formal agreements’ are highlighted in ‘yellow’ and IS programs ‘government organised’ are highlighted in ‘blue’. Looking at Table 7.1, the colour-coding helps to highlight connections between the three elements across the different development models. These connections suggest development pathways, which should be discussed further.

TABLE 7.1: SUMMARY OF COMMON INDUSTRIAL SYMBIOSIS STRUCTURES

Location	Evolution	Start	Governance	Organisation	Champion	Funding	Source
Denmark, Kalundborg	self-organised	1961	self-governed	open	yes	private	Gertler (1995)
Australia, Kwinana	facilitated	2003	facilitated	research project with formal agreements	yes	public/ private	Van Beers et al. (2005)
Australia, USG	government initiated	2012	facilitated	open	yes	public	Rosano (2013)
South Korea, Ulsan	government initiated	2005	facilitated	government organised project	not specified	public/ private	Behera et al. (2012)
UK, Humberside	self-organised	2002	facilitated	open	not specified	public/ private	Mirata (2003)
Netherlands, Rotterdam	self-organised	1994	facilitated	research project with formal agreements	not specified	public/ private	Heeres et al. (2004)
Germany, Pfaffengrund	facilitated	1996	facilitated	research project with formal agreements	yes	public/ private	Sterr and Ott (2000)
Austria, Syria	self-organised	-	Self-governed	open	-	private	Schwarz and Steininger (1997)
US, Devens	government initiated	1999	facilitated	open	yes	public	Deutz et al (2008)
Canada, Burnside	facilitated	1992	facilitated	university/open	yes	public/ private	Peck (1999) Adams (2011) Côté et al. (2006)
New Zealand, Kawerau	self-organised	2010	facilitated	open	not specified	private	web/ personal com

In Figure 7.1, the flow sheet presents the four main models of IS development, based on the analysed of IS programs in Chapter 4.

Model 1: Self-organised – self-governed – open organisational style e.g.

- Kalundborg, Denmark
- Styria, Austria

Model 2: Self-organised – facilitated – open organisational style e.g.

- Humberside, UK
- Kawerau, New Zealand

Model 3: Facilitated – research project with formal agreements e.g.

- Kwinana, Australia
- Paffengrund, Germany

Model 4: Planned – facilitated – open organisational style e.g.

- Upper Spencer Gulf (USG), Australia
- Devens, US

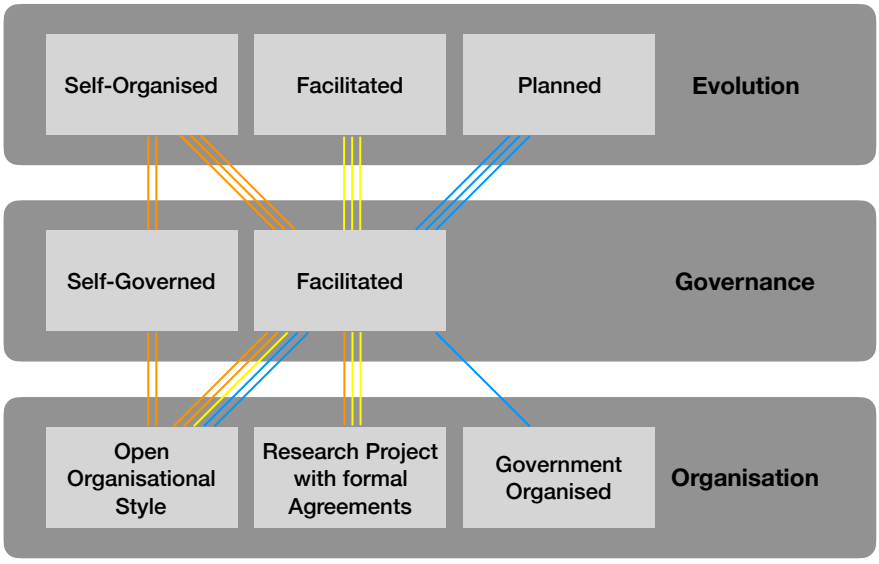

FIGURE 7.1: COMMON IS DEVELOPMENT MODELS

7.2. Comparative examination of major IS projects and identification of key success factors

Case studies depicted in Chapter 4 highlight factors influencing the IS development process and highlighted that in some instances, these factors are unique to specific projects. The review of influencing factors (Chapter 5) shows

how different factors influence the IS development process and more importantly, that the effects can cascade and affect other elements within the IS development process. The interaction of these effects shape the IS development process. For example, the analysis of stakeholder groups and stakeholder processes highlights the importance of motivational factors and stakeholder objectives, where these objectives can influence and shape the overall IS project objectives. Chapter 5 also provides an analysis of the funding structures of IS programs, which identified three general funding models (private, public and co-funded). Important to note is a connection between stakeholder processes and the funding structure, and that financial buy-in creates an emotion connection to the project, which then keeps stakeholders interested in the project beyond its initiation. Chapter 5 also highlights the value and importance of cognitive influences as they affect the organisational aspects of IS. It is important to investigate factors shaping these specific pathways in order to fully understand the key success factors behind each IS development model.

7.2.1. Model 1: Self-organised – self-governed – open organisational style

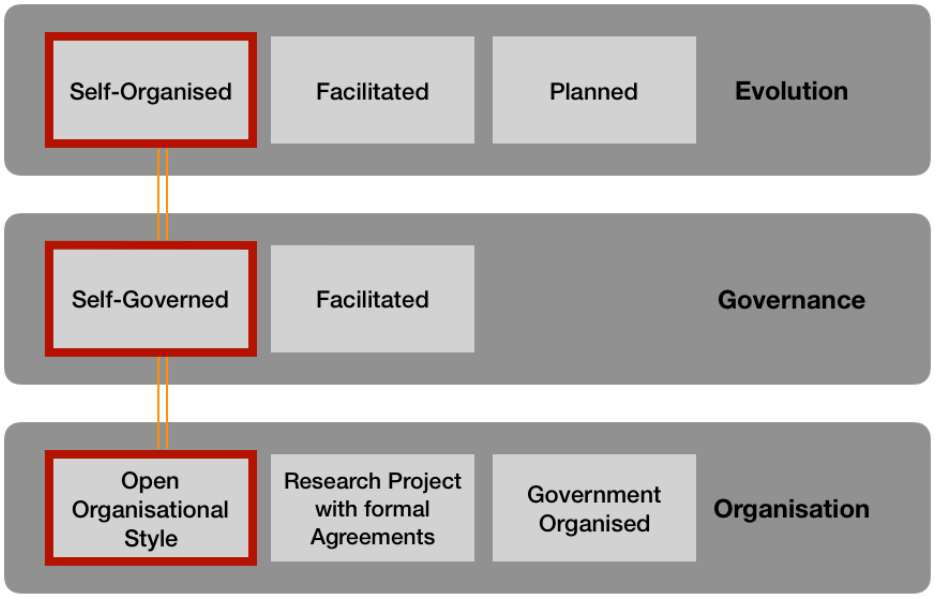

FIGURE 7.2: DEVELOPMENT MODEL 1

The two examples for this development model, IS developments in Kalundborg and Styria (Sections 4.1 and 4.7), have shown that the symbiotic trade of by-products can be a normal business activity for the parties involved (business

as usual). One company has a product to sell, researches its market value and searches for a buyer. The organisational structure of these exchanges is fairly simple; typically, only two parties are involved in setting up a bilateral symbiotic exchange. Both stakeholders are seen as equals in the trade and reach an agreement, based on their business objectives. The main motivational driver for by-product exchanges is financial gain, however to explore opportunities for these kind of exchanges, a certain level of opportunism/entrepreneurship/ingenuity and commitment is also required. This underlines the role of managers in setting the frame for this type of exchange. It is important to note that the development of IS in Kalundborg was supported by champions which kept an open mind to trade opportunities which were not just financially sound but also environmentally beneficial.

Key success factor

The key success factor for the establishment of a self-organised and self-governed IS is a 'convincing business case' for the involved managers. That is, a business case which is feasible from a technical and regulatory point, socially acceptable and financially attractive, in line with the company's business objectives, and to a certain extent, are in line with personal commitment of managers towards sustainable industrial practices.

7.2.2. Model 2: Self-organised – facilitated – open organisational style

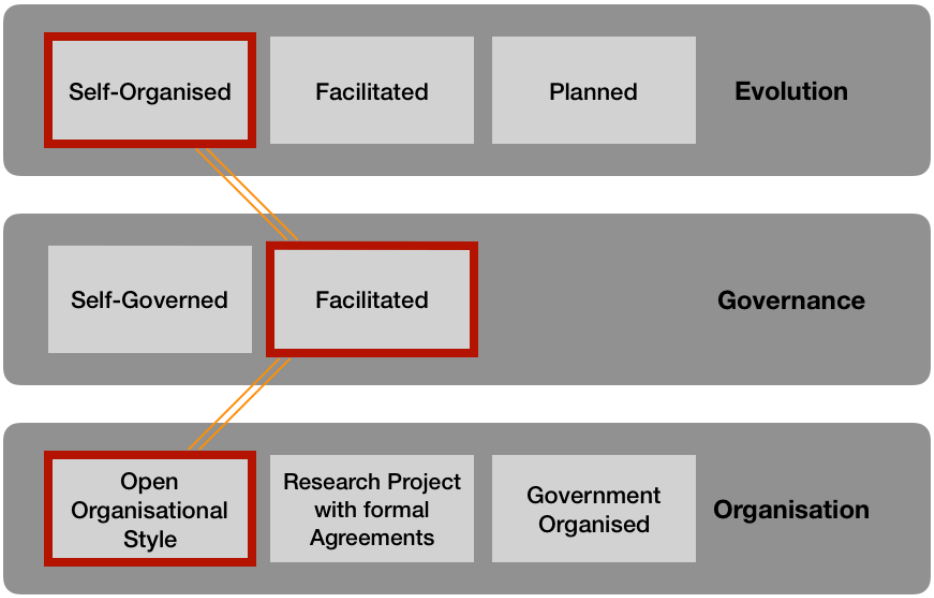

FIGURE 7.3: DEVELOPMENT MODEL 2

The IS developments in Humberside (UK) and Kawerau (New Zealand) (Section 4.4 and 4.10) were initiated by industry stakeholders, but both followed a more structured development model shortly after becoming aware of IS opportunities. Unlike Model 1, the businesses in Model 2 are not fully aware of specific exchange opportunities and therefore looked for partners to help identify possible exchanges and facilitate the development process. In both cases, governmental agencies are appointed as facilitators, which collect and consolidate input/output data from all industry stakeholders and act as incubator/communication hub. Although the facilitators in both cases are governmental agencies, the development conditions affecting the IS in Humberside and Kawerau differ. For example, in comparison to the IS in Kawerau, the Humberside project involves a much larger target area, shows a higher diversity of industry stakeholders and their facilitator was highly specialised. More specifically, the sole function of the National Industrial Symbiosis Program (NISP) was to facilitate symbiotic by-product exchanges in the United Kingdom. These two IS developments also differ in their funding structures; NISP is a publicly funded agency. However, both cases also indicate, that their 'open' organisational structure is a result of the project initiation in which the industry stakeholders had a key (driving) role, shaping the IS development structure. Although the IS program involves a larger number of stakeholders, a symbiotic exchange in this model (typically) involves two industry stakeholders and a facilitator.

Key success factor

In Model 2, an industry stakeholder typically becomes interested in the concept of IS. They take the first step and approach local governmental agencies to explore local (regional) options for IS development. The commitment of industry stakeholders is linked to the level of expected gain (Section 5.4.1). On this basis, the identification of business opportunities is the central IS objective for the businesses stakeholder and facilitators involved; a convincing business case (see Section 7.3.1) is the key success factor. Another key success factor lies in the facilitation process. Businesses are initially interested and committed to the process, but their support and attention might fade or wane over time. Therefore, it is important for governmental facilitators to keep businesses

engaged by developing effective communication channels, addressing their objectives but also to communicate the facilitation strategy clearly to all stakeholders so they know what to expect from the project and how to measure its progress. In addition, governmental investments and financial support of the IS project could also be considered important success/motivation factors for IS development.

7.2.3. Model 3: Facilitated – research project with formal agreements

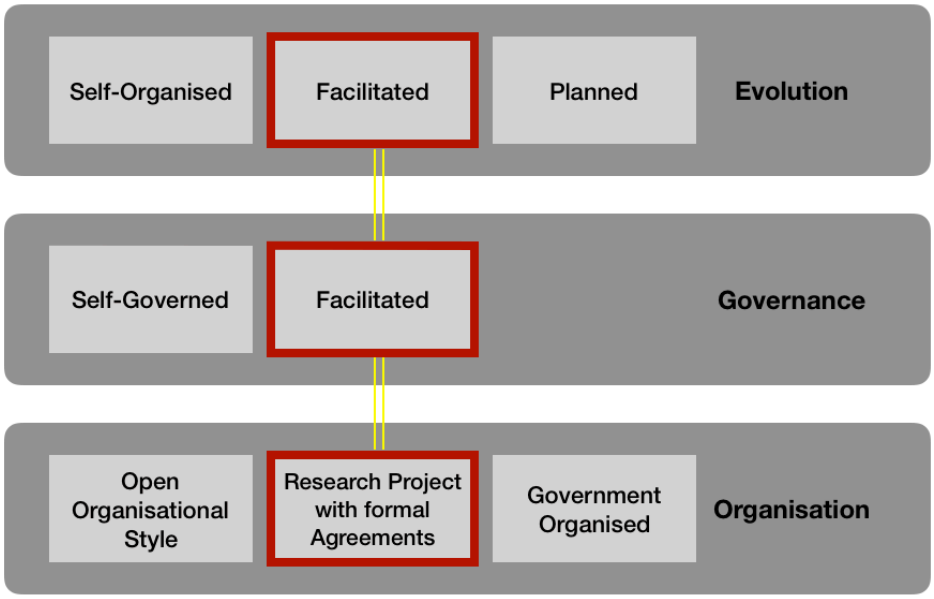

FIGURE 7.4: DEVELOPMENT MODEL 3

Model 3 refers to IS development programs which are initiated and developed by a third party (facilitator), usually guided by contractual agreements. Two cases discussed in this research display this development structure; Kwinana (Australia) and Paffengrund (Germany). In both cases, scientists interested in sustainable development and promoting Industrial Ecology (facilitators/champions, see Section 5.2) saw the potential IS offered for a win-win in improving industrial efficiencies whilst reducing their environmental impact. In Kwinana the facilitators approached industry stakeholders to participate in a collaborative IS research project. Their participation was however based on the awareness of previous established symbiotic exchanges and their mutual (financial) benefits. The program facilitators in Germany approached the city council for support, and in conjunction with a regional development council identified the industrial area of Pfaffengrund. The industrial area was chosen as it would benefit economically from such a

project. Both cases display a common element in their project governance, with scientists as key members of the facilitation team. Also, both programs were funded through public and private moneys to assist the facilitation process and early feasibility studies, although specific elements within the financial model differ (e.g. amount, in-kind contributions). Also, the establishment of symbiotic exchanges was fully covered by the industry partners involved in the exchange. As discussed in Chapter 5, funding structures are reflected as part of formal agreements, which ensure that stakeholder objectives are deliberated.

Key success factor

As in Model 1 and 2, a convincing business model and facilitation are key to successful IS development. In comparison to the Model 2 the facilitators differ and bear a key role in the initiation process and therefore, seem to carry a larger responsibility for successful IS development. An important difference between Model 2 and 3 is the initial engagement of the industry stakeholders by an independent third party and the level of IS awareness.

7.2.4. Model 4: Planned – facilitated – open organisational style

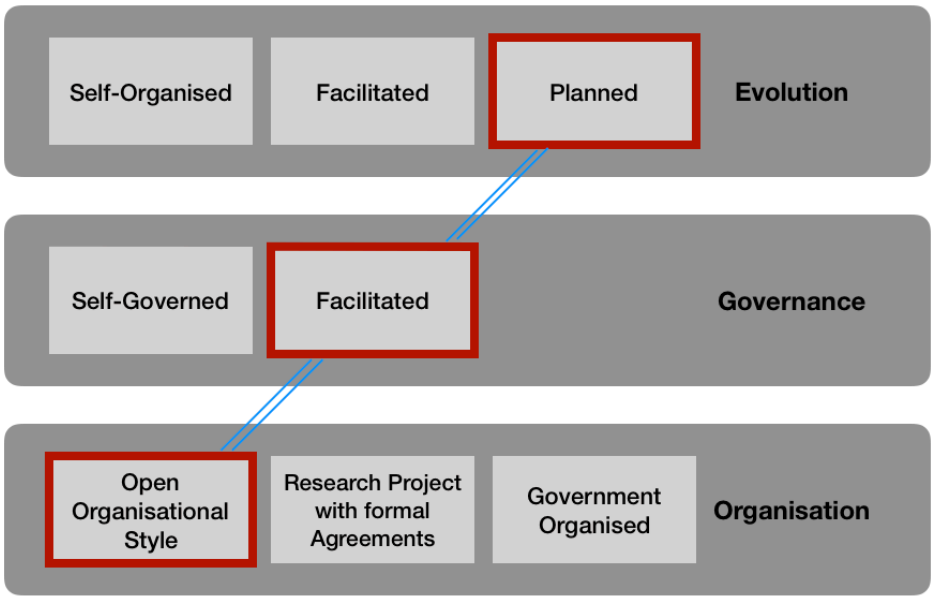

FIGURE 7.5: DEVELOPMENT MODEL 4

In Model 4 the start of an IS program is initiated by government but its development is facilitated by other entities. Two programs were identified that follow this development model, USG in South Australia and Devens in the US. Both IS programs were started with the objective to foster regional sustainable

development. Though both are initiated though governmental agencies, their approaches differed significantly. Knowing the benefits of the previous held IS program in Kwinana, Australia, the DMITRE (Department of Manufacturing, Innovation, Trade and Resources) promoted the benefits of IS and the program itself to established businesses in the region, recruited participants, a facilitator and allocated public funding to the program to assist with facilitation (data collection, input/output data matching) and administrative tasks. In Devens, the development team formulated a design concept for the target area and approached then stakeholders directly with the development opportunity.

The case studies highlight that facilitators do not follow the same strategies to form an IS/IE, but both focussed on bringing stakeholders to the table discussion to promote benefits of IS and to facilitate the IS development. The two programs differed in the size of the target area, industries present, and volumes types of by-products. In comparison to Devens, the USG program involved a larger project area with predominantly large-scale mining and resource processing industries. Therefore, not only their regulatory framework differed but also some of their major development conditions. Their key similarity is the planned governmental approach to build/design an IS/IE developments, the promotion of the concept and the recruitment of stakeholders and the presence of project champions supporting IS development and networking.

Key success factor

In Model 4 the development of an initial ‘buy-in’ or an emotional attachment is important to ensure the participation of industry stakeholders. In this model, the challenge is to get past the initial contact and canvass and promote the IS program. The stakeholders’ level of options on symbiotic exchanges might be limited (e.g. due to the strategic development plan) and the commitment regarding IE could be inhibited by their commitment regarding their main business operations.

7.2.5. Differentiation of development models and summary of key development factors

The presented development models do share similarities but also differ in some aspects from each other. The bullet points below help to differentiate the development models; these points of differentiation as well as a summary of the key development factors for each development model are shown in Table 7.2.

- In Model 1 and 2 the industry stakeholders initiate, whereas in Model 3 and 4 the project initiation starts with facilitators.
- Model 1 and 2 differ in the knowledge industry stakeholders have in regards to possible by-product market opportunities. If an industry stakeholder of Model 2 were fully aware of a viable business opportunity, they would theoretically pursuit it without the assistance of a facilitator.
- Model 2, 3, and 4 differ in the kind of information exchanged between the industry stakeholder and facilitator. In Model 2 the facilitators are presented with the businesses' willingness (motivation) to cooperate, whereas in Model 3 and 4 motivational/financial incentives have to be communicated to generate initial buy-in. So, information exchange in Model 2 serves as input-output matching mainly, while additional motivation/buy-in information needs to be provided by the facilitators in Model 3 and 4.
- Model 2, 3 and 4 also differ in the level of engagement of the facilitators. However, the level of engagement is based on their organisational/operational structures and the specific needs of the individual IS program.
- A key difference between Model 2 and 3 are the facilitators; governmental agencies versus independent (university) researchers.
- Also, Model 3 and 4 differ in the main project objective. Whereas Model 3 aims to develop a successful and continuing IS, Model 4 uses IS as a tool for regional development.
- An important difference between Model 1 and Models 2, 3 and 4 is the initial decision of industry stakeholders to participate. Development

Model 1 usually involves two industry parties, whereas industry partners in the other models have to be convinced first of the proposed development model; possible exchange opportunities have to be identified during the development process.

TABLE 7.2: SUMMARY OF DEVELOPMENT MODELS AND KEY DEVELOPMENT FACTORS

Development Model	Evolution	Governance	Champion	Funding
Model 1	Self-organised Initiation is driven by industry stakeholders due to knowledge of market opportunities	Self-governed-open organisational style Usually two parties are involved in development and implementation of by-product exchanges.	Not specified	Privately funded A convincing business case allows for an autonomous implementation
Model 2	Self-organised Initiation is initially industry driven due to knowledge of possible benefits through IS. However, no detailed knowledge of market opportunities is present.	Facilitated – open organisational style IS development is facilitated by governmental agencies; their main tasks are: • building an exchange/communication network, • identification of IS /business opportunities and • sustaining industry engagement (buy-in)	Not specified	Privately funded or co-funded with public monies
Model 3	Facilitated Initiation is driven by facilitators with scientific background in IS Important are: • recruitment of industry stakeholders creating initial 'buy-in' • attaining project funding (public, private)	Facilitated – research project with formal agreements Subsequent development guided by contractual agreements between stakeholders. Facilitation process requires to: • sustain the engagement of industry stakeholders, • deliberation and management of project objectives, and • identification of IS/business opportunities	Personal convictions of facilitators aided the IS initiation and development.	Co-funded through public and private moneys to assist the facilitation process and early feasibility studies
Model 4	Planned planned governmental approach driven by regional development Important are: • recruitment of industry stakeholders, creating initial 'buy-in' or an emotional attachment	facilitated – open organisational style The developer's main tasks are • sustain the engagement of industry stakeholders, • management of individual project objectives and • identification of IS/business opportunities	Project champions supporting IS development and networking	facilitation publicly funded

7.3. Management considerations for IS development

7.3.1. Model 1: Self-organised – self-governed – open organisational style

In Development Model 1 the evolution and development of the IS are characterised by the opportunism of industry stakeholders, knowledge of market opportunities and the straightforward development process of selling and buying. Due to the opportunistic nature of Model 1, it is assumed that the focus supporting this type of IS development lies in legal and physical pre-existing structures, which include legal frameworks, local natural resources and agglomeration effects. Governmental incentives can particularly influence these structures, by enhancing agglomeration effects and providing supportive regulatory or legislative conditions. Possible management considerations include:

- regional development,
- environmental legislation,
- circular economy,
- recycling networks and
- peer pressure.

Regional Development incentives can positively influence economic, social and environmental aspects of a region. Governmental incentives can also foster IS development. For example, through strategic planning of industrial activities, regional development can facilitate the right mix of industries from which an IS can be developed and regional sustainable industrial development is supported.

In addition to environmental legislation for solid, liquid or gaseous emission control, a circular economy approach would assist IS development in this model (see Section 3.1). Circular economy specifically promotes the reduction of material and energy waste flows. Besides recycling quota for specific waste streams, a circular economy act can include other industrial ecology tools such as extended producer responsibility, design and technology standards to ensure best reduce, reuse and recycling practices. One advantage of a national circular economy act is, that it encourages more IS development

through systematic and promotional efforts that can influence sustainability consciousness and behaviour. For example, the perception of waste by individuals and businesses can be changed over time, and instead of disposing, waste is increasingly seen as a secondary raw material.

Recycling networks including by-product exchange databases are also helpful to foster serendipitous IS development in form of multiple symbiotic by-product exchanges (see Section 4.9). Though such networks do not necessarily focus on promoting best practice with regards to the optimal material and energy utilization, they allow basic screening for exchange opportunities and information exchange between possible trade partners. Additionally, recycling networks can help to develop secondary raw material markets supporting circular economy principles. Due to the nature of promoting by-product material trades, recycling networks and databases should be based in either regional (economic) development offices or trade departments. These departments usually have a strong engagement with local industry and therefore are able to promote by-product exchanges (and IS) as part of sustainable regional development.

The spontaneous initiation and development can also be a result of knowledge transfer and peer pressure. In the past twenty years, increased public awareness on environmental problems, sustainability, recycling technologies, product and material life cycles have led to e.g. higher pollution standards, education and research in the field of by-product utilisation.

7.3.2. Model 2: Self-organised – facilitated – open organisational style

Though industry stakeholders are the initiators in Model 2, the facilitation process is key to successful IS development. Beside the identification of business opportunities, it is critical to sustain the initial interest of the industry stakeholders. The following management considerations may aid IS development in Model 2:

- selection of the right facilitator,
- IS Development and communication strategies.

The facilitators, in this case governmental agencies, serve businesses as communication and information exchange hubs which are also used as base to link material in- and output. Governmental agencies such as regional development offices or departments of commerce are in constant contact with businesses and therefore might be the best governmental facilitator as they are already familiar with local industries, know their business interest and possibly have business relations. To preserve the initial interest of industry stakeholders, the facilitator should follow the lead of the businesses and show interest in their aspirations/ambitions (the identification of synergies). The officers involved in the development process need allocated time for facilitation practices. Alternatively, waste exchange networks can be developed with allocated staff and funds to keep staff informed on new reuse practices.

Facilitators need to identify a development/communication strategy together with the initiating businesses, so that it is in line with their expectations and achievable in regard to workloads. In order to aid information exchange, it is helpful for the facilitator to address the regional regulatory and social context. This will create awareness for local environmental issues, generate peer pressure among local businesses and to foster a regional sustainability standard.

7.3.3. Model 3: Facilitated – research project with formal agreements

In Model 3, facilitation is key to the successful IS development, too. The main drivers of the project initiation and development are the facilitators, which have a background in research and an interest in sustainable industrial production. Due to the engagement of the facilitators, their knowledge on sustainability issues and prevention technologies, the management considerations focus on:

- social and management skills,
- local knowledge and
- promoting IS.

Due to the positive effects champions have on IS developments, facilitators initiating by-product exchange programs would benefit from having similar skill sets and attributes like champion (see Section 5.2.2). The facilitators need to be communicative and should have social management skills to foster

networking and information exchange among stakeholders, but also to manage the different project objectives (see Section 5.1.1). Ideally, the facilitator is, like a champion, able to inspire industry stakeholders with their enthusiasm to question the status quo regarding business practices and to promote businesses to participate in an IS program. If necessary, facilitators are able to improve their skills and rehabilitate deficits, through training and workshops. Besides skills and attributes, facilitators need to have local knowledge on the industrial areas (pre-existing structures) and cultural backdrop (SLO). They can gather further local information by conducting a SWAT analysis (strengths, weaknesses, opportunities, threats) (Chui 2004; Veiga 2009) on the target region.

When promoting IS programs, facilitators have to highlight potential benefits for the businesses and the region (social benefits and sustainable industrial development). Also, showing practical examples can assist local businesses/industries to better relate to IE/IS incentives. Facilitators approaching possible industry stakeholders need to provide information on the planned project including project duration, course, possible costs (funding structure) and risks. In the next step, facilitators assist in deliberation of project objectives which then are defined in contractual agreements framing the IS project. To assist successful synergy implementation, these formal agreements need to include the strategies (framework) to assist the realization of set project objectives, program duration and the management of funds. Important too is the definition of organisational structures such as roles and responsibilities of stakeholders which ensures non-discrimination in the development process. Overall, formal agreements set boundaries and bind key performance indices.

In this development model, buy-in can also be generated through subsidised feasibility studies. In this case, industry stakeholders which are not fully convinced of the profitability of the IS project, might still participate if they can avoid financial loss.

7.3.4. Model 4: Planned – facilitated – open organisational style

The IS development in the Model 4 is based on a (re-)development plan. Important aspects are financial or emotional buy-in regarding the proposed development strategy and the level of commitment in IE and main business operations. The development strategies need to appeal to possible new industrial stakeholders and therefore, management considerations need to include:

- attractive development plan,
- promotion of the development plan and
- social management skills.

The planned design should be attractive for and appeal to businesses so they participate. The regional development office needs to scout and analyse development opportunities in the wider region, particular with regards to natural resources and infrastructure. With this information regional developers can evaluate which type of synergies best to focus on (e.g. utilities, by-products). With this context, it might be good to keep the plan flexible (within reason) until scoping meetings with possible stakeholders have been made.

Facilitators need to adapt management strategies from champions. For example, they need to drive, facilitate and advance the project by encouraging the adoption of sustainable practices and reinforcing ecological values resulting from IS programs. Like champions, it is required from the facilitators to collaborate with other stakeholders and use their abilities and skills to influence and guide process developments and overcome resistances during the different project stages (see Section 5.2.2). To further advance a facilitators' skills, they need specialised training to develop their skills. Also, facilitated discussion and workshops to promote sustainability outcomes aid peer pressure and behaviour change (see Section 6.2). Regional industry and social knowledge might be beneficial for facilitators in this model. Understanding the economic, social and environmental needs of a region, as well as the knowing the local mentality will help to identify a common ground for IS and aid the facilitation process.

Chapter 8. Concluding remarks and recommendations

8.1. Research gap, aim and question

This research aimed to enhance the understanding of IS development models to assist ongoing and future IS development and to provide further insight into the development mechanisms of IS. The focus of this study was on the identification of factors influencing IS initiation and IS development processes, and to illustrate the impact these factors have. The following three research questions were examined by this research:

1. What are the models of IS development?
2. What influences these models?
3. What is needed to adjust the models to foster IS development?

An initial literature review showed that previous research presented a general overview of IS programs, their development models and factors influencing their development. Although the literature discussion on these topics is available it lacks a comparative review of the IS development processes. This research addresses this gap by:

- providing a comparative examination of major IS projects,
- investigating what influence IS initiation and development processes including organisational features and funding structures,
- reviewing additional social, management and local contributing factors that have not been collectively acknowledged in detail in the literature to date, and
- defines IS development models by reviewing factors relevant for specific development scenarios presented.

8.2. Findings

To answer the three research questions and adding to the IS literature, this thesis provided:

- a classification of IS activities and common operational challenges (Chapter 4),
- classification of funding models (Chapter 4),

- insights on the effects of individual factors on the IS process and that these factors can have an effect on each other (Chapter 5),
- review on cognitive elements in addressing organisational and human behaviour change towards sustainability management (Chapter 6), and
- an identification of four IS development models, factors affecting their specific development process and management considerations (Chapter 7).

8.2.1. Identification of IS development models

This thesis identified four development models based on a review of international IS case studies, through the classification of IS activities and common operational aspects.

Model 1: Self-organised – self-governed – open organisational style
Model 2: Self-organised – facilitated – open organisational
Model 3: Facilitated – research project with formal agreements
Model 4: Planned – facilitated – open organisational style

Though, IS development is not inflexible as the applied model can change into another form over time. This review also noted many common factors in IS initiation and development. These include stakeholder engagement, project champions and funding types as well as policy and economic influences, project management styles and specific IS facilitation agents. Managing these elements can be a challenge (Section 3.3) and addressing these factors appropriately is crucial for successful IS development, regardless of the development model.

In addition, this research identified three general funding models; private, public and co-funded (public and private funding) and that these models can change over time and are able to transition into other funding models. It was found that the funding structure can influence program objectives, which creates the initial financial and emotional buy-in of stakeholders. It is evident that financial buy-in creates an emotional connection to the project, which is important in ensuring the long-term commitment of stakeholders and the successful ongoing development of the IS program.

8.2.2. Influences on IS development models

The current research underlines the importance of financial incentives, pre-existing collaborative structures, championing and the right mix of industries in IS initiation. It should also be acknowledged that a broad range of organisational management factors influence IS initiation, including peer pressure, organisational sustainability culture and values, and the presence of an IS champion to facilitate the IS initiation process are also very important. Though all these factors have an effect on each of the four development models in some way, not all factors have an equal impact on a specific model. Therefore, key success factors have been defined for each development model in order to identify management considerations aiding the (specific) development process. The key success factors are a convincing business case for the involved parties and the facilitation processes concerned with the development of collaborations (e.g. generating and sustaining interest in IS and IE concepts). Whilst the key success factors appear similar in nature, the differences between the development models become apparent when looking at the organisational aspects (i.e. facilitator, champion, motivation/stakeholder objectives, funding, project management).

8.2.3. Adjusting IS development models

In order to support IS development, this thesis presents management considerations which can have a positive effect on the development/facilitation process. These include governmental incentives like regional development or legislative changes, and social and operational management elements. The effects of some governmental incentives, like regional development and infrastructure projects, are not necessarily seen immediately due to implementation periods. However, incentives concerning the material loop directly, like recycling quota, increasing taxes for waste and high disposal costs, can have more immediate impact on IS activities. This process/effect is highlighted by the opportunistic nature of Model 1, which displays that IS can be a natural phenomenon (business as usual) based on legal and physical pre-existing structures (legal frameworks, local natural resources and agglomeration effects). These elements are the basis for all development models. However, some aspects around the facilitation processes become

more prominent success factors in Model 2, 3 and 4. This presents a skill/character shift from business management skills and opportunism towards organisational and cognitive management requirements between Model 1 and Model 4.

Since most IS programs are facilitated, the following aspects are worth considering early in the development process: project management (organisational) and cognitive characteristics. Therefore, this study supports previous research on the importance of project management and highlights the correlation between cultural influences, program management styles, skills and attributes of managers, facilitators or champions in terms of preferred management styles of all involved parties. Therefore, this study emphasises the need for IS program facilitators to identify and address a preferred management style and the specific objectives of stakeholders, and then to adjust the IS project management strategy accordingly. Through additional training and skill development cognitive abilities can be further enhanced. Thus, having an understanding of the local political and social environment is also very important in the facilitation process in order to design effective communication and IS development strategies.

Further supporting the development of IS in industrial areas are regional development offices which can maintain by-product exchange databases or function as a networking agent to discuss common interests e.g. infrastructure and industrial development opportunities.

8.3. Concluding remarks

Sustainable industrial production and IS starts with an awareness of the benefits of IE and circular economy principles of eco-efficiency, reducing waste and improving environmental performance. Behaviour change in regard to sustainable development (SD) has occurred in the past, resulting in increased public awareness and sustainability focussed education programs (Section 6.2). Although managers within organisations may support sustainable development change, the current business models still focus primarily on growth (Section 5.1.1). Insights into human behaviour and the role of individuals presented in this thesis indicate that there is still a lack of

collective thinking and action in regard to SD in society and the business world, often leaving it up to individual leadership (champions, Section 5.2) to bring about the sustainability change required. With the right organisational support, IS programs are able to provide this leadership.

This research has identified a number of financial, cognitive and organisational mechanisms that are directly attributable to the ongoing achievements of a number of the world's largest and most successful IS programs. There remains however, further research which could help promote the ongoing success of IS development.

8.4. Future Work

- Additional research is needed to further investigate the value of public policy in IS development particularly highlighting the funding and regulations required to support or encourage IS engagement.
- Secondly, further research is needed to investigate the role of education and training in the sustainable development process. This would also assist the development of specific training programs for mangers and facilitators to enable them to promote the benefits of IS and Industrial Ecology in sustainable economic development.
- Thirdly, an investigation into the potential for enhanced regional and economic development using industrial symbiosis programs.
- Fourthly, IS development would benefit from some collective research and international promotion as an alternative industrial production model in newly developing economies.

"Ruin is the destination towards which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all."

(Hardin 1968, 1244 reprinted as (Hardin 2009)

Chapter 9. References

Adams, C.A., 2002. Internal organisational factors influencing corporate social and ethical reporting: Beyond current theorising. *Accounting, Auditing & Accountability Journal*, 15(2), pp.223-250.

Adams, C.A. et al., 1998. Corporate social reporting practices in Western Europe: legitimating corporate behaviour? *The British Accounting Review*, 30, pp.1-21.

Adams, M., 2011. *Year End Report to Senate*, Eco-Efficiency Centre.

Ajzen, I., 1991. The theory of planned behavior. *Organisational behavior and human decision*, 50, pp.179-211.

Ajzen, I. & Fishbein, M., 1980. *Understanding Attitutudes and Prediction Social Bahavior*, Englewood Cliffs: Prentice-Hall Inc.

Allenby, B., 1999. Culture and industrial ecology. *Journal of Industrial Ecology*, 3(1), pp.2-4.

Ammon, F., 2010. *The Eastern European Expansion of the EU: Are International Enterprises Only Competitive by Offshoring?*, GRIN Verlag.

Andrews, C.J., 2001. Building a micro foundation for industrial ecology. *Journal of Industrial Ecology*.

Andrews, C.J., 1999. Putting Industrial Ecology into Place Evolving Roles for Planners. *Journal of the American Planning Association*, 65(4), pp.364-375.

Ashford, N.A. et al., 2012. The crisis in employment and consumer demand: Reconciliation with environmental sustainability. *Environmental Innovation and Societal Transitions*, 2, pp.1-22.

Ashton, W.S., 2009. The Structure, Function, and Evolution of a Regional Industrial Ecosystem. *Journal of Industrial Ecology*, 13(2), pp.228-246.

Ashton, W.S. & Bain, A.C., 2012. Assessing the “Short Mental Distance” in Eco-Industrial Networks. *Journal of Industrial Ecology*, 16(1), pp.70-82.

Australia, G.O., 2011. *South Australia's Strategic Plan*,

Ayres, R.U., 1989. Industrial metabolism. In: *Technology and Environment*. Washington, DC: National Academy of Engineering, pp.23–49.

Ayres, R.U., 2006. Turning point: The end of exponential growth? *Technological Forecasting and Social Change*, 73(9), pp.1188-1203.

Ayres, R.U. & Simonis, U.E., 1994. *Industrial metabolism: restructuring for sustainable development*, Tokyo: United Nations University Press.

Baas, L., 2008. Industrial symbiosis in the Rotterdam Harbour and Industry Complex: reflections on the interconnection of the techno- sphere with the social system. *Business Strategy and the Environment*, 17(5), pp.330-340.

Baas, L., 2011. Planning and Uncovering Industrial Symbiosis: Comparing the Rotterdam and Östergötland regions. *Business Strategy and the Environment*, 20(7), pp.428-440.

Baas, L., 2007. To make zero emissions technologies and strategies become a reality, the lessons learned of cleaner production dissemination have to be known. *Journal of Cleaner Production*, 15(13-14), pp.1205-1216.

Baas, L. & Boons, F., 2004. An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems. *Journal of Cleaner Production*, 12(8-10), pp.1073-1085.

Baas, L. & Huisingh, D., 2008. The synergistic role of embeddedness and capabilities in industrial symbiosis: illustration based upon 12 years of experiences in the Rotterdam Harbour and Industry Complex. *Progress in Industrial Ecology - An International Journal*, 5(5/6), pp.399-421.

Bakshi, B. & Fiksel, J., 2003. The quest for sustainability: Challenges for process systems engineering. *AIChE Journal*, 49(6).

Balogun, J. & Johnson, G., 2005. From Intended Strategies to Unintended Outcomes: The Impact of Change Recipient Sensemaking. *Organization Studies*, 26(11), pp.1573-1601.

Bandura, A., 1988. Organisational Applications of Social Cognitive Theory. *Australian Journal of Management*, 13(2), pp.275-302.

Bandura, A., 2002. Social Cognitive Theory in Cultural Context. *Applied Psychology*, 51(2), pp.269-290.

Bansal, P. & Bogner, W.C., 2002. Deciding on ISO 14001: economics, institutions, and context. *Long Range Planning*, 35(3), pp.269-290.

Barr, S. et al. 2011. Citizens, consumers and sustainability: (Re)Framing environmental practice in an age of climate change. *Global Environmental Change*, 21(4), pp.1224-1233.

Behera, S.K. et al., 2012. Evolution of 'designed' industrial symbiosis networks in the Ulsan Eco-industrial Park: “research and development into business” as the enabling framework. *Journal of Cleaner Production*, 29-30, pp.103-112.

Best, M.N. & Thapa, B., 2013. Motives, facilitators and constraints of environmental management in the Caribbean accommodations sector. *Journal of Cleaner Production*, 52, pp.165-175.

Bilec, M.M. et al., 2009. Analysis of the Design Process of Green Children's Hospitals: Focus on Process Modeling and Lessons Learned. *Journal of Green Building*, 4(1), pp.121-134.

Blair, C., 1992. A community perspective on air pollution: industry's near neighbours. *Clean Air: Journal of the Clean Air Society of Australia and New Zealand*, 26(1), pp.17-19.

Boons, F. & Baas, L., 1997. Types of industrial ecology: the problem of coordination. *Journal of Cleaner Production*, 5(1-2), pp.79-86.

Boons, F. & Roome, N., 2001. Industrial ecology as a cultural phenomenon: On objectivity as a normative position. *Journal of Industrial Ecology*, 4(2).

Boons, F. et al., 2011. The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. *Journal of Cleaner Production* 19(9-10), pp.905–911.

Boons, F. et al., 2014. A process perspective on industrial symbiosis. *Journal of Industrial Ecology* 18(3), pp.341–355.

Branson, R.C., 2011. *Bilateral Industrial Symbiosis: An Assessment of its Potential in New South Wales to Deal with Manufacturing Waste*, The University of Sydney.

Brüggemeier, F. & Rommelspacher, T., 1992. *Blauer Himmel über der Ruhr: Geschichte der Umwelt im Ruhrgebiet 1840-1990*, Essen: Klartext Verlag.

Burns, C. & Carter, N., 2010. Is Co-decision Good for the Environment? An Analysis of the European Parliament's Green Credentials. *Political Studies*, 58(1), pp.123-142.

CECP, 2007. *Regional Resource Synergies for Sustainable Development in Heavy Industrial Areas: An Overview of Opportunities and Experiences*, Perth, Western Australia: CECP.

Cammell, S., 2013. Kawerau IS.

Carroll, A.B., 1999. Corporate Social Responsibility: Evolution of a Definitional Construct. *Business & Society*, 38(3), pp.268-295.

Cebrián, G. et al., 2013. Organisational learning towards sustainability in higher education. *Sustainability Accounting, Management and Policy Journal*, 4(3), pp.285-306.

Chertow, M.R., 2004. Industrial symbiosis. *Encyclopedia of Energy*, pp.407-415.

Chertow, M.R., 2000. Industrial symbiosis: literature and taxonomy. *Annual review of energy and the environment*, 25, pp.313-337.

Chertow, M.R., 1998. The Eco-industrial Park Model Reconsidered. *Journal of Industrial Ecology*, 2(3), pp.8-10.

Chertow, M.R., 2007. “Uncovering” industrial symbiosis. *Journal of Industrial Ecology*, 11(1), pp.11-30.

Chertow, M.R. & Ehrenfeld, J., 2012. Organizing Self-Organizing Systems. *Journal of Industrial Ecology*, 16(1), pp.13-27.

Chertow, M.R. & Lombardi, D.R., 2005. Quantifying Economic and Environmental Benefits of Co-located Firms. *Environmental Science and Tecnology*, 39(17), pp.6535-6541.

Chertow, M.R. et al., 2008. Industrial Symbiosis in Puerto Rico: Environmentally Related Agglomeration Economies. *Regional Studies*, 42(10), pp.1299-1312.

Chertow, M.R. et al., 2004. *The Industrial Sybmiosis Research Symposion at Yale: Advancing the Study of Industry and Environment*, New Haven, Connecticut, USA: Yale School of Forestry and Environmental Studies.

Chiu, A.S.F. & Yong, G., 2004. On the industrial ecology potential in Asian Developing Countries. *Journal of Cleaner Production*, 12(8-10), pp.1037-1045.

Christensen, J., 2013. Kalundborg IS.

Christensen, J., 2012. The Kalundborg Symbiosis: What, who, when, how and why? *University of Surrey*, pp.1-45.

Ciliberti, F. et al., 2011. CSR codes and the principal-agent problem in supply chains: four case studies. *Journal of Cleaner Production*, 19(8), pp.885-894.

Coe, D.T., 2007. *Globalisation And Labour Markets: Policy Issues Arising From The Emergence Of China And India*, OECD.

Cohen-Rosenthal, E., 2000. A Walk on the Human Side of Industrial Ecology. *American Behavioral Scientist*, 44(2), pp.245-264.

Cohen-Rosenthal, E. & Musnikow, J., 2003. *Eco-industrial Strategies*, Greenleaf Publishing.

Commission of the European Communities, 2001. *Green Paper Promoting a European Framework for Corporate Social Responsibility COM(2001) 366 final*, Brussels: Commission of the European Communities.

Corder, G.D., 2005. *Potential Synergy Opportunities in the Gladstone Industrial Region*.

Corder, G.D., 2008. *Developing Local Synergies in the Gladstone Industrial Area*, Centre for Sustainable Resource Processing.

Costa, I. et al., 2010. Waste management policies for industrial symbiosis development: case studies in European countries. *Journal of Cleaner Production*, 18(8), pp.815-822.

Crocker, R. & Lehmann, S., 2013. Prologue. In *Motivating Change*. Routledge, pp. 1-8.

Côté, R.P. & Cohen-Rosenthal, E., 1998. Designing Eco-Industrial Parks: A Synthesis of some Experiences. *Journal of Cleaner Production*, 6, pp.181-188.

Côté, R.P. & Hall, J., 1995. Industrial parks as ecosystems. *Journal of Cleaner Production*, 3(1-2), pp.41-46.

Côté, R.P. et al., 2006. Eco-efficiency and SMEs in Nova Scotia, Canada. *Journal of Cleaner Production*, 14(6-7), pp.542-550.

Dames, M., 1990. *Kwinana Heavy Industry Economy Study*,

Davis, K., 1960. Can business afford to ignore social responsibilities? *California Management Review*, 2(3), pp.70-76.

Day, B.A., 2007. Environmental communication for aquatic stewardship. In *American Fisheries Society Symposium*. American Fisheries Society Symposium. pp. 45-53.

Doménech, T. & Davies, M., 2011. The role of Embeddedness in Industrial Symbiosis Networks: Phases in the Evolution of Industrial Symbiosis Networks. *Business Strategy and the Environment*, 20(5), pp.281-296.

Drumwright, M., 1994. Socially responsible organisational buying: environmental concern as a noneconomic buying criterion. *The Journal of Marketing*, 58, pp.1-19.

Ebner, D. & Baumgartner, R.J., 2006. The relationship between Sustainable Development and Corporate Social Responsibility. In pp. 1-17.

Ehrenfeld, J., 2007. Would industrial ecology exist without sustainability in the background? *Journal of Industrial Ecology*, 11(1).

Ehrenfeld, J. & Gertler, N., 1997. Industrial Ecology in Practice: The Evolution of Interdependence at Kalundborg. *Journal of Industrial Ecology*, 1(1), pp.1-13.

Eilering, J.A. & Vermeulen, W.J., 2004. Eco-Industrial Parks: Toward Industrial Symbiosis and Utility Sharing in Practice. *Progress in Industrial Ecology*, 1, pp.245-270.

Engberg, H., 1993. *Industrial Symbiosis in Denmark*, New York, NY: New York University.

Erkman, S., 1997. Industrial ecology: an historical view. *Journal of Cleaner Production*.

Esty, D.C. & Porter, M.E., 1998. Industrial Ecology and Competitiveness. *Journal of Industrial Ecology*, 2(1), pp.35-43.

Faucheux, S. & Nicolaï, I., 1998. Environmental technological change and governance in sustainable development policy. *Ecological Economics*, 27, pp.243-256.

Ferrer, G. et al., 2012. Green City. *Journal of Industrial Ecology*, 16(1), pp.142-152.

Fischer- Kowalski, M. et al., 2011. Methodology and indicators of economy-wide material flow accounting. *Journal of Industrial Ecology*, 15, pp.855-876.

Fishbein, M. & Ajzen, I., 1975. *Belief, attitude, intention, and behavior: an introduction to theory and research*, Addison-Wesley Pub. Co.

Friedman, M., 1962. *Capitalism and Freedom*, Chicago: University of Chicago Press.

Frosch, R.A., 1992. Industrial Ecology: A Philosophical Introduction. In *National Acedemy of Science*. National Acedemy of Science. Washington DC, pp. 800-803.

Frosch, R.A. & Gallopoulos, N.E., 1989. Strategies for Manufacturing. *Scientific American*, pp.1-7.

Garner, A. & Keoleian, G.A., 1995. *Industrial Ecology: An Introduction*, National Pollution Prevention Center for Higher Education.

Geels, F.W., 2013. The impact of the financial–economic crisis on sustainability transitions: Financial investment, governance and public discourse. *Environmental Innovation and Societal Transitio."*, 6, pp.67-95.

Geng, Y. & Doberstein, B., 2008. Developing the circular economy in China: Challenges and opportunities for achieving "leapfrog development". *International Journal of Sustainable Development & World Ecology*, 15(3), pp.231-239.

Geng, Y. et al., 2012. Towards a national circular economy indicator system in China: an evaluation and critical analysis. *Journal of Cleaner Production*, 23(1), pp.216-224.

Gertler, N., 1995. *Industrial Ecosystems: Developing Sustainable Industrial Structures*, Massachusetts Institute of Technology.

Gertler, N. & Ehrenfeld, J., 1996. A down-to-earth Approach to Clean Production. *Technology Review*, 99(2), pp.48-54.

Gibbs, D., 2003. Trust and networking in inter-firm relations: the case of eco-industrial development. *Local Economy*, 18(3), pp.222-236.

Gibbs, D. & Deutz, P., 2005. Implementing industrial ecology? Planning for eco-industrial parks in the USA. *Geoforum*, 36(4), pp.452-464.

Gibbs, D. & Deutz, P., 2007. Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production*, 15(17), pp.1683-1695.

Giurco, D. et al., 2011. Backcasting energy futures using industrial ecology. *Technological Forecasting and Social Change*, 78(5), pp.797-818.

Goleman, D., 2000. Leadership that gets results. *Harvard Business Review*, (2), pp.78-93.

Golev, A. et al., 2014. Industrial symbiosis in Gladstone: a decade of progress and future development. pp. 1–9.

Hamilton, D.S. & Quinlan, J.P., 2008. *Germany and Globalization*, Center for Transatlantic Relations.

Hardin, G., 2009. The Tragedy of the Commons*. *Journal of Natural Resources Policy Research*, 1(3), pp.243-253.

Harris, S., 2004. *Drivers and Barriers to Industrial Ecology in the UK*, Edingurgh: University of Edinburgh.

Harris, S., 2008. *Mechanisms to enable Regional Resource Synergies: Facilitating Structures & Operational Arrangements*, CECP.

Heck, P. & Birkenfeld, E.C., 2006. *Circular Economy-related International Practices and Policy Trends*, Beijing: The World Bank.

Heeres, R.R. et al., 2004. Eco-industrial park initiatives in the USA and the Netherlands: first lessons. *Journal of Cleaner Production*, 12(8-10), pp.985-995.

Herbertson, J., 2013. Kwinana IS.

Hewes, A.K. & Lyons, D.I., 2008. The Humanistic Side of Eco-Industrial Parks: Champions and the Role of Trust. *Regional Studies*, 42(10), pp.1329-1342.

Hill, C. & LLC, A.S., 2001. *NJCAT Technology Verification - By-Product Synergy Process*,

Holt, D., 2010. Where are they now? Tracking the longitudinal evolution of environmental businesses from the 1990s. *Business Strategy and the Environment*, 20(4), pp.238-250.

Holt, D. & Ghobadian, A., 2009. An empirical study of green supply chain management practices amongst UK manufacturers. *Journal of Manufacturing Technology Management*, 20(7), pp.933-956.

Hutchinson, C., 1996. Integrating Environment Policy with Business Strategy. *Long Range Planning*, 29(1), pp.11-23.

IfW, 2002. *Jahresbericht 2002*, Institute für Weltwirtschaft.

Ilieva, V., 2008. *Transforming Teachers' Knowledge and Skills: Lesson Study in Mathematics Instruction Sensitive for Diverse Learners at Middle Level*, ProQuest.

Jackson, T., 2005. *Motivating Sustainable Consumption: A review of evidence on consumer behaviour and behavioural change*,

Jelinski, L. et al., 1992. Industrial ecology: concepts and approaches. In *Proceedings of the National Academy of Science*. Proceedings of the National Academy of Science.

Jensen, P.D. et al., 2012. “Habitat” Suitability Index Mapping for Industrial Symbiosis Planning. *Journal of Industrial Ecology*, 16(1), pp.38-50.

Jiang, M.P. & Tovey, K., 2010. Overcoming barriers to implementation of carbon reduction strategies in large commercial buildings in China. *Building and Environment*, 45(4), pp.856-864.

Jovane, F. et al., 2008. The incoming global technological and industrial revolution towards competitive sustainable manufacturing. *CIRP Annals - Manufacturing Technology*, 57(2), pp.641-659.

KIC, 2012. Kwinana Industrial Council. *http://www.kic.org.au/about.asp*. Available at: http://www.kic.org.au/about.asp.

Kahn, M.A., 1995. Sustainable development: The key concepts, issues and implications. *Sustainable Development*, 3, pp.63-69.

Kim, M.H., 2009. *Eco-Industrial Development in the U.S. Spatial Forms, Contxtual Factors, and Institutional Fabrics or Breener Plants and Offices*, New Brunswick, New Jersey.

Kirkegaard, J.F., 2007. *Offshoring, Outsourcing, and Production Relocation--Labor-Market Effects in the OECD Countries and Developing Asia*, Peterson Institute for International Economics.

Klinger, D. et al., 1994. RyderFIRST: facilitating a turnaround in ryder system's consumer truck rental division. *The Journal of Strategic Information*.

Knight, P., 1990. A Rebirth of the Pioneering Spirit. *Financial Times*, pp.1-2.

Korhonen, J., 2004. Industrial ecology in the strategic sustainable development model: strategic applications of industrial ecology. *Journal of Cleaner Production*, 12(8-10), pp.809-823.

Korhonen, J., 2003. On the ethics of corporate social responsibility–considering the paradigm of industrial metabolism. *Journal of Business Ethics*, 48, pp.301-315.

Korhonen, J., 2002. The dominant economics paradigm and corporate social responsibility. *Corporate Social Responsibility and Environmental Management*, 9(1), pp.66-79.

Kuehr, R., 2007. Towards a sustainable society: United Nations University's Zero Emissions Approach. *Journal of Cleaner Production*, 15(13-14), pp.1198-1204.

Kurland, N.B. & Zell, D., 2011. Green management. *Organisational Dynamics*, 40(1), pp.49-56.

Kurup, B., 2007. *Methodology of capturing environmental, social and economic implications of industrial symbiosis in heavy industrial area*, Perth, Western Australia: Curtin University of Technoloy.

Lambert, A.J. & Boons, F., 2002. Eco-Industrial Parks: Stimulating Sustainable development in Mixed Industrial Areas. *Technovation*, 22, pp.471-484.

Lehtonen, M., 2006. Deliberative Democracy, Participation, and OECD Peer Reviews of Environmental Policies. *American Journal of Evaluation*, 27(2), pp.185-200.

Lifset, R. & Graedel, T.E., 2002. Industrial ecology: goals and definitions. In *A Handbook of Industrial Ecology*. Edward Elgar Publishing, pp. 3-15.

Lloyd, G. & Phillips, M., 1994. Inside IBM: Strategic Management in a Federation of Businesses. *Long Range Planning*, 27(5), pp.52-63.

Lorenzoni, I. et al., 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change*, 17(3-4), pp.445-459.

Lowe, E.A., 1997. Creating by-product resource exchanges: strategies for eco-industrial parks. *Journal of Cleaner Production*, 5, pp.57-65.

Lowe, E.A. & Evans, L.K., 1995. Industrial Ecology and Industrial Ecosystems. *Journal of Cleaner Production*, 3(1-2), pp.47-53.

Lowe, E.A. et al., 1996. Fieldbook for the Development of Eco-Industrial Parks - Final Report October 1996., pp.1-344.

Lucas, K. et al., 2008. Promoting pro-environmental behaviour: existing evidence and policy implications. *Environmental Science & Policy*, 11(5), pp.456-466.

Luken, R. & van Rompaey, F., 2008. Drivers for and barriers to environmentally sound technology adoption by manufacturing plants in nine developing countries. *Journal of Cleaner Production*, 16(1), pp.S67-S77.

Mackenzie, S., 2002. Applied Sustainability LLC: Making a Business Case for By-Product Synergy., pp.1-14.

Mangan, A., 1997. By-Product Synergy: A Strategy for Sustainable Development - A Primer. *BCSD-GM*, pp.1-36.

Markard, J. et al., 2012. Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), pp.955-967.

Markewitz, K. et al., 2012. From BRIQ to Industrial Symbiosis Projects: Industrial Ecology in Quebec, Canada. *The 18th Greening Industry Network Conference*, pp.1-14.

Martin, S.A. et al., 1996. *Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues*, Center for Economics Research and Indigo Development.

Mathews, J. & Tan, H., 2011. Progress toward a circular economy in China. *Journal of Industrial Ecology* 15(3), pp.435–457.

Michael, P., 2013. Upper Spencer Gulf IS Project.

Michell, L. & West, P., 1996. Peer pressure to smoke: the meaning depends on the method. *Health Education Research*, 11(1), pp.39-49.

Mirata, M., 2004. Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges. *Journal of Cleaner Production*, 12(8-10), pp.967-983.

Mirata, M., 2003. Industrual Symbiosis in the UK (aption from JoCP paper). *Lund University*, pp.1-23.

Multhauf, R.P., 1967. Industrial Chemistry in the Ninetheenth Century. In *Technology in Western Civilisation: The Emergence of Modern Industrial Society, Earliest Times to 1900*. New York, United States: Oxford University Press, pp. 468-488.

Muratovski, G., 2013. Advertising, public relations and social marketing. In *Motivating Change*. Routledge, pp. 178-197.

Neville, M., 2013. Kwinana IS.

Newton, P. & Meyer, D., 2011. Who cares? An exploration of attitudes and behaviour towards the conservation of resources. In pp. 267-291.

Northmore, S. & Hart, A., 2011. Sustaining community-university partnerships. *Gateways: International Journal of Community Research and Engagement*, 4, pp.1-11.

OECD, 2009a. *Eco-Innovation in Industry: Enabling Green Growth*, Paris, France: OECD.

OECD, 2009b. *Policy Responses to the Economic Crisis: Investing in Innovation for Long-Term Growth*, OECD.

Ogbonna, E & Harris, L., 2001. The founder's legacy: hangover or inheritance? *British Journal of Management*, 12, pp.13-31.

Ogbonna, E. & Eilkinson, B., 2003. The False Promise of Organisational Culture Change: A Case Study of Middle Managers in Grocery Retailing*. *Journal of Management Studies*, 40(5), pp.1151–1178-28.

Ohnishi, S. et al., 2012. Econometric analysis of the performance of recycling projects in Japanese Eco-Towns. *Journal of Cleaner Production*, 33, pp.217-225.

Pagani, F., 2002. Peer Review as a Rool for Co-operation and Change. *African Security Review*, 11(4), pp.15-24.

Panter-Brick, C. et al., 2006. Culturally compelling strategies for behaviour change: A social ecology model and case study in malaria prevention. *Social Science & Medicine*, 62(11), pp.2810-2825.

Paquin, R.L. & Howard-Grenville, J., 2012. The Evolution of Facilitated Industrial Symbiosis. *Journal of Industrial Ecology*, 16(1), pp.83-93.

Paquin, R.L. & Howard-Grenville, J., 2009. Facilitating Regional Industrial Symbiosis: Network Growth in the UK's National Industrial Symbiosis Programme. In F. A. Boons & J. Howard-Grenville, eds. London, UK: The Social Embeddedness of Industrial Ecology, pp. 1-33.

Park, H., 2011. *Eco-Industrial Park in Ulsan, Republic of Korea*,

Park, H. et al., 2008. Strategies for sustainable development of industrial park in Ulsan, South Korea—From spontaneous evolution to systematic expansion of industrial symbiosis. *Journal of Environmental Management*, 87(1), pp.1-13.

Peattie, K. & Hall, G., 1994. The greening of local government: A survey. *Local Government Studies*, 20(3), pp.458-485.

Peck, S., 1999. *EIP Development and Canada: Final Report*,

Petty et al., 2004. Management and policy aspects of industrial ecology: an emerging research agenda. *Business Strategy and the Environment*, 13(5), pp.289-305.

Porter, M.E., 2000. Location, Competition, and Economic Development: Local Clusters in a Global Economy. *Economic Development Quarterly*, 14(1), pp.15-34.

Preston, L., 2001. Sustainability at Hewlett-Packard: From the theory to practice. *California Management Review*, 43(3), pp.26-37.

Price, R. & Brodie, R.J., 2001. Transforming a Public Service Organization from inside Out to Outside in: The Case of Auckland City, New Zealand. *Journal of Service Research*, 4(1), pp.50-59.

Prno, J. & Slocombe, D.S., 2012. Exploring the origins of “social license to operate” in the mining sector: Perspectives from governance and sustainability theories. *Resources Policy*, 37(3), pp.346-357.

Reinhardt, F., 1999. Market Failure and the Environmental Policies of Firms: Economic Rationales for “Beyond Compliance” Behavior. *Journal of Industrial Ecology*, 3(1), pp.9-21.

Resources, B.O. & Economics, E., 2011. *Resources and Energy Statistics 2011*, Canberra, Australia: Bureau of Resources and Energy Economics.

Rezaei, M., 2013a. Upper Spencer Gulf IS Project.

Rezaei, M., 2013b. *Upper Spencer Gulf Industrial Symbiosis Project: Final Report*, Perth, Western Australia.

Richardson, J. et al., 2009. Health, energy vulnerability and climate change: A retrospective thematic analysis of primary care trust policies and practices. *Public Health*, 123(12), pp.765-770.

Rosano, M. & Biswas, W., 2013. De-constructing the sustainability challenge for engineering education. An industrial ecology approach. In *6th International Conference on Engineering Education for Sustainable Development*. 6th

International Conference on Engineering Education for Sustainable Development. pp. 1-12.

Rosano, M. & Schianetz, K., 2014. Measuring sustainability performance in industrial parks: a case study of the Kwinana industrial area. *International Journal of Sustainable Development*, 17, pp.261-280.

SKM, 2007. *Kwinana Industrial Area Integrated Assessment*, Perth, Western Australia: KIC.

Saikku, L., 2006. *Eco-Industrial Parks*, Mikkeli.

Sakr, D. et al., 2011. Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context. *Journal of Cleaner Production*, 19(11), pp.1158-1169.

Schwarz, E.J. & Steininger, K.W., 1997. Implementing nature's lesson: the industrial recycling network enhancing regional development. *Journal of Cleaner Production*, 5, pp.47-56.

Schwarz, E.J. & Steininger, K.W., 1995. *The Industrial Recycling-Network Enhancing Regional Development*, University Graz.

Schwarz, E.J., Bruns, K. & Lopatka, M., 1996. Rückstandsbezogene Zusammenarbeit im Ruhrgebiet. In Umwelt und Energie - Handbuch für die betriebliche Praxis, pp. 297-322.

Seethaler, R. & Rose, G., 2004. Application of psychological pronciples to primote travel behaviour change. *Transport Engineering in Australia*, 9(2), pp.67-84.

Shi, H. et al., 2012a. China's Quest for Eco-industrial Parks, Part I. *Journal of Industrial Ecology*, 16(1), pp.8-10.

Shi, H. et al., 2012b. China's Quest for Eco-industrial Parks, Part II. *Journal of Industrial Ecology*, 16(3), pp.290-292.

Snyder, N.H. & Wheelen, T.L., 1981. Managerial Roles: Mintzberg and the Management Process Theorists. *Academy of Management Proceedings*, 1981(1), pp.249-253.

Steg, L. & Vlek, C., 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, 29(3), pp.309-317.

Stern, P.C. et al., 1995. Values, Beliefs, and Proenvironmental Action: Attitude Formation Toward Emergent Attitude Objects. *Journal of Applied Social Psychology*, 25(18), pp.1611-1636.

Sterr, T., 2000. Inter-industrial Materials Flow Management – the Rhine-Neckar-Experience (South Germany). In *HelSIE Symposium on Industrial Ecology and Material Flows*. HelSIE Symposium on Industrial Ecology and Material Flows. pp. 285-293.

Sterr, T., 2013. Rhein-Neckar Triangle IS.

Sterr, T. & Ott, T., 2004. The industrial region as a promising unit for eco-industrial development—reflections, practical experience and establishment of innovative instruments to support industrial ecology. *Journal of Cleaner Production*, 12(8-10), pp.947-965.

Swan, C. et al., 1999. Optimization and Economic Evaluation of Coal Fly Ash Reuse in New Synthetic Lightweight Aggregates. In *International Ash Utilization Symposium*. International Ash Utilization Symposium. pp. 1-7.

Symbiosis, 2013. Symbiosis (biology). *Encyclopaedia Britannica Online*.

Taylor, A., 2010. Building leadership capacity to drive sustainable water management: the evaluation of a customised program. *Water Science & Technology*, 61(11), pp.2797-2807.

Taylor, A., 2008. *Leadership in Sustainable Urban Water Management: An investigation of the champion phenomenon within Australian water agencies*, Monash University.

Taylor, A., 2007. Sustainable Urban Water Management Champions: What do we know about them? In *Rainwater and Urban Design 2007*. Rainwater and Urban Design 2007. pp. 1-11.

Taylor, A. et al., 2011. An investigation of champion-driven leadership processes. *The Leadership Quarterly*, 22(2), pp.412-433.

Taylor, Martin, 2002. Waste and Emission Reduction Through Regional Synergies in the Kwinana Industrial Area. In *Green Processing*. Green Processing. Cains, Queensland, pp. 73-78.

Taylor, Michael, 2011. *The influence of transformative coaching on managerial behaviour, leadership style, individual and ream engagement* D. Aiken, ed., Stellenbosch University.

Tibbs, H., 1993. Industrial Ecology: An Environmental Agenda for Industry. *Global Business Network*, pp.1-30.

Tilbury, D., 1995. Environmental Education for Sustainability: defining the new focus of environmental education in the 1990s. *Environmental Education Research*, 1(2), pp.195-212.

Tonglet, M., 1999. *Shoplifting as Consumer Misbehaviour*. University of Leicester

Tucker, J.L., 2010. Green Chemistry: Cresting a Summit toward Sustainability. *Organic Process Research & Development*, 14(2), pp.328-331.

UNESCO, 2012. *The Impact of the Economic Crisis on Higher Education*, Bangkok, Thailand: UNESCO Bangkok.

Uzzi, B., 1997. Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. *Administratice Science Quarterly*, 42(1), pp.35-67.

Uzzi, B., 1996. The Sources and Consequences of Embeddedness for the Economic Performance of Organizations: The Network Effect. *American Sociological Review*, 61(4), pp.674-698.

Vastag, G., 2004. Revisiting ISO 14000 Diffusion: A New “Look” at the Drivers of Certification. *Production and Operations Management*, 13(3), pp.260-267.

Veiga, L.B.E. et al., 2009. Eco-industrial park development in Rio de Janeiro, Brazil: a tool for sustainable development. *Journal of Cleaner Production*, 17(7), pp.653-661.

Vermeulen, W.J., 2006. The social dimension of industrial ecology: on the implications of the inherent nature of social phenomena. *Process in Industrial Ecology*, 3(6), pp.574-598.

Vickers, I. & Cordey-Hayes, M., 1999. Cleaner Production and Organisational Learning. *Technology Analysis & Strategic Management*, 11(1), pp.75-94.

Vilana, J.R. & Rodríguez-Monroy, C., 2010. Influence of cultural mechanisms on horizontal inter-firm collaborations., pp.1-38.

Visser, W. & Crane, A., 2010. Corporate Sustainability and the Individual. *SSRN Paper Series*, pp.1-20.

Wright, T.S.A., 2002. Definitions and frameworks for environmental sustainability in higher education. *International Journal of Sustainability in Higher Education*, 3(3), pp.203-220.

Young, R., 2000. *Alberta By-Product Synergy*,

Young, W. et al., 2009. Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development*, pp.n/a-n/a.

Yu, C. et al., 2011. Eco-industrial park develoment in China: An overview of the status quo. In *5th International Conference on Eco-Cities in PAN-ASIA*. 5th International Conference on Eco-Cities in PAN-ASIA. Baltimore, pp. 1-21.

Yu, C. et al., 2013. Understanding the Evolution of Industrial Symbiosis Research. *Journal of Industrial Ecology* 18, pp.280–293.

Yuan, Z. et al., 2006. The circular economy: A new development strategy in China. *Journal of Industrial Ecology*, 10(1-2), pp.4-8.

Zhu, Q. et al., 2007. Industrial symbiosis in China: A Case Study of the Guitang Group. *Journal of Industrial Ecology*, 11(1), pp.31-42.

Zibarras, L. & Ballinger, C., 2010. *Promoting environmental behaviour in the workplace: A survey of UK organisations*, London: City University London.

de Haan, J. et al., 1996. Government Capital Formation: Explaining the Decline. *Weltwirtschaftliches Archiv*, 132(1), pp.55-74.

del Río, P. et al., 2010. Policy Strategies to Promote Eco-Innovation. *Journal of Industrial Ecology*, 14(4), pp.541-557.

in-kind, 2013. in-kind. *Oxford Dictionary Online*.

van Beers, D., Bossilkov, A. & Lund, C., 2009. Development of large scale reuses of inorganic by-products in Australia: The case study of Kwinana, Western Australia. *Resources, Conservation and Recycling*, 53(7), pp.365 - 378.

van Beers, D., 2008a. *Application of the cleaner production framework to the development of regional synergies in heavy industrial areas: a case study of Kwinana (Western Australia)*, Curtin University of Technology.

van Beers, D., 2008b. *Capturing Regional Synergies in the Kwinana Industrial Area*, Perth, Western Australia: CECP.

van Beers, D., 2007. *Capturing Regional Synergies in the Kwinana Industrial Area*, Perth, Western Australia: CECP.

van Beers, D. & van Berkel, R., 2007. Collaburative Industry Research to Develop Regional Synergies. *ISIE*, pp.1-6.

van Beers, D. et al., 2005. *Capturing Regional Synergies in the Kwinana Industrial Area*, Perth, Western Australia: CECP.

van Beers, D. et al., 2007a. Industrial Symbiosis in the Australian Minerals Industry: The Cases of Kwinana and Gladstone. *Journal of Industrial Ecology*, 11(1), pp.55-72.

van Beers, D. et al., 2007b. Regional synergies in the Australian minerals industry: Case-studies and enabling tools. *Minerals Engineering*, 20(9), pp.830-841.

van Berkel, R., 2007. Cleaner production and eco-efficiency initiatives in Western Australia 1996–2004. *Journal of Cleaner Production*, 15(8-9), pp.741-755.

van Berkel, R. et al., 2009a. Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. *Journal of Environmental Management*, 90, pp.1544-1556.

van Berkel, R. et al., 2009b. Quantitative Assessment of Urban and Industrial Symbiosis in Kawasaki, Japan. *Environmantal Science and Technollogy*, 43(5), pp.1271-1281.

van Berkel, R. et al., 1997. Development of an industrial ecology toolbox for the introduction of industrial ecology in enterprises—I. *Journal of Cleaner Production*, 5(1-2), pp.11-25.