Chapter 1
Food for Thought: Seeking the Essence of Industrial Symbiosis

Pauline Deutz

Abstract Researchers and practitioners would benefit from a definition of industrial symbiosis which clearly distinguishes essential from contingent characteristics. The definition also needs to be translatable between both language and policy contexts. Industrial symbiosis is herein defined as a flow of underutilized resource(s) (comprising substances and/or objects and/or energy), from an entity which would otherwise discard them, to another entity which uses them as a substitute for new resources. Choice of terms is justified by reference to academic and policy literature. This definition has an underlying assumption of resource efficiency, by contrast to other approaches which mistakenly emphasized economic benefits, which are contingent rather than essential characteristics.

Keywords Industrial symbiosis · Industrial ecology · Policy · Resources · Waste

1.1 Introduction

Industrial symbiosis (IS) is a field of study and environmental business practice within the interdisciplinary field of industrial ecology (IE). Core to the idea of IS is a collaborative approach to the extraction of value from otherwise underexploited resources. However, after two decades of debate, the definition of IS remains contested (Lombardi and Laybourn 2012), even whilst authors develop theorizations (e.g., Paquin and Howard-Grenville 2012). Without a clear understanding of what is IS, and the implications of that, efforts to build theories may be at cross purposes and possibly emphasize incidental rather than key characteristics. A clear understanding of underlying assumptions and their implications for methodology is critical to any research endeavor (Creswell 2003). Clarity and consistency of definition are no less a concern for policy initiatives, which for IS are found across the globe (Lombardi and Laybourn 2012). Assumptions underlying research relate to ontology and epistemology, which respectively ask questions about what exists and how we can gain knowledge of it (Spash 2012). It is beyond the scope of this chapter

P. Deutz (✉)
Department Geography, Environment and Earth Sciences,
University of Hull, Hull HU6 7RX, UK
e-mail: p.deutz@hull.ac.uk

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to address the ontology and epistemology of IS comprehensively. I also cannot address in detail the variety of IS policy initiatives, rather the aim is to consider the underlying commonalities. The chapter focuses on the urgent and critical ontological question of what is IS.

Although studied by engineers and natural scientists as well as social scientists, IS is a social phenomenon (Andrews 2000/2001). Arguably, this makes IS more complex to define than either the physical objects that more typically comprise the object of natural science study (Sayer 1984), or the engineered systems that are intentionally defined and controlled to suit a specific purpose (Andrews 2000/2001). For social phenomena the boundaries between object and ideas about the object can be hard to disentangle, with ideas (and potentially the object) heavily contingent on historical and geographic context (Sayer 1984); the "object" of social science study may be an idea (Sayer 1984). Indeed, in some usages IS is an idea, i.e., that industry could and should be reorganized into industrial ecosystems (see below). This chapter argues, however, that the term industrial ecosystem should be reserved for the idea, or ideal, of that reorganization. IS could better be defined as a distinct, observable phenomenon.

This chapter argues that an unambiguous definition of IS is required, which identifies essential features, as distinct from contingent properties. The latter may accurately describe some instances of IS in practice, but should not be considered defining characteristics. Furthermore, any definition of IS needs to be translatable between different language and policy contexts. The proposed definition identifies resource efficiencies as the essence of IS, justifying the choice of terms by reference to the IS literature and relevant policy documents.

1.2 Industrial Symbiosis and Industrial Ecosystems

Almost from the beginning of the widespread usage of the term IS there have been both different usages of the term, and other expressions used synonymously. Current academic and policy interest in IS (and IE more generally) stems from the fortuitous near coincidence of the Frosch and Gallopoulos (1989) article advocating "industrial ecosystems" and the 1990 discovery of an apparent industrial ecosystem in practice at Kalundborg, Denmark (e.g., Jacobsen 2006). The *Financial Times* article that publicized Kalundborg called its network of waste exchanges an "industrial ecosystem", presenting IS as "the term preferred by the locals" (Knight 1990, p. 15). An industrial ecosystem applies the lessons that industrial ecology draws from biological systems (Frosch and Gallopoulos 1989; Korhonen and Baumgartner 2009). The term Industrial ecosystem continues to appear in the IS literature to evoke a resource efficiency network of the type displayed at Kalundborg (e.g., Chertow and Ehrenfeld 2012).

IS has taken root in the literature in a sense similar to that of an industrial ecosystem (e.g., Wolf et al. 2007; Lombardi et al. 2012). The most widely cited definition of IS (Lombardi and Laybourn 2012) comes from Chertow (2000): "The part of industrial ecology known as industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity."

This definition closely corresponds to circumstances at Kalundborg, and could be seen as an elucidation of the idea of an industrial ecosystem, rather than a separate empirical phenomenon.

However, there have been, and still are, alternative approaches, which see symbiosis as the individual relationships, the sum of which may comprise an industrial ecosystem: "Although there are many examples of symbiosis involving the exchange of material and the cascading of energy and water … multifaceted industrial ecosystems are few and far between." (Côte and Cohen-Rosenthal 1998; see also Behera et al. 2012). The centrality of inter-firm resource transactions is important to many authors' concepts of IS (e.g., Jensen et al. 2011). The focus on individual inter-firm relationships corresponds to the perspectives of participating firms, even when they happen to be part of a network of such relationships (Posch 2010). In addition, however, terms such as "synergies" are used for the individual inter-firm relationships (e.g., Mangan 1997; Jensen et al. 2011). Potential ontological confusion is compounded by the use of expressions such as "regional synergies" (van Beers et al. 2007) and "by-product synergy networks" (Cimren et al. 2011) as equivalents to industrial ecosystems. The individual resource flow relationship is the foundation for the definition of IS proposed herein; it offers a distinct concept and highlights the essential IS property of resource conservation potential.

1.3 (Re)Defining Industrial Symbiosis

The following definition of IS is proposed:

> Industrial symbiosis is a flow of underutilized resource(s) (comprising substances and/or objects and/or energy), from an entity which would otherwise discard them, to another entity which uses them as a substitute for new resources.

All work on IS is clear that IS does not refer to a "business as usual" transaction between bodies, i.e., the sale of a good for the purpose for which it was intended. A defining characteristic of IS is the idea of extracting additional value from a resource that might otherwise be disposed of (or dispersed to the atmosphere or as effluent to a waterway). The definition does not preclude a potential requirement for resource processing prior to use by the receiving entity (e.g., as described by Behera et al. 2012 at Ulsan in South Korea). However, the receiving entity is not primarily a waste disposal facility (Chertow 2007); IS is an alternative to disposal. The term "entity" is used (Chertow 2007) to avoid being prescriptive on the type(s) of organization that may be involved. Critically, some level of separation between entities is implied; system rather than organizational boundaries distinguish IS (and IE) from other environmental management approaches (Deutz 2009).

IS transactions can, as at Kalundborg, include substances in solid, liquid, or gaseous form and/or energy. I suggest that IS is defined to include all these types of "resources", as the principle of a transaction that saves resources is more fundamental to the phenomenon than the implications of differences between those resources. This is not to preclude the potential for differences between resource types to have implications for IS (c.f., van Beers et al. 2007; Ashton 2008), rather to confirm IS could involve any of them. "Underutilised" (Jensen et al. 2011) emphasizes that the resources have been consumed in some sense. A related key point is that the originating entity does not want the resource. Thus, IS transaction could (*in extremis*) include raw materials that have been ordered in excess by a manufacturer, and would otherwise be thrown away, but not "business as usual" sale of raw materials by an extractive firm. IS could also be a means for a manufacturer to extract some value from "business as usual" products for which there is no "business as usual" demand. Significantly, I use the word flow rather than exchange, to avoid any suggestion that there needs to be a two-way trade of materials between any two entities for IS to be observed. Notably, however, any flow has to be accommodated in the institutions of exchange that govern inter-firm relationships in general (Miller and Ford 2007). The return flow within an IS relationship could be material, but also financial, a service or potentially based on the assumption of a future return. IS flows do often literally flow in that they comprise "continuous-process waste streams" (Lyons 2007), but this is an observation that merits more investigation, not a necessary characteristic of IS.

1.4 Language and Policy Context

The proposed definition has deliberately avoided terms such as "waste", "by-product" and "residual" which are commonly used in IS to refer to the underutilized resources being transferred. Sometimes a distinction between these terms is clearly implied (e.g., Chertow and Ehrenfeld 2012), though not necessarily elucidated. In other work two or more of the terms are used interchangeably (e.g., Mangan 1997; Posch 2010). Readers therefore will inevitably be making their own interpretations according to what is common and/or policy usage (not necessarily the same thing) in their geographic context. Significantly, waste, by-product and residual all have distinct (but not mutually exclusive) dictionary definitions in the English language (Table 1.1). Equivalents do not necessarily exist in other languages.

Furthermore, these waste-related terms have specific policy connotations, which vary at scale of governance (e.g., UN usage differs from EU; Table 1.1), are likely to vary between political jurisdictions and are vulnerable to political redefinition over time. The UN usage, for example, implies that waste is a general term for something that is to be discarded; if it has value can be called a product (sic), or is otherwise a residual (Table 1.1). Conversely, the EU uses residual as a term for something that is waste if it has no assured route to reuse, or a by-product if it meets all of several conditions (Table 1.1). In addition, the same substance can at different times,

Table 1.1 Comparison of definitions of terms frequently used in discussions, descriptions and definitions of IS. Quotation marks indicate exact quotes; other expressions have been paraphrased for brevity

Term	Dictionary definition (Chambers Dictionary 2013)	European Union definition (EU 2008)	United Nations definition (UN 2012)
Waste	Something no longer needed in its present form which must be processed; or refuse, rubbish	"any substance or object which the holder discards or intends or is required to discard" (EU 2008, p. 9)	"Discarded materials no longer required by the owner or user" (UN 2012, p. 51)
By-product	"A secondary and often commercially important product that is formed at the same time as the main product during a chemical reaction or manufacturing process"	"A substance or object, resulting from a production process, the primary aim of which is not the production of that item" is a by-product if all the following conditions hold: • further use is certain, and legal • the substance is produced as "integral part of a production process," and • requires no preprocessing "beyond normal industrial practice" (EU 2008, p. 11)	Not applicable: the UN uses the word "product" in a context that approximates the use of by-product by the other sources: Waste with a positive value "is considered a product…rather than a residual" (UN 2012, p. 51), i.e., discarded material exchanged between economic units, for example scrap metal, for which the discarder receives payment
Residual	"Something that remains left over as a residue", e.g., left over after a process (e.g., evaporation) or when other parts have been taken away	'Not used. In UK 'residue' covers both waste and by-products (DEFRA 2012)'	"Flows of solid, liquid and gaseous materials, and energy that are discarded, discharged… through processes of production, consumption or accumulation" (UN 2012, p. 49)

depending on demand and supply, technological developments and social expectations, as well as regulatory requirements, be a challenge to dispose of, a lucrative by-product, or even become product in its own right (Desrochers 2009). These elements will vary geographically, too. The proposed definition of IS, therefore, does not discriminate between transactions according to their assumed ease of finding a receiver, though one might classify different types of IS according to such criteria.

Avoiding specific terms such as waste and by-product helps to define IS in a manner accessible to different languages and policy contexts. The proposed definition is a deliberate attempt to be broad. It should not exclude very much that currently exists under the banner of IS. But setting an inclusive definition is not to stifle debate. On the contrary, this should open a lively debate on the observed forms of IS, the circumstances that favor them and potential theorizations, without sensitivity as to what is or is not IS. However, selecting the resource based relationship as the essence of IS is consciously relegating other aspects from the Chertow (2000) and related definitions to the status of contingencies.

1.5 Contingent Characteristics of IS

Several characteristics of IS that are commonly included in definitions are excluded from the one proposed here on the grounds that they are not essential to the definition. Rather, as will be briefly discussed in this section, they are contingent characteristics that can take on a range of different forms or values, but should not be seen as determining whether or not a given phenomenon is IS.

The environmental benefits of IS are often assumed rather than measured (Boons et al. 2011), albeit the Kalundborg industrial ecosystem and others do have impressive resource conservation statistics (e.g., Jacobsen 2006; Behera et al. 2012). Chertow and Ehrenfeld (2012) contend that an IS transaction should be environmentally beneficial by definition, i.e., any non-environmentally sound underutilized resource transaction would not be deemed IS. However, this is problematic. Detailed and precise environmental impact assessments are difficult to undertake, even if assumptions can be made about what is and is not harmful to the environment. It does not seem desirable to make a property, which is likely unknown, and potentially unknowable, a defining characteristic of IS. This is not to say that IS should be promoted for its own sake, regardless of environmental side effects. Ideally the latter should be at least estimated on a case by case basis. An existing relationship found to be of doubtful environmental benefit, would bear closer investigation, but would not cease to be IS.

Economic benefits, or competitive advantage, are a widely cited aspect of IS (e.g., Chertow 2000; Cimren et al. 2011; Lombardi and Laybourn 2012). Economic savings not only can occur from IS, but are seen as critical to IS agreements (e.g., Jacobsen 2006). However, observing the coincidence of economic and environmental benefit has resulted in undue confidence that they are associated with each other. In the US context, initiatives to construct industrial ecosystems were far more often led by economic development than environmental protection agencies (Deutz and Gibbs 2008). Furthermore, emphasizing competitive advantages of IS distracts from the arguably more important point of the potential resource efficiencies. Defining IS by the essential characteristic of resource flow helps to clarify a likely more transferable lesson from Kalundborg than the vision of a collaborative ecosystem. Economic benefits, or disbenefits, are highly contingent, e.g., on the price of raw materials, the cost of waste disposal. If resource conservation were a sufficient social/political priority, IS could be a regulatory requirement for one or both entities involved, irrespective of the financial implications. These may seem rather radical and potentially unwise suggestions. However, the principle to establish is simply that IS is in essence a resource conservation rather than necessarily an economic efficiency tool. It is a political decision as to how far environmental protection should be limited to initiatives that may provide cost savings. Social benefits from IS are scarcely mentioned in the literature, and as with economic, are potential empirical features of a given IS, highly worthy of exploration, but not a defining characteristic.

In addition, the proposed definition says nothing about the geographic distance between the entities or networking. The local scale is often prioritized in IS projects (e.g., Wolf et al. 2007; Van Berkel et al. 2009), but it can be found in practice at scales up to and including global (Lyons 2007). Networking, and proximity may, possibly in combination, be important precursors to IS (Deutz and Gibbs 2008; Jensen et al. 2011). However, they are not defining characteristics, and neither necessary nor sufficient to engender IS. In keeping with Chertow's reference to "physical exchange", I am excluding inter-firm networking and knowledge transfer from the definition of IS (in contrast to Lombardi and Laybourn 2012); "industrial ecology" can be used for such nonphysical environmental cooperation between entities.

Thus several previously key aspects of IS are shown to be contingent properties, influenced by wide range of potential circumstances. The final section considers the implications of confining the definition of IS to the essential characteristics.

1.6 Conclusions: Changing the Assumptions of IS

This chapter has proposed a definition of industrial symbiosis which identifies the resource conservation relationships between two or more entities as the essential characteristic of the phenomenon. The resulting definition is therefore specific (there must be a physical flow of the kind specified), whilst encompassing a wide range of possibilities (e.g., in terms of geographic scale, number of participants, whether or not the flows are economically attractive to any or all participants). It is also designed to be transferable across language and policy contexts.

IS under the proposed definition becomes essentially an option for environmental protection. There is an underlying assumption that the environment should be protected, but not that IS is necessarily the most beneficial approach in any given circumstance. Removing the normative assumptions often surrounding IS (e.g., Boons and Roome 2001), may greatly ease communications between the different epistemologies contributing to IS research. Calls for social science contributions to what had been an engineering field (Vermeulen 2006), have been heeded (e.g., Doménech and Davies 2010). However, communications between the various epistemologies are limited. Clarifying the ontology of IS is at least an important first step to facilitate communication across the field.

In policy terms, IS as a resource efficiency measure offers potentially a strong tool for environmental protection, whereas it has proved a weak tool for economic development (Deutz and Gibbs 2008). The drivers for IS could be enhanced by recycled materials requirements for manufacturers, for example (the EU Producer Responsibility Regulations provide a gentle signal; Deutz 2009). However, the proposed definition by no means mandates a regulatory approach to IS, or precludes voluntary IS relationships where there happens to be financial benefit.

The proposed definition of IS is designed to be a prelude to much further research, whether primarily empirical or theoretical. Research is needed to identify, describe, classify, understand, measure/model the environmental impacts of, and ultimately to build theories to attempt to explain, all the many spatially and temporally contingent variants of IS and how stakeholders engage with them. This work would feed directly into policy considerations. What initiative would work best in a given circumstance? How would firms react? Opinions can of course differ on the appropriateness of IS under given circumstances, or its social/environmental value in general. Such debates are extremely healthy, but easier if not involving territorial disputes over what is and is not IS.

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