ULTIMATE

WATER SMART INDUSTRIAL SYMBIOSIS

Deliverable 4.3

Innovative solutions to governance challenges and innovation support for water-smart industrial symbiosis

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[1] PU = Public
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Executive Summary

Summary of Deliverable 4.3. Innovative solutions to governance challenges and innovation support for water-smart industrial symbiosis

This document, Deliverable 4.3, describes the research activities undertaken between August 2023 and June 2024 under WP4, Task 4.3 of the ULTIMATE project.

Industrial Symbiosis (IS) commonly refers to collaborative efforts among industries in the exchange of materials, energy, water, and by-products. It contributes to a circular economy by reconciling economic, environmental, and social objectives. Water-Smart Industrial Symbiosis (WSIS) specifically develops synergies with regard to smart water (re)use and resource extraction from wastewater. In practice, WSIS requires alignment of interests of different actors and involves the creation of new interdependencies across sectors.

Focussing on WSIS as a social environment, the report asks: How do cases of Water-Smart Industrial Symbiosis function in terms of their organizational structure and governance? The report analyses the social roles and relations between actors in existing IS settings, namely four ULTIMATE Case Studies (CSs). It details the actors that are involved in the CSs, their roles and responsibilities, and the relationships between them. In so doing, the report highlights lessons learnt from WSIS cases regarding the types of actors that are involved and how they relate to one another in the collaborations. It brings into view how the relationships between actors develop and how are they consolidated in agreements and contracts. Moreover, the report reflects on the question of how public authorities and industry strategists can foster fruitful social relations among actors that are engaged in WSIS or are willing to become involved.

The results in this report are based on 12 online interviews with a range of stakeholders in each CS. The CSs were selected to include diverse types of partnerships, namely: 1) a collaboration between industrial companies and an industrially-owned water-energy-telecom multi-utility in Spain; 2) a centrally coordinated IS consisting of a public-private partnership between industry and a municipal water utility in Italy; 3) an industrial company which contracts and provides IS services to a number of commercial companies in the UK; and 4) a centrally coordinated IS in collaboration with a municipal utility in Denmark.

For the analysis of the data, the report reviews the existing literature on IS governance, and places this literature in dialogue with insights from the social sciences into the maintenance and consolidation of social relations. The main analytical elements in this framework are: 1) the need for alignment of interests and the work that goes into this achievement; 2) the importance of trust in relationships within the Industrial Symbiosis Network (ISN); 3) the important role of coordinating actors in the ISN; and 4) the importance of proximity in resource exchanges and social relationships.

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This leads to the insights that external pressure enables WSIS, which can be leveraged by industries and authorities; that industrial symbiosis networks are diverse in structure and complexity; that local authorities can play an important role in WSIS, provided that they have adequate resources; and that utilities often manage social relations as well as water. The report provides 4 key governance propositions in line with these insights.

The report concludes that WSIS is in the interest of industries, as much as it is a public concern, and that the governance of, and conditions for successful WSIS are highly diverse. The governance structure of WSIS needs to be strongly aligned with the symbiotic exchange as a business model. Moreover, cases of WSIS demonstrate a commitment to personal and long-standing relationships between people and between organisations, and the consolidation of social relationships in ISNs relies heavily on the mediating role of coordinating actors.

The social dynamics and governance approaches identified in this report may contribute to the adoption and further development of WSIS systems in the ULTIMATE CSs and elsewhere and thus contribute to Europe's commitment to strengthen its water-smart society.

Disclaimer

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Abbreviations

CS	Case Study
IS	Industrial Symbiosis
ISN	Industrial Symbiosis Network
WSIS	Water-Smart Industrial Symbiosis

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1. Introduction

The term Industrial Symbiosis (IS) is commonly used as an umbrella to describe collaborative efforts among industries in the exchange of materials, energy, water, and by-products, thus contributing to a circular economy and reconciling economic, environmental, and social objectives (Albino et al. 2016; Chertow 2000; Faria et al. 2021). The overall goal of IS is to decouple economic growth from resource extraction and environmental pollution in the form of waste disposal and greenhouse gas emissions. Water-Smart Industrial Symbiosis (WSIS) specifically looks at synergies that can be developed with regard to smart water (re)use and resource extraction from wastewater.

In practice, separate industries typically identify underutilized resources and connect flows of materials, as well as services, infrastructure, and technologies, and seek partners that might be able to make use of these by-products and waste streams as resources in their own production processes. In this process, the requirements of different actors need to be aligned and new interdependencies are created. Such exchanges are, by definition, instances of social interaction.

The ULTIMATE project develops and tests technological innovations that will enhance the possibilities of water reuse and resource recovery in industrial processes. The aim of the project is to act as a catalyst for WSIS in which (waste)water is a reusable resource as well as a vector for energy and materials to be extracted, treated, stored and reused within a dynamic socio-economic and business-oriented industrial ecosystem.

Focussing on the latter ecosystem as a social environment, the report asks the following main research question: *How do cases of Water-Smart Industrial Symbiosis function in terms of their organizational structure and governance?*

The report answers the research question by analysing the social roles and relations between actors in existing IS settings, in the context of the ULTIMATE Case Studies (CSs). It does so by detailing the actors that are involved in the CSs, their roles and responsibilities, and the relationships between them.

In so doing, the report highlights lessons learnt from WSIS cases regarding the types of actors that are involved and how they relate to one another in the collaborations. How do the relationships between actors develop and how are they consolidated in agreements and contracts? Finally, the report will reflect on the question of how public authorities and industry strategists can foster fruitful social relations among actors that are engaged in WSIS or are willing to become involved.

This report builds on, and should be read in conjunction with deliverable D4.2, which describes governance barriers and opportunities for adoption and upscaling. For more information on IS policy, please refer to D4.2 as well as D5.2 (policy recommendations).

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The remaining chapters of this report discuss 2) the methodology of the study; 3) key insights into IS as a social setting; 4) an analysis of four ULTIMATE CSs; 5) a discussion of the results and governance propositions in terms of a) the influence of external pressure, b) the diversity of Industrial Symbiosis Network (ISN) structures, c) the role of local authorities, and d) the role of utilities. Finally, chapter 6) provides concluding remarks and a summary of governance propositions.

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2. Methodology

The results in this report are based on a series of semi-structured, online interviews with a range of actors involved in the various case studies. To enable a more in-depth analysis of the governance structure and social relationships within the cases, 4 out of 9 ULTIMATE cases were selected for this study. The CSs were selected to include a diverse set of cases in terms of the types of partnerships involved. The selected CSs are:

- CS1 - Tarragona, Spain, which consists of a collaboration between industrial companies and an industrially-owned water-energy-telecom multi-utility.
- CS3 - Rosignano, Italy, a centrally coordinated IS consisting of a public-private partnership between industry and a municipal water utility.
- CS7 - Tain, UK, an industrial company which contracts and provides IS services in relation to a number of commercial companies.
- CS9 - Kalundburg, Denmark, a centrally coordinated IS in collaboration with a municipal utility.

To recruit respondents, researchers consulted with the lead CS ULTIMATE Partner. In most cases, this has been a partner from the local utility, which, as this report argues, must be seen as a key actor in the functioning and governance of WSIS. In collaboration with this partner, relevant organizations and persons were identified. These include representatives from the utilities (4 interviews), industrial companies and business associations (3), IS consortia (2), government (1), as well as 2 interviews with knowledge institutes involved in the CS. The interviews per CS are listed in Table 1 with their corresponding organization type. The interviews are referenced in the text below by their respective number, e.g. [1.1], which corresponds with the numbers in Table 1. Written consent was obtained from all interview participants.

The interviews were held online using Microsoft Teams or similar software and the conversations were recorded after consent of the interviewee. In addition, notes were taken during the interview. The recordings were not transcribed but re-watched to fill in potential gaps in the researchers' notes. Except for one interview [1.3], all interviews were held in English. The main questions were sent to the interview participants in advance to allow for their preparation and foster their understanding of the purpose of the conversations. The reports were analysed using deductive, theoretical coding based on the conceptual framework outlined in Chapter 0; the same coding was applied to all interviews.

To complement the interviews, information was derived from organizations' annual reports, brochures, websites, and promotional materials. The results were validated by the CSs, who complemented the reported results if necessary. Due to the focus on specific CS contexts, the results outlined in this report are not meant to be read as comprehensive, but rather as indicative of the social dynamics in WSIS governance that may be of specific relevance to the activities of ULTIMATE partners in the CSs, as well as to regulators and industry associations interested in the feasibilities of WSIS.

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Table 1 Interviews per case study.

Case study	#	Interviewee organization	Organization type	ULTIMATE partner	Gender (F/M/X)	Lang
CS1 Tarragona, ES	1.1	Eurecat	Knowledge institute	YES	F	EN
	1.2	Aitasa	Utility	YES	M	EN
	1.3	AEQT	Business association	NO	F + F	ES
CS3 Rosignano, IT	3.1	Aretusa	IS consortium	YES	F + F	EN
	3.2	ASA	Utility	YES	M	EN
CS7 Tain, UK	7.1	Cranfield	Knowledge institute	YES	M	EN
	7.2	Scotch Whiskey Association	Business association	NO	F	EN
CS9 Kalundburg, DK	9.1	Kalundborg Forsyning	Utility	YES	F + M	EN
	9.2	Kalundborg Symbiose	IS consortium	NO	M	EN
	9.3	Kalundborg Municipality	Government	NO	F	EN
	9.4	Kalundborg Refinery	Industry	NO	M	EN
	9.5	Kalundborg Forsyning	Utility	YES	M	EN
Total	12 interviews			7 partners 5 others	8 women 7 men	5 EN 1 ES

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3. Social Relations in Water Smart Industrial Symbiosis Governance

This section elaborates on the idea that IS is a particular arena of social exchange. To do so, it reviews the existing literature on IS governance, and places this literature in dialogue with insights from the social sciences into the maintenance and consolidation of social relations.

IS, in its essence, revolves around the exchange of goods, materials, and finances. It typically brings together a diversity of industries that are not traditionally dependent on (or even related to) one another in supply chains, and in so doing creates new interdependencies across their diverse sectoral domains (e.g. Fraccascia et al. 2019; Lybæk et al 2021).

A common approach within IS studies to understanding this interdependence is by establishing resource flow charts (see, for example, Liu et al. 2023; Lybæk et al. 2021; Shi and Chertow 2017). By mapping resource input and output of different actors, potential avenues for resource recovery as well as costs and benefits can be established. Typically, such material exchanges are represented in charts that display the main actors and the volumes of material in- and output. Such overviews can help the participating actors to understand their potential symbiotic exchanges and can be instrumental in aligning interests. Several (online) tools for this type of exercise are available.[1] However, a network of material flows alone is not enough to establish durable industrial exchanges. Rather, this study departs from the basic social science insight that social relations require continuous maintenance and consolidation.

Hence, the remainder of this section looks into elements derived from the literature that underpin the establishment and maintenance of durable social relationships in IS, thus building the analytical framework of the analysis (Table 2). These analytical elements are: 1) the need for alignment of interests and the work that goes into this achievement; 2) the importance of trust in relationships within the ISN; 3) the important role of coordinating actors in the ISN; 4) the importance of proximity in resource exchanges and social relationships.

3.1. Alignment of interests

While IS is often seen as promoting circularity and long-term cultural change, it is also recognized that the exchanges that lie at its foundation must be economically viable to the actors involved (Albino et al. 2016; Faria et al. 2021). In the end, IS brings together for-profit companies, for whom their engagement in the IS must at least not jeopardize, but should ideally support, their business. Economic benefits of IS typically include

[1] See, for example, the IS Screening Tool and the Symbiosis Readiness Level (SRL) approach offered by the Kalundborg Symbiose (https://www.symbiosis.dk/en/inspiration/), and the Eco-Industrial Parks – Toolbox developed by the United Nations Industrial Development Organization (UNIDO) (https://hub.unido.org/eco-industrial-parks-tools).

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reduced costs of resource purchase, waste disposal and wastewater discharge, as well as potential revenues from the sale of waste as by-products. Logically, the governance of IS affects how firms create and capture value. In other words, IS affects their competitive advantage (Fraccascia et al. 2019).

Because of this economic requirement, alignment of incentives and needs of the participating actors is recognized as necessary for successful IS. In this context, alignment implies not only that the goals of individual companies are guaranteed (economic goals), but also that the goals of the IS are guaranteed (i.e. environmental goals) and that these goals are beneficial to all (win-win) (Albino et al. 2016). In this process of weighing costs and benefits, incentive misalignment may occur. This refers to a situation in which benefits of collaboration in the ISN are unevenly distributed, or when the common goal of the ISN (business + environment) does not align with the business interests of one or more of the participating actors (Albino et al. 2016). As a result, actors may choose not to engage with, or withdraw from an ISN.

This is to say that alignment might not be easy to achieve. To the contrary, alignment of interests requires work, and spans more than just costs and benefits. It also involves achieving a shared understanding of the relations, a willingness to disclose business interests, activities and objectives. **Therefore, the analysis of the case studies below looks into the work that goes into developing and maintaining alignment between actors** and the distribution of responsibilities in these activities.

Moreover, as institutional relations may be difficult to adjust once they have been established, one concern with IS is that increased interdependence between companies may develop path-dependencies, whereby the development of the IS system becomes governed by its own history (Albino et al. 2016). Therefore, when considering the governance of particular IS cases, it is important to understand the early developments of the exchange and its continuation into the present. A historical perspective may thus be helpful to understand how contemporary social relations have come about and why they have obtained their current forms, as well as to bring into view the scope of possible avenues for further development. **Therefore, in each of the case descriptions below, a brief section is dedicated to a description of its historical development.**

3.2. The importance of trust

The literature often mentions trust as an essential ingredient for successful IS relations (e.g. Albino et al. 2016; Chertow 2007; Faria et al. 2021; Fraccascia et al. 2019). Studies of cooperative relationships have shown that just because interests are aligned and cooperative relationships would be beneficial to each individual actor, this does not necessarily motivate actors to act accordingly (Binmore and Dasgupta, 1986, cited in Gambetta 1988: 216; Dunn 1988; Luhmann 1988). Trust between actors is often the missing ingredient.

Despite this recognized importance, very few studies have explicitly examined the development and conditions of trust in the context of IS. Some predictive models of IS systems include a quantitative parameter for trust, sometimes in binary form (trust

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existing or not existing) or on a scale from low (0) to medium (0.5) and high (1) (e.g. Albino et al. 2016). But while such models can be useful to predict the effects of increased trust on other aspects of the IS, they do not satisfy the need to understand how trust is established and maintained in ISNs.

To approach this gap, we now turn to the literature on trust from the social sciences, mainly anthropology, sociology, economics, and political science—disciplines that have traditionally sought to understand the relationships among and between people and institutions. This literature offers a number of insights that are relevant to the governance of IS.

To avoid misunderstandings, it is useful to begin with what trust is *not*. Trust is not necessarily a measure of social connectedness. Some communities are known to have emerged around relations of distrust, which can paradoxically form the basis of successful cooperation between actors (Gambetta 1988). Similarly, greater intimacy does not necessarily equal greater trust (Coates 2018). For instance, increased intimacy between actors inevitably involves an increased vulnerability to the violation of trust. Hence, intimacy (close personal relations) can in some cases be a source of distrust. These first, perhaps somewhat disenchanting insights, are relevant to the governance of IS, as they are helpful to understand how some transactional relations might be very productive, even if they might lack high levels of intimacy between actors. Moreover, they encourage a critical perspective on the assumption that the level of trust necessarily correlates with the level of cooperation between firms (Faria et al. 2021).

Generally, trust has to do with how people in different positions get along. To put this stronger: “the act of trusting appears to be a shared necessity for social life to be possible” (Coates 2018: 4). In this broad definition, trust is not simply a characteristic of transactional interactions between two actors, but rather emerges from a set of circumstances; a social configuration that allows actors to feel the confidence they need to proceed with the interaction (Pink 2021).

The establishment of this confidence is based on imagination, performance, and reciprocity (Coates 2018). Trust relies on a certain level of imagination with regard to the character of a relationship (in the sense that *I believe that I am trusted by you and that you are trustworthy*). Higher trust in this sense refers to an actor believing more confidently that they are in a mutually dependable relationship. Trust also needs to be made explicit (i.e. performed), in order to be recognizable by others (in the sense that *I let you know that I trust you and convince you to trust me*). And trust is reciprocal in the sense that actors must have a sense that its establishment is mutual, and that if trust is not reciprocated (or not performed as such), it can result in reduced trust. Hence, “it is necessary not only to trust others before acting cooperatively, but also to believe that one is trusted *by* others” (Gambetta 1988: 216, original italics).

It is thus important to communicate trust between actors, so as not only to trust others, but to let them know that they are trusted, and so that they are encouraged to develop and express their trust in return. Often, this performance is very subtle and rather tacitly embedded in interactions, conversations, and agreements. Moreover, how trust is performed differs greatly between cultural contexts and has to do with norms and

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values relevant to that particular social setting. This relates to the insight from IS studies that trust is related to information sharing, which can be a barrier in IS relations between private companies (Neves et al. 2019), as well as the insight that agreed upon information and communication strategies within the ISN can contribute to trust (Faria et al. 2021).

Trust is anticipatory, which means it enables actors to envision their interactions in a future tense, and act upon this image of the future accordingly. This is not the same as predictability. Where predictability can be produced by exerting power, i.e. imposing one's will (Hardy et al. 1998), "trust is concerned with how we feel as we move forward, and how we feel about what might be going to happen next" (Pink 2021: 4). As such, trusting involves an element of uncertainty, and thus becomes especially important in moments when things do not go as planned or expected (Coates 2018). At the same time, confidence in the future is vital for businesses, but they might not have the time, resources, or organizational structure available to invest in the personal relationships and reciprocal performance of trust. Instead, companies may resort to legal documents such as contracts to foster a sense of certainty and confidence.

However, contracts and other legal documents should not be purely conceived as replacing trusting relationships. To the contrary, trust is known to be affected by, and embedded in, materials and documents (Coates 2018; Jiménez 2011; Kaplonski 2016; Speirs 2016;). In other words, contracts do not substitute trust, but can provide actors with the necessary confidence to develop mutual trust, and trust can enhance the efficacy of contracts in IS (Albino et al. 2016).

While these characteristics of trust are useful to think with, studying trust in an empirical sense remains notoriously difficult, precisely because the concept itself remains evasive and is only sporadically made explicit or reflected upon by actors themselves (Broch-Due and Ystanes 2016). Hence, this report does not pretend to offer an extensive analysis of the intricate social dynamics and functioning of trust. Rather, to approximate the importance of trust in IS, when looking into the consolidation of relationships between actors in the cases below, **attention will be paid to the role of documents and contracts in consolidating the social relations between actors, and to subjective descriptions of the relationships between actors.** Moreover, mundane interactions between actors in an ISN will be considered in light of the performance of trust.

3.3. The importance of proximity

Many studies on IS consider geographic proximity to be an essential ingredient for successful collaborations, or even a key characteristic of IS (Chertow 2000; Fraccascia et al. 2019). The exchange of materials and flows between companies is facilitated by their vicinity to one another. Geographic proximity between actors in an ISN minimizes transportation, which reduces the need for investment in extensive infrastructures and transportation costs. In many existing cases of IS possible symbiotic exchanges have been identified on the basis of proximity (i.e. neighbouring companies exploring how they could benefit from one another's byproducts), while seeking symbiotic exchanges at a distance might come less naturally. Moreover, the proximity of resources,

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possibilities of discharge, and transportation costs are known to be important factors in determining business location, which has been suggested to make existing IS attractive to newly settling companies (Chertow 2000).

Technically, proximity is not a strict prerequisite for IS, which could be established at any distance as long as the exchange is economically and environmentally viable. The transportation costs and environmental impact should then be in balance with the benefits of the exchange. However, in the case of water-related collaborations (as in WSIS), the generally cheap price of water means that a business case for transporting water resources over longer distances is not likely to be successful.

These technological and financial considerations are complemented by the fact that geographic proximity might also foster social proximity (Fraccascia et al. 2019). Being physically close to one another facilitates information sharing, transparency and collaboration between actors. In this way proximity can be expected to have a positive effect on the social relationships between actors in an ISN, and may also facilitate trust (Albino et al. 2016). This relates to the insight that IS not only requires good social relationships between partners, but it can also be a way to create and improve relationships (Chertow 2000). The exchange of materials, flows, and by-products can bring the partners closer together and can form the basis of newly formed networks. The case studies below are all instances of geographically localized networks, and **the analysis pays attention their layout, infrastructure, and social networks.**

3.4. The role of coordinating actors

Resource dependence between firms requires coordination of relationships and exchanges. Coordination can take the form of a government that applies control mechanisms in a top-down manner, but many cases of self-organized ISNs have a formal or informal coordinating actor as well. Coordination does not necessarily need to take the form of a central agent that manages the entire system. Rather, in this study, we approach coordination as involving one or more actors that mediate in the ISN, i.e. that promote and coordinate social interactions and thereby facilitate the IS. Coordinating actors may be government agencies, utilities, R&D institutions, business associations, or dedicated consortium organizations (Faria et al. 2021), and coordination may in some ISNs be highly centralized while loosely defined in others (Fraccascia et al. 2019: 118). Coordinating actors might also be involved in identifying symbiotic opportunities, facilitating strategic discussions for the ISN, and managing external relations.

Given this study's focus on Water-Smart IS (WSIS), we pay particular attention to the role of utilities in the ISN. Utilities are often responsible for the management of water supply, treatment, and wastewater discharge. In this role, they have a central place in the ISN and connections with many IS partners as well as authorities. However, to what extent utilities might also play a coordinating role in terms of the management of social relationships is not clear in the literature.

Also, local authorities appear to be in a particular position vis-à-vis the ISN, either as part of the network or as a local partner and regulator. Studies that have focused on

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the role of municipalities in IS have demonstrated that municipalities can be especially important in overcoming barriers related to collaboration and networking. Local authorities can form a link between companies and the community by combining public and private values and goals. The importance of proximity in ISNs (see above) further puts a spotlight on the role of municipalities, which can act as key actors in overseeing the local territory and the variety of actors that operate within its boundaries, thereby "grounding IS to a local context" (Södergren and Palm 2021a: 3). Limitations of municipal involvement in IS may be a lack of capacity (although a municipally-owned utility may extend the public involvement in IS); and the limited geographical scope of municipal agencies, given that IS can (and often does) cross administrative boundaries (Södergren and Palm 2021a).

These insights raise the question to what extent municipalities and utilities may take the role of local facilitator, and how they might perform this role. **Hence, the analysis of the case studies below will pay particular attention to the formal and informal roles of local authorities and utilities.**

Table 2 Analytical framework and operationalization in the CSs.

Analytical elements	Aspects investigated in the CSs
Alignment of interests	Historical development and activities aimed at developing and maintaining alignment between actors.
Trust	The role of documents and contracts and subjective descriptions of relationships.
Proximity	Geographical layout, infrastructures, and social networks.
Coordinating actors	Formal and informal roles of consortia, local authorities and utilities.

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4. Governance characteristics of the case studies

This section describes the characteristics of the case studies in terms of their governance and social relations. Table 3 provides an overview of these characteristics for each of the selected case studies.

Table 3 Characteristics of the case studies.

	CS1 Tarragona, ES	CS3 Rosignano, IT	CS7 Tain, UK	CS9 Kalundburg, DK
Description of WSIS	A collaboration between industrial companies and an industry-owned utility.	A centrally coordinated public-private partnership between industry and a municipal utility.	An industrial company which contracts and provides IS services to other companies and agriculture.	A centrally coordinated collaboration among industries and a municipal utility.
Main actors in WSIS	30+ industrial companies, 1 utility, 1 business association.	1 industrial company, 1 utility, 1 IS consortium, 2 municipalities.	1 industrial company, agricultural partners.	17 industrial companies, 1 utility, 1 IS consortium, 1 municipality, external companies.
Utility	Private company, owned by industries.	Regionally operating, 60% owned by municipalities.	On-site at the industrial company.	Municipal utility that provides for community and industries.
Coordination and control	Formal in business association. Informal through utility.	Formal in IS consortium. Informal through utility.	Central control by the industrial company.	Formal in IS consortium. Informal through utility.
Main reuse purposes	Save water, Reduce discharge.	Save water.	Nutrient recovery, Reduce discharge.	Save water, Nutrient recovery, Reduce discharge.
External pressure	Water scarcity, Discharge limits.	Water scarcity.	Discharge limits.	Water scarcity, Discharge limits.

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Role of local authorities (municipal)	Limited involvement in ISN. Limited responsibility for environmental permits.	Indirect involvement in ISN as utility shareholders. Collaboration with industry (regional development). Responsible for permits and control.	No involvement in ISN. Partly responsible for permits (inland waters).	Formalized involvement in ISN as partner of consortium and shareholder of utility. Responsible for permits and control.

4.1. CS1 Petrochemical Complex of Tarragona, Spain

Table 4 Overview of interviews for CS1.

Interview	Organization	Organization type	Project partner	Gender
1.1	Eurecat	Knowledge institute	YES	F
1.2	Aitasa	Utility	YES	M
1.3	AEQT	Business association	NO	F + F

The petrochemical complex of Tarragona, also known as the Chemmed Cluster, is currently the largest chemical cluster in southern Europe. Over 30 petrochemical companies are located in two main industrial parks known as the North Polygon and the South Polygon, which amount to a total surface of about 1200 hectares near the Mediterranean coast and the Port of Tarragona. The complex produces plastics, fuel, and a range of chemical products. The petrochemical complex of Tarragona has been developing as a site of industrial symbiosis since the 1960s, when three companies that were based in the Tarragona area founded a shared utility, AITASA, to manage their water supply. About a decade later, more companies settled in the region and joined the board of AITASA.

Key drivers for the development of industrial water reuse in Tarragona have been a combination of demographic and economic developments and environmental constraints, as well as a clear push from the government. In the early 2000s, the prospect of population growth in Tarragona and further expansion of the industrial activities in the region meant that water shortages were expected to become increasingly problematic, exacerbated by a projected increase of meteorological droughts. Water reuse by the industry in particular was able to indirectly liberate essential freshwater resources for municipal use. With the prospect of increasing water shortages, the industry sought to secure its success in the future and invested in the development of reused water [1.3]. Around that time, the public administration of

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Catalunya, through the Catalan Water Agency (Agència Catalana de l'Aigua, ACA) also began to promote water reuse. Channelling EU funds, the administration partly funded the installation of the necessary infrastructures to enable municipal wastewater reuse in the cooling towers of the industries, which became operational in 2011.

The main actors involved in the IS in Tarragona are:

- **AITASA**. Founded by and for the industries as a shared water utility, AITASA remains fully owned by the industrial companies. Originally charged with the task of acquiring and managing groundwater resources in the area, its mandate has expanded to include other services as well. Currently, AITASA provides the industries with fit-for-use water, chlorinated and demineralized water, and steam. AITASA is also responsible for the joint management of industrial wastewater and has developed water reuse and resource recovery projects. AITASA also manages the administration, maintenance, operational control, and surveillance of the shared industrial pipeline infrastructures (the "Dixquimics" and "Repsol" racks) that connect the North and South polygons with one another and with the Port of Tarragona, as well as the joint marine sewage outlet. Initially, the volume of water each company could receive from AITASA was linked to its stock share in the company, at 1m^3 per hour per stock. This later changed to the company's average investment per joint project, which enables companies to decide whether or not to participate in particular water-related projects led by AITASA.
- **Chemical Business Association of Tarragona (AEQT).** The AEQT was established in 1977 and currently has 34 member companies (referred to as 'participants'), covering both the North and South industrial clusters, as well as a number of chemical companies in the broader region. The main aim of the AEQT is to foster the development of the Chemmed Cluster. It does so by representing the industries in lobby activities and in dialogue with government actors, and by attracting investors to the area. A key task of the AEQT is to offer a platform for exchange among the companies, for which the association is organized in working groups that cover safety, environment, social and labour issues, energy, territory and infrastructure, as well as commissions dedicated to specific technological innovations. Moreover, the AEQT organizes outreach and educational activities. It also coordinates relations with AITASA, the port of Tarragona and the industry's shared maintenance, security and monitoring service companies, which are represented in the independent Association of Service Companies of Tarragona (AEST).
- **Industries**. Over 30 industrial companies are located in the Chemmed Cluster, including a number of multinationals such as DOW Chemicals, Repsol, and Shell, as well as a range of national chemical producers. Many of the companies in the area are members of the AEQT and/or AITASA, though not all of them. Their participation mainly depends on their business interest in the water-related

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services of AITASA and the lobbying and joint development concerns of the AEQT.

- **Public Authorities.** Within Spain's federal state structure, the Autonomous Community of Catalonia has a wide-ranging capacity to dictate policy within its territory, and accordingly, can be seen as the main governmental reference for the regional development of IS (as opposed to the Spanish federal government). Through environmental policies, the Catalan government has been pushing for reduced water consumption in the region. Environmental policy is largely centralized at the Community level, and municipalities have relatively little mandate over or involvement in the industrial activities, except for issues such as noise and smell pollution in the immediate environs of a company. The government (whether federal, Catalan, provincial, or municipal) does not participate actively in the projects and commissions of the industrial organizations.

The basic starting point for water reuse in Tarragona is an exchange between the Catalan authorities (through the ACA), the industries (represented in the AEQT), and the industrial joint utility (AITASA). In this regard, the Tarragona case study presents an interesting perspective on how public and private sectors can collaborate in the development of WSIS. Namely, a public investment in infrastructure has enabled the industries to reuse municipal wastewater, in return for which the companies liberated their surface and groundwater rights for municipal use [1.2]. In this agreement, the industry's private utility (AITASA) has been designated to manage the treatment plants and distribution networks. In this capacity, AITASA manages agreements with the authorities regarding the requirements about quality and quantity of discharge [1.2].

However, as one interviewee pointed out, the relationship between the companies and the administration could be improved [1.2]. Particularly, the industries notice that the pace at which the utilities and industries seek to innovate does not match the (slower) timeframes of the public authorities from which approval for projects is required. In new projects related to water reuse initiated by the industry, governmental participation has been low, apart from meetings to discuss adaptation of discharge policies that currently stand in the way of the implementation of water reuse (for which limitations of concentrations and volumes would need to be adapted, see deliverable D4.2). Moreover, the industrial actors that were interviewed complained that new policy restrictions on industrial water use have not taken into account the existing water reuse scheme in Tarragona. Since restrictions and measures to reduce water consumption are directed at, and considered a responsibility of individual companies, this policy appears to overlook their communal efforts in developing WSIS and, it could be argued, would discourage communal reuse initiatives [1.3].

The relationship between AEQT and AITASA offers another interesting perspective on how the IS in Tarragona functions. AEQT and AITASA are closely related, and both are owned by the local industrial companies (which partly overlap). Yet, they are independent from one another and neither has executive power over the other. A significant difference between both organizations is that AITASA is primarily concerned

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with the development and execution of (water-related) projects based on shared interests of the associated companies, while the AEQT does not develop projects but functions as a platform for discussion of topics that are of concern to the companies, for which it has a number of dedicated committees. As our interviewees indicated [1.3], this division of roles and responsibilities works very well. Where possible, the two organisations collaborate, as for example when the director of AITASA takes part in the environmental committee of AEQT. The integration of each organisation in the activities of the other has enabled AEQT and AITASA to jointly take up the implicit task of simplifying inter-company and public-private relations and bringing disperse objectives together.

While AITASA is officially charged with the management of (waste)water streams and treatment plants, it also plays an important role in consolidating the collaborations among the industries. For the projects that are decided upon by the companies' directors in the executive board, AITASA is charged with the technical development and establishment of project agreements. Each project is substantiated by two main documents: 1) A main agreement (*acuerdo*), signed by the representative of the participating companies, which details the company's shares of investment; and 2), a project regulation (*reglamento*), which stipulates how the project will operate in terms of payments, costs and responsibilities, and risks. This document also details contingency plans and protocols for potential irregularities in the project's execution, to prevent ad-hoc decision-making and disagreements between actors along the way. The regulation functions as a policy document for the project. In this way, AITASA's project documents can be seen as a way to formalize the symbiotic relationships between companies, and in a detailed manner. In the words of one interviewee, "everything is defined, documented, and established by notary" [1.3].

Behind the scenes, moreover, this shows the consolidating work performed by the utility, consisting of a process of negotiations and the management of social relations. "We spend a lot of energy to develop these rules," one AITASA representative told us, adding that "this is how we align the companies. Always we have to work to align all of them in the same direction. This is our work in AITASA" [1.2]. These activities are a clear example of the facilitating role of utilities in WSIS that goes beyond water management and includes a formal and informal mandate beyond water management. The utility is at least partly responsible for relations management and for fostering collaborations in the ISN; it stimulates dialogue between the industries with regard to water and wastewater-related issues. At the same time, the utility needs to keep in mind its own interests and requirements, for example in terms of the volumes and types of water it is able to manage. Therefore, such requirements, as well as AITASA's authority to refuse unfit company effluents, are often also included in project regulation documents [1.2].

Hence, a key advantage of the WSIS system in Tarragona is that the utility serves as a single mediation point between the industry and the authorities. This allows the petrochemical companies to focus on their core business, outsourcing water treatment and distribution tasks. Still, they maintain control, by outsourcing this task to their common utility. By centralizing its water intake and outlet, the industry can act quickly and efficiently in response to changing rules and regulations. Trust is ensured through the organizational structure of the symbiosis, as each company has stakes in the utility,

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the projects, and their success, and by the annotation of project details and agreements between the actors. Moreover, AITASA is a not-for-profit company, which secures its objective to develop projects in the best way possible for the companies and administrations. At the same time, this also means that the utility does not have the power to make strategic decisions independent from the industry.

4.2. CS3 Consorzio Aretusa, Rosignano, Italy

Table 5 Overview of interviews for CS3

Interview	Organization	Organization type	Project partner	Gender
3.1	Aretusa	IS consortium	YES	F + F
3.2	ASA	Utility	YES	M

The development of water reuse started in the 1990s, when the first contract was established between a regionally operating water utility (ASA) and Solvay, with the aim to explore the possibilities of reusing municipal wastewater for Solvay's cooling towers. Solvay's use of treated wastewater meant that the company needed to extract less groundwater from its wells, which was made available to ASA for the production of drinking water. In 2001,a consortium (Consorzio Aretusa) was established, which brings together the industry and the utility in a formalized manner.

The key external driver for treatment of municipal wastewater for industrial use has been water scarcity, which has become an increasingly pressing issue in the wider region, exacerbated by the anomalous distribution of precipitation combined with increasing temperatures. As our interlocutor from the water utility commented, "already in the 2000s it was clear that water for agriculture and industry would compete with drinking water" [3.2]. Hence, the need to reduce pressure on drinking water supply was a direct reason to develop alternative solutions. An additional driver for the industry has been that reused water is cheaper that groundwater. While the difference in price would in itself not be sufficient for a quick return on investment, this is a factor that favours the transition to reused water.

The main actors in the Rosignano CS are:

- **ASA.** ASA is the utility that provides drinking water to municipalities in the Livorno region, including Rosignano and Cecina. It is 60% owned by public authorities and 40% owned by a private company. In addition to providing drinking water, ASA is responsible for the treatment of municipal wastewater of Rosignano and Cecina and the production of industrial water, for which it rents the treatment plant from Aretusa. ASA is also president and major shareholder of the Aretusa consortium.
- **Solvay Chimica Italia**. Solvay is a multinational, private company that produces a wide range of chemical products for the food, automotive, construction, and

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health industries, among others. It has a large plant based in Rosignano for the production of soda ash, which is used for the production of glass, detergent and other chemical purposes. Solvay uses the post-treated wastewater from Rosignano and Cecina mainly in its cooling towers. The reduction of groundwater use by Solvay allows for a parallel construction in which ASA is enabled to withdraw groundwater from Solvay's wells for the production of drinking water.

- **Consorzio Aretusa.** Aretusa is the consortium of ASA and Solvay, and was established as a non-profit organization to facilitate the investments needed for water reuse. Its main purpose has been to obtain a bank loan for the financing and construction of a new wastewater post-treatment plant, which allowed for the further treatment of effluents for industrial and agricultural purposes. Aretusa continues to own the wastewater treatment plant, the management and maintenance of which is entrusted to ASA through a rent agreement. The rent paid by ASA has been calculated to cover the costs of the investment loan. Aretusa is 45% owned by ASA, 10% by Solvay, and 45% by its technology provider.
- **Rosignano and Cecina**. Rosignano and Cecina are two municipalities in the vicinity of Solvay's soda ash production facilities. The municipalities are not members of Aretusa, nor are they active partners in the development of the industrial symbiosis. However, both municipalities have close ties with ASA (partly owned by the municipalities). The municipalities also coordinate issues regarding urban and industrial development and environmental planning with Solvay.

To a large extent, the relationships between these actors are transactional. Simply put, ASA pays for the water it withdraws from Solvay's groundwater wells; the citizens of Rosignano and Cecina pay for their use of ASA's drinking water; Solvay pays ASA for the water it gets from the reclamation plant; and ASA pays Aretusa to rent and operate the reclamation plant; which in turn enables Aretusa to pay off its bank loan. These relationships are consolidated in a series of contracts and agreements. This includes a contract between ASA and Solvay, which stipulates the estimated volumes that are transferred to Solvay, the costs per cubic meter to keep the investment in balance, and the expected quality parameters of the industrial water.

However, perhaps the main mechanism for consolidating the relationship between partners is Aretusa itself. Both ASA and Solvay own shares in this consortium and are (literally) invested in its success, and Aretusa functions as a coordinating actor as well as a forum of exchange between ASA and Solvay. As pointed out by our interviewees [3.1; 3.2], there is a shared interest in the activities contributing to the WSIS, and there is room for constant dialogue between the partners for further development and improvement in the system. In this way, Aretusa materializes the shared interest of the different actors in realizing water reuse in a manner that is beneficial to everyone involved. To nuance this, it should be noted that Solvay has a minor share in Aretusa, which means the financial stakes of Aretusa's success are relatively low for the

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industrial company, while the stakes for ASA are potentially much higher. This imbalance appears to have been mitigated by Solvay's reliance on ASA for the provision of industrial water, establishing a relationship of interdependence.

The results of the investment and the functioning of the Aretusa wastewater treatment plant are considered by all actors to be very positive. Hence, in addition to contractual agreements, the relationships between the actors is characterized by some level of trust that has been established over the course of two decades in which the WSIS has been operative. As one interviewee from Aretusa put it: "trust is the result of years of relationship between the two companies and is maintained thanks to the excellent results obtained over the years" [3.1].

A key advantage of the governance constellation of this case appears to be its simplicity in terms of business relations. Effectively, the entire WSIS functions as a single business model with multiple actors, in which each actor takes responsibility for their share of the process, and in which the internal relations are consolidated through a shared understanding of the system and a set of clearly defined contracts.

4.3. CS7 Glenmorangie whisky distillery, Tain, United Kingdom

Table 6 Overview of interviews for CS7

Interview	Organization	Organization type	Project partner	Gender
7.1	Cranfield	Knowledge institute	YES	M
7.2	Scotch Whisky Association	Business association	NO	F

This IS revolves around the Glenmorangie whisky distillery in Tain, Scotland. Established in 1843, Glenmorangie produces single malt Scotch whisky for consumption in the UK and export. The distillery has an on-site anaerobic digestion plant (AD) which extracts organic load from the wastewater and produces biogas. The biogas is used internally for heating, while the sludge is used as fertilizer by local farmers. In addition to this, the ULTIMATE project has been exploring the possibilities of recovering additional nutrients (ammonia and phosphorus) from distillery wastewater, RO treatment of wastewater for internal reuse, and heat recovery from treated wastewater.

The Glenmorangie distillery has established a strong profile in environmental and social sustainability, with several internal and external projects. For example, the company has an on-site material recycling policy, is a partner in the Dornoch Environmental Enhancement Project (DEEP) to restore oyster reefs in the bay, and supports giraffe (the company's emblem) conservation projects. Hence, reuse fits well within the company's sustainability ambitions.

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The main benefit for Glenmorangie is the biogas production which saves energy costs. Additionally, environmental legislation limits the possibility to dispose effluent directly to the sea, which means that the company also benefits from farmers using its sludge, as this reduces the company's waste disposal costs. Freshwater scarcity, on the other hand, is not a key driver in this CS, which limits the business interest in additional internal water reuse. Another limiting factor for distilleries to adopt on-site reuse is the associated increase in the company's CO_2 emissions. Hence, many distilleries may prefer to have waste materials handled by other companies.

Besides **The Glenmorangie Company** the main actors in this ISN are:

- **Alpheus.** Glenmorangie distillery has outsourced the maintenance and operation of its on-site utility to Alpheus, a company that specializes in wastewater treatment. Alpheus is involved in operational decision-making and contracted to meet Glenmorangie's KPI's of effluents and biogas.
- **ROCK Highland.** ROCK Highland is a company created to deal with industrial waste and use it for agricultural purposes. Under agreement between Glenmorangie and ROCK Highland, farmers collect sludge from the distillery's AD several times a day, and distribute this directly onto their fields (mainly Barley used for whisky production and grasslands).

At the core of this IS, then, is a fairly simple agreement between the distillery and farmers. Farmers collect the sludge from Glenmorangie's production site, for which they do not have to pay. In this way, the distillery benefits from reduced waste disposal costs and the farmers benefit from reduced fertilizer expenses. Similar agreements between distillers and farmers are common in Scotland, although they take different forms from case to case. Smaller distilleries may have agreements with single farmers, which has historically been consolidated by only very basic paperwork, if any. In other cases, farmers collectively engage in the collaborations through contractors that operate across several farms, or between multiple distilleries, as in this CS. Then, a number of larger Anaerobic Digestion companies operate in the region, collecting waste from distilleries and other industries, processing it, and selling the digestate under commercial agreements. Considering that farmer demand for fertilizers can vary throughout the year, some distilleries opt for more centralized digestate collection.

To further understand the symbiotic relationship between distillers and farmers, it is important to note that "distilleries are quite heavily embedded in their local communities" [7.2]. Distillers are not only employers in local communities, many distillers also have established long-standing relationships with farmer who pick up organic by-products and use it as cattle feed, or, as in the case of Glenmorangie, collect sludge to distribute on their fields. Seen in a broader industry-perspective, proximity tends to be important to distillers, who may be localized in isolated rural areas and the Scottish islands. The transportation of waste materials is a key issue, which strengthens commitment to local solutions. The commercial interest in by-products of the whisky industry has increased over the past years, as other value-add end uses have been identified beyond farming [7.2]. However, when developing new symbiotic

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opportunities it is recognised that distillers may choose not to disturb existing and well-established local relationships.

Authorities have been involved through regulation and monitoring of water intake and discharge. Moreover, AD plants are regulated within existing site-wide licenses and will in the next years be subject to stricter controls as proposed by the Scottish Environment Protection Agency (SEPA). The SEPA has also been involved in assessing impact of land-spread of sludges. In this way, public authorities are in an important position to develop drivers for the industry to develop internal reuse and symbiotic relationships. However, government agencies are not directly involved as partners in the ISN.

The symbiotic relationships in this CS thus revolve around a main industrial company that has established external ties for the use of its by-products. The operational aspects of this have been outsourced to other companies, but ownership and decision-making capacity, as well as financing responsibilities, remain with the main company. Hence, the company has few obligations towards other actors in the ISN. This culminates in a fairly accessible, low-threshold type of IS that is firmly rooted in local relationships, and that is easily manageable by the actors involved.
A downside if this can be that the IS is strongly dependent on the ambitions and operations of a single actor. The sustainability ambitions and innovative approach of the main company can push further development of reuse, but changes in strategy might also push the company to focus on its core business and slow down the pace of IS-related innovation.

4.4. CS9 Kalundborg Industrial Symbiosis Complex, Kalundborg, Denmark

Table 7 Overview of interviews for CS9

Interview	Organization	Organization type	Project partner	Gender
9.1	Kalundborg Utility	Utility	YES	F + M
9.2	Kalundborg Symbiose	IS consortium	NO	M
9.3	Kalundborg Municipality	Government	NO	F
9.4	Kalundborg Refinery	Industry	NO	M
9.5	Kalundborg Utility	Utility	YES	M

What is now known as the Kalundborg industrial symbiosis began in the early 1960s and gradually developed as a collaboration between private companies, and was

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recognised as an symbiosis in 1972. The symbiosis has grown steadily and currently consists of 17 companies of various sizes. In response to increasing international attention, a visitor centre was established in 1996. This later became the Kalundborg Symbiose Association and was embedded in the municipality of Kalundborg. In 2020, the association was reorganized as a private entity to allow more room for its consulting activities; the municipality remained involved as a prominent member of the association.

While water streams are an important aspect of the IS, exchanges of excess energy and materials are also significantly involved. In terms of water, the key driver for industrial water reuse is the pressure on local water resources, namely groundwater and lake Tissø, as well as the industries' wishes to expand existing factories and attract new factories. The total permitted consumption of surface water from the lake is limited in order to protect its ecology and its future viability as a water resource. This means that the industrial cluster in Kalundborg has been forced to look for alternative sources. As the industry has grown over the years, so has its water demand, which, among other solutions, is being met through innovative reuse and exchange. The awareness of this need to exchange resources is shared by all the partners. "If we would not share the water, we would all not have enough" said one industry representative [9.4].

In addition to this external driver, an added benefit (internal driver) for participation in the symbiosis is the advanced collaboration between companies. The symbiosis has in itself become a value proposition, as it promises new companies a strong network of partners, a collective political voice, and reduced costs of waste(water) disposal. Moreover, as our interviewees indicated, the Kalundborg Symbiose is an internationally known brand that is positively regarded by customers and investors. In other words, being associated with the symbiosis has direct and indirect value to companies.

The main actors in the Kalundborg IS are:

- **Kalundborg Symbiose.** The Symbiose is the membership association and administrative centre that coordinates and facilitates the IS. It currently has 17 member organizations including the municipality of Kalundborg, and the utility (Kalundborg Forsyning) and the industries. The members pay an annual fee depending on the size of the company. The core of the Symbiose consists of the directors' board, in which the CEOs of the member organizations meet and define the agenda for the association. In addition, it includes an advisory board which consists mainly of technical experts of the member organizations. Specialist working groups have been established to address specific issues or explore newly emerging concerns and opportunities. Moreover, the Symbiose organizes international partnerships, outreach, and education programs. As such, the Symbiose functions as a forum for exchange, an innovation platform, and as an advocate of the industries in the region.
- **Kalundborg Utility.** Kalundborg Utility is the water utility of Kalundborg, which provides drinking water to citizens as well as district heating, sewage water

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treatment, and it supplies surface water to some of the industrial companies. The utility also manages a large share of the pipelines that have been constructed between companies to enable the exchange of excess resources. The utility is fully owned by Kalundborg Municipality and treats and disposes the wastewater for the industries. For this, it monitors the waste streams and manages discharge permits. Moreover, it addresses environmental concerns such as brine disposal and micropollutants. The utility does not control all the streams in the symbiosis. Rather, if one company can use stream from another, they can make agreements between them without interference from the utility.

- **Industries.** 17 industrial partners are members of the Kalundborg Symbiose association, including large industries such as the Kalundborg Refinery, Novonesis and the Novo Nordisk pharmaceutical company, as well as a number of smaller companies.
- **Kalundborg Municipality.** The municipality of Kalundborg is represented in the directors' board of the Symbiose, which means it as a prominent voice in the association. It takes an active, mediating role in facilitating IS, seeking to create a favourable environment for companies to settle and invest in the area. The municipality is responsible for the provision of waste(water) disposal permits, and in this role often also has a seat at the table in discussions between the wastewater treatment plant (Kalundborg Utility) and companies.

While the Kalundborg IS is highly organized and its activities extend beyond materials exchange, its origins lie in a series of bilateral agreements between companies, which continues to exist in its current structure. The main premise for WSIS solutions continues to be the mutual, mostly bilateral, business benefits that can be developed. For example, our contact person at the Kalundborg Refinery reflected on the logic behind reuse exchanges: "If we were not to take that water from [the other company], then they would need a new permit to discharge it. So they benefit from us taking the water. In turn, we buy the water cheaper from them than we could have produced it ourselves" [9.4].

The main coordinator of the IS, Kalundborg Symbiose, was established relatively recently. It has a neutral, facilitating role within the community of public and private partners, while the actual agreements about the nature and volumes of exchange are established between the companies. The fee that members pay for their membership of the Symbiose is also separated from the fees that companies pay to one another for the exchange of materials and streams. Hence, the formal role for the Symbiose is to facilitate processes and dialogues. The Symbiose provides the partners in the ISN with a platform to discuss upcoming topics, such as potential co-investment opportunities, and to identify new opportunities for collaboration and exchange.

The Symbiose also serves as a shared programme to organize outreach and communication activities. In this way it enables external relations with the wider community, maintains relationships with external stakeholders such as farmers, and organizes educational activities and site visits. The Symbiose also represents the industries through lobbying. In this regard, it seeks to align the interests of the

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companies it represents and seeks to “speak with a common voice” [9.2] to policy makers. In this capacity, the Symbiose has for example commented on new Danish legislation for water reuse (see Deliverable D4.2 for more information).

There has been some discussion as to what should be the limits of this platform function. For example, the municipality, as ISN partner, has brought the topics of corporate social responsibility and environmental projects to the table, while other participants have argued that the symbiosis should remain focused on water and materials reuse, so as not to “dilute its purpose” [9.2, 9.4]. This shows that the involvement of the municipality in the ISN brings in different types of social and environmental concerns, which the companies themselves might not have prioritized.

The municipality has a particularly influential role in this IS, and has been a driving factor in the development of the Symbiose association. As one interviewee put it, “The municipality basically organizes the whole thing” [9.4]. The municipality also takes an active role in identifying potential symbiotic exchanges between companies, and introduces newly arriving businesses to the Symbiose [9.3]. This extended involvement of the local authorities is appreciated by the companies, who tend to accept municipal proposals as part of their good relationships with the municipality [9.2].

In addition to the Symbiose and the municipality, the utility (Kalundborg Utility) has an informal task of managing some aspects of the relationships between companies. As mentioned above, companies in the Kalundborg IS often make bilateral agreements with one another if they can use each others’ resources. The utility does not control these bilateral streams nor the agreements that are made. Also exchanges of dry matter and steam are not managed by the utility [9.1]. Still, the utility has an important task of overseeing water supply and demand, as well as the overall wastewater treatment and discharge, and central heating and cooling.

While companies acquire permits on an individual basis, the utility also keeps in check the implications of new permits and industrial developments for the IS and the wider community as a whole [9.5]. The utility has limited capacity, defined by legislation, for wastewater treatment, both in terms of volumes and the types of substances it is able to process. Therefore, some industries may have to pretreat their wastewater to comply with their permits and their agreements with the utility [9.1]. In a way, the limited capacity of the utility functions as an ‘external’ pressure (in addition to the limited availability of freshwater) for industries to reconsider their use and discharge of water. Hence, the communal approach taken in Kalundborg is to a significant extent brought into view by the utility itself.

In principle, all actors within the IS have equal say in the Symbiose and before the municipality and utility. However, the companies vary significantly in size, and therefore in financial means, resource use, and wastewater discharge. Novo Nordisk particularly stands out as the world’s largest insulin manufacturing plant, which employs 4500 people and is set to expand further in the next years. Another large company is the Kalundborg Refinery, which is Denmark's largest oil refinery, with 400 employees. In addition to these large companies, a number of small and medium-sized enterprises (SMEs) participate in the symbiosis.

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Having big companies like Novo Nordisk and the Refinery on board has been very important to the Symbiose, as they have taken the lead in developing symbiotic exchanges and thus have been a driving force in the IS as a whole [9.2]. Also to the utility, the difference in size between companies matters, as about 70% of its capacity to process wastewater is taken up by a single actor, while the remaining 30% is allocated to all other companies and the city [9.1].

At the same time, the participation of smaller companies is valued, both as an extension of the ISN, and as a particular type of input in the Symbiose as a forum. The Symbiose recognizes that SMEs might not have the same concerns as large companies regarding resource needs or waste disposal, but “we consider them as equal partnerships, not in terms of resources, but in terms of input” [9.2]. The larger companies are able to put in more resources in the development of IS projects, while the network as a whole (including the larger actors) benefits from the presence of diverse companies that can all contribute.

Moreover, equal treatment of all partners participating in the Symbiose, is considered important to enable constructive dialogue between the partners [9.2]. This is further enhanced by regular meetings between the companies in the Symbiose: the board and advisory board meet on a monthly basis, and domain experts meet in topical discussion groups. The building of social relations in the ISN was emphasized by all of our interviewees. One interviewee said: “to a great extent the Symbiose is a way to meet and establish trustful relations, so you have a face and know who to call. You develop a feeling of who could be interesting in the collaboration” [9.4]; Another said: “don’t underestimate the importance of knowing each other, having good relations” [9.1]. Our interviewees also mentioned that due to these close relationships between companies and their representatives, the level of social control between companies is high, which strengthens the ISN, while the existence of bilateral agreements allows for sufficient flexibility [9.1, 9.4].

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5. Discussion

5.1. External pressure enables WSIS

The results of this study suggest that WSIS might be virtually impossible without external pressure. Environmental concerns (water scarcity, pollution) is known to stimulate IS and incentives to reduce waste and use less resources can be expected to further drive IS development (Faria et al. 2021). Given the primacy of external pressure in the analysed CSs, this report proposes that external pressure can be understood as a primary driver for the development of WSIS.

External pressure can take various forms, the most important for WSIS being water scarcity, policy restrictions, and market pressure. Water (and resource) scarcity occurs when water demand exceeds supply, or when the needs of different industrial and public actors conflict. Water is generally cheap, and the return on investment for reuse is therefore very low. What follows logically is that companies are likely to make such an investment only when the limited availability of water poses a challenge to their business, when the company is exceptionally concerned with its environmental footprint, or when water reuse can be combined with other benefits such as reducing energy consumption. Prime examples of this are the Danish Kalundborg case (CS9), in which industries developed symbiotic relations in response to limited available water, and the Italian Rosignano case (CS3), in which conflicting water needs of the community and the industry were addressed through reuse of municipal wastewater. Policy restrictions typically take the form of discharge limitations or high discharge costs, which may stimulate companies to look for alternative uses of their waste and by-products, either through internal reuse or by establishing symbiotic relationships with external partners in the area (CS7). Market pressure to enhance sustainability in the production chain, to conform to environmental certification, or to increase transparency can stimulate companies to adjust their internal strategies and to include environmental impact (including water use and discharge) as Key Performance Indicators (KPIs).

The case studies further show that, in response to external pressure, industries are able to develop creative mechanisms for water reuse and resource recovery. This further demonstrates that WSIS can be in the interest of industries, as much as it is a public concern, and that public investment is not necessarily required to develop a well-functioning symbiosis, although it may help establishing it in early stages. These perspectives raise the question to what extent the development of a circular economy is a public responsibility, and how and to what extent governments can rely on and foster the innovative capacity of the industries themselves. The Rosignano case (CS3) is a clear example of a ‘bottom-up’ WSIS that functions as a coherent business plan with multiple actors, in which the coordinating actor (Aretusa) plays a facilitating role and ensures alignment of interests. The petrochemical complex in Tarragona (CS1), on the other hand, is an example of a case in which a significant public investment of EU and Catalan funds was made to enable industrial water reuse, which resonated with the foresight among the industries that they would need to invest in alternative water sources in order to secure their existence. The case of Tarragona also underscores the importance of recognizing communal water reuse as one expression

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of the responsibility of individual companies. Focusing on individual companies and not recognizing shared efforts might discourage such initiatives between companies. This leads to Governance Proposition 1:

GOVERNANCE PROPOSITION 1:

a) Public authorities should recognize and foster optimal conditions for industries, utilities and authorities to consider WSIS favourably.

b) Public authorities should incorporate WSIS into sustainability performance audits and evaluations to ensure comprehensive assessment.

Industries are more likely to consider WSIS opportunities favourably in the case of increased external pressure that pushes them to look for alternative resources and uses for waste streams. Public authorities should be aware of different types of external environmental pressures, such as environmental conditions (e.g. water scarcity), market dynamics (e.g. sustainability requirements) and regulatory mechanisms (e.g. environmental legislation and permits). By using market and regulatory mechanisms, authorities can leverage the environmental pressure and encourage industries to develop IS systems that benefit the business, community, and environment.

Environmental audit and evaluation approaches should take the impact of IS systems into account and not focus solely on the impact of individual companies. A system´s view on the efficacy of collaborations for water reuse is required.

See ULTIMATE deliverable D4.2 for a more extensive analysis of policy barriers for WSIS.

5.2. Industrial symbiosis networks are diverse in structure and complexity

The case studies analysed in this report are each organised in quite different ways. CS1 (Spain) and CS9 (Denmark) both consist of large industrial sites with multiple companies involved in WSIS. CS3 (Italy) en CS7 (UK), on the other hand, both consist of a single industrial partner that engages in external relations for reuse purposes. This number and types of organisations involved in the ISN evidently influence the governance structures, the need for coordination, and the power relations between actors. Moreover, while this report has focused on the internal organization of the WSIS, it should be noted that ISNs often involve actors from other sectors, notably agriculture, fisheries, and forestry, as is the case in CS7 and CS9 where the by-products from industrial producers are used by agricultural companies (see also Neves et al. 2019).

These various governance structures each have their advantages and disadvantages. Key advantages of the smaller consortia are the direct relations between the actors and the relative simplicity of agreements and exchanges. A disadvantage is that the continuation and effectiveness of the WSIS is largely dependent on the agenda (i.e. willingness and ability) of a single industrial actor, and thus susceptible to change at the management level. An advantage of the larger type of collaboration is the greater

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potential to identify multiple possibilities for exchange, to combine treatment and distribution efforts, and to co-invest in the necessary infrastructures. The larger consortia also appear less prone to short and medium-term fluctuations, as they are less immediately affected by changes in an individual company's participation. A disadvantage of larger consortia is that they might be more susceptible to path-dependencies, as changing the structure of the collaborations between many different actors can be a challenge.

A popular definition of IS includes the requirement that "at least three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis" (Chertow 2007: 12). This definition sets more complex ISNs apart from more simple ones. By this definition, CS3 and CS7 in this study would not count as instances of IS because fewer than three actors or fewer than two resources are involved. In this way, defining IS on the basis of the number of actors could potentially exclude many viable and promising instances of industrial, inter-company, and cross-sectoral water and resource reuse. Indeed, this analysis underscores that a single industrial actor with an in-house utility that distributes its waste or by-products (CS7) can in its local context be just as impactful as a large industrial park elsewhere. Hence, stimulating circularity in industrial context should preferably not be limited to a minimum of actors and should instead be open to the wide variety of possibilities and networks that can emerge in different places.

Many definitions of IS can be found in the literature that omit such requirements. Most of these focus on the exchange as the essence of IS; some emphasize the commercial character of IS and its instrumental value as a business model; some explicitly mention the collaborative nature of IS, and recognize that this collaboration may also include shared services; some define IS based on the aim of contributing to circularity and mitigating environmental strain; and finally, some authors have recognized IS not primarily as an exchange, but as a social process. **Error! Reference source not found.** provides an overview of these different emphases in IS definitions with one or two examples for each type.

Table 8 Definitions of Industrial Symbiosis by focus area.

IS definition emphasis	Examples
Resource exchange	"the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer." (CEN 2018: 7)
Business and competitiveness	"engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products." (Chertow 2000) "a type of business model adept for circular practices, such as the recycling of water, wastewater, energy, materials, etc." (Södergren and Palm 2021a: 2)

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Collaboration, exchange, and shared services	"a collaborative strategy in which companies exchange and reuse physical resources, such as byproducts, water, and energy, and/or share services, for example involving waste management and infrastructure." (Park et al. 2018: 1) "a collaborative approach concerning the physical exchange of materials, energy, and services between partnering firms and utility sharing of related infrastructures." (Fraccascia et al. 2019)
Contribution to circularity and environmental outcomes	"the cooperative exchange of resources through business networks aimed at achieving at the same time economic, environmental, and social advantages" (Albino et al. 2016: 4353). "the involvement of several organizations in a network to promote eco-innovation and long-term cultural change" (Lombardi and Laybourn 2012, cited in Faria et al. 2021)
Social processes	"a complex social process wherein different industrial actors identify the potential of their underutilized resources and connect their flows of secondary materials, water, energy resources, services, infrastructure, and technology." (Faria et al. 2021: 3; see also Posch et al. 2011).

These different emphases (resource exchange, competitiveness, collaboration, environmental mitigation, and social processes) reflect the variety of approaches to IS. Taking into consideration these various definitions, policy makers, funders, authorities, and industries have a responsibility to consider which aspects of IS they wish to focus on. Are efforts to stimulate IS purely aimed at the ability to exchange resources and by-products? Or is the social and environmental impact of these exchanges a leading criterium? This leads to Governance Proposition 2:

GOVERNANCE PROPOSITION 2:
To effectively stimulate WSIS, public and private actors should:
a) Acknowledge and embrace the diverse range of WSIS collaborations.
b) Clearly articulate and prioritize the focus of their efforts to stimulate WSIS.

ISNs are diverse in their structure and complexity, which is a strength of, and an enabling factor for WSIS. Policy makers, funders, and authorities can stimulate WSIS by embracing this diversity and enabling different types of bottom-up collaborations.

When seeking to stimulate WSIS, it should be clear to actors with what aim this is done, to what criteria WSIS should comply, and how success is defined and evaluated. Different actors in the ISN may have different objectives and definitions which means that a collaborative process of goal definition may be a fundamental towards such a clarification action.

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5.3. Local authorities can play an important role in WSIS

While in some cases the role of municipalities is fairly limited (as in CS1 and CS7), some of the CSs described above demonstrate that the influence of municipalities can clearly extend well beyond the role of permit provider. Municipalities are generally well positioned to engage with the industry and local communities to facilitate or enhance such exchanges. This resonates with the insight from IS literature that proximity is key to successful collaborations (Albino et al. 2016; Chertow 2000; Faria et al. 2021; Fraccascia et al. 2019). Moreover, municipalities often own or co-own utilities, which positions them as actors with a direct interest in IS, and municipalities can be in a good position to combine public and private goals and values (Södergren and Palm 2021a).

For example, local governments are an essential element in the WSIS system in Rosignano (CS3), as it is the municipal wastewater utility that provides the source of reused water, and the municipalities benefit directly from reduced groundwater use by the local industry. However, the municipalities have little influence over the governance of the WSIS. Formally, the municipalities are only involved in the WSIS as (minor) shareholders of the utility, and, through the utility's shares in Aretusa, are indirectly owners of the IS consortium. The consortium itself operates mainly as a mechanism for investment in infrastructures and as a forum for exchange between the utility and the industrial partner. In Kalundborg (CS9), the municipality has a more active role in the ISN, and proactively facilitates exchanges between companies. While the symbiosis association is currently an independent organization, it used to be hosted by the municipality. As a board member of the association, the municipality also influences its agenda. This leads to Governance Proposition 3:

GOVERNANCE PROPOSITION 3:
Local authorities can facilitate the establishment and functioning of WSIS, provided that they have adequate resources.

The contribution of local authorities to WSIS can be multiple:

- Become directly involved in exchange of (waste)streams as a WSIS partner (CS3);
- Exert influence as shareholders of utilities (CS3);
- Play a mediating role as active partner in, or coordinator of the ISN (CS9);
- Put pressure on companies to explore the possibilities of reuse through permits and policies for waste disposal and resource use.

In order for local authorities to utilize this potential, they need to have the appropriate knowledge, capacity, and network.

5.4. Utilities manage social relations as well as water

As can be seen in the CSs above, the utilities tend to have an exceptional role in the management of WSIS, not only in terms of distributing water, managing

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(waste)streams, and maintaining infrastructure, but also in terms of the social relations that constitute the ISNs. The utilities divert and absorb some of the direct relations between actors, and in their role as 'neutral' service provider, can mediate in the ISN. They can do so by managing relations, contracts, and permits with authorities and companies (CS1, CS9).

While many studies have emphasized the importance of a coordinator in IS, this informal coordinating function of the utilities is not often recognized in the literature but seems to have a positive effect on the effectiveness of WSIS. As utilities manage streams and flows, they simultaneously give a frame and orientation to social relations within the ISN and thereby play a crucial role in enabling WSIS. This leads to Governance Proposition 3:

GOVERNANCE PROPOSITION 4:
Public authorities and private IS partners should recognize and empower utilities in their role as WSIS facilitators.

Utilities are in an important position to facilitate the development of WSIS and ISNs. Authorities, as well as the companies that participate in an ISN, should understand, enable, and make use of their potential as mediators in complex networks of exchanges.

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6. Conclusion

This report has looked into the organisational structure (governance) of four cases of WSIS, with a particular focus on how these cases function in terms of their organizational structure and governance.

The analysis of the case studies has shown some of the efforts that organisations put into maintaining alignment between actors, which is a key task for IS coordinating actors, and, as this study demonstrates, for informal facilitators. It has done so through a description of the historical development and infrastructural and organisational layout of each CS and a focus on the role of documents and contracts in consolidating the social relations between actors, as well as subjective descriptions of the relationships between actors.

A first conclusion that needs to be drawn from the analysis in this report is that **the governance of, and conditions for successful WSIS are highly diverse**. Local conditions, including environmental pressure and possibilities differ significantly. Also, governmental structures are highly diverse between countries, regions, and localities.

This diversity points at the creativity and proactive stance with which industries, utilities and authorities have addressed environmental concerns and have taken the responsibility to make a positive contribution to the circular economy. It also points to the need for tailored approaches and solutions that fit within their specific local context. A key imperative for any overarching governance framework for WSIS, then, is to embrace the diversity and creativity inherent in this field and to provide room (in terms of policies, funding, and regulation) to experiment with changes.

A second conclusion is that **WSIS is in the interest of industries, as much as it is a public concern**. The cases further demonstrate that rules and regulations are an important driver for industrial water reuse, as well as environmental pressure such as water scarcity. Moreover, industries need resources and indirectly benefit from a healthy natural and social environment.

Thirdly, the CS show **a commitment to personal and long-standing relationships between people and between organisations**. Through their participation in the ISN, individuals working at different companies come together and develop personal ties that make negotiations, collaboration, and exchange easier. The levels of trust are further strengthened by the quality and reliability of the exchange, and materialised in contracts and agreements that are the foundation to much of what can be achieved in the ISN.

That said, the study also shows that **the governance structure of WSIS is strongly aligned with the symbiotic exchange as a business model**, whereby costs and benefits are leading to decision-making at a management level. A profitable business model remains the first and foremost precondition for companies to engage in WSIS.

Finally, **the consolidation of social relationships in ISN relies heavily on the mediating role of coordinating actors**, which can be dedicated IS consortia,

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municipal agencies, or informal facilitators such as utilities. These different roles and capacities of facilitators merit further consideration in future studies and WSIS-enabling policies.

6.1. Summary of governance propositions for WSIS

The table below (Table 9) summarizes the governance propositions discussed in this report.

Table 9 Summary of governance propositions for WSIS

#	Governance propositions for WSIS
1	**a) Public authorities should recognize and foster optimal conditions for industries, utilities and authorities to consider WSIS favourably.** **b) Public authorities should incorporate WSIS into sustainability performance audits and evaluations to ensure comprehensive assessment.** Industries are more likely to consider WSIS opportunities favourably in the case of increased external pressure that pushes them to look for alternative resources and uses for waste streams. Public authorities should be aware of different types of external environmental pressures, such as environmental conditions (e.g. water scarcity), market dynamics (e.g. sustainability requirements) and regulatory mechanisms (e.g. environmental legislation and permits). By using market and regulatory mechanisms, authorities can leverage the environmental pressure and encourage industries to develop IS systems that benefit the business, community, and environment. Environmental audit and evaluation approaches should take the impact of IS systems into account and not focus solely on the impact of individual companies. A system´s view on the efficacy of collaborations for water reuse is required.
2	**To effectively stimulate WSIS, public and private actors should:** **a) Acknowledge and embrace the diverse range of WSIS collaborations.** **b) Clearly articulate and prioritize the focus of their efforts to stimulate WSIS.** ISNs are diverse in their structure and complexity, which is a strength of, and an enabling factor for WSIS. Policy makers, funders, and authorities can stimulate WSIS by embracing this diversity and enabling different types of bottom-up collaborations. When seeking to stimulate WSIS, it should be clear to actors with what aim this is done, to what criteria WSIS should comply, and how success is defined and evaluated. Different actors in the ISN may have different objectives and definitions which means that a collaborative process of goal definition may be a fundamental towards such a clarification action.

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3 Local authorities can facilitate the establishment and functioning of WSIS, provided that they have adequate resources.

The contribution of local authorities to WSIS can be multiple:

- To become directly involved in exchange of (waste)streams as a WSIS partner (CS3);
- To exert their influence as shareholders of utilities (CS3);
- To play a mediating role as active partner in, or coordinator of the ISN (CS9);
- To put pressure on companies to explore the possibilities of reuse through permits and policies for waste disposal and resource use.

In order for local authorities to utilize this potential, they need to have the appropriate knowledge, capacity, and network.

4 Public authorities and private IS partners should recognize and empower utilities in their role as WSIS facilitators.

Utilities are in an important position to facilitate the development of WSIS and ISNs. Authorities, as well as the companies that participate in an ISN, should understand, enable, and make use of their potential as mediators in complex networks of exchanges.

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