Barriers to Industrial Symbiosis

Insights from the Use of a Maturity Grid

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Keywords:

Gladstone (Australia)
industrial ecology
industrial symbiosis (IS)
maturity grid
resource synergies

Summary

The concept of industrial symbiosis (IS) over the last 20 years has become a well-recognized approach for environmental improvements at the regional level. Many technical solutions for waste and by-product material, water, and energy reuse between neighboring industries (so-called synergies) have been discovered and applied in the IS examples from all over the world. However, the potential for uptake of new synergies in the regions is often limited by a range of nontechnical barriers. These barriers include environmental regulation, lack of cooperation and trust between industries in the area, economic barriers, and lack of information sharing. Although several approaches to help identify and overcome some of the nontechnical barriers were examined, no methodology was found that systematically assessed and tracked the barriers to guide the progress of IS development. This article presents a new tool—IS maturity grid—to tackle this issue in the regional IS studies. The tool helps monitor and assess the level of regional industrial collaboration and also indicates a potential path for further improvements and development in an industrial region, depending on where that region currently lies in the grid. The application of the developed tool to the Gladstone industrial region of Queensland, Australia, is presented in the article. It showed that Gladstone is at the third (active) stage of five stages of maturity, with cooperation and trust among industries the strongest characteristic and information barriers the characteristic for greatest improvement.

Introduction

The investigation of waste and by-product[1] reuse opportunities in heavy industrial areas to develop and enhance industrial symbiosis (IS) can be a challenging task. However, even the presence of a feasible technical solution cannot guarantee that a project will proceed with implementation. In many cases, government environmental policies, trust and communication between industries, specific management practices within the industries, and other nontechnical barriers become a significant hurdle for the recognition and further development of a potential synergy (Brand and de Bruijn 1999).

A check for major nontechnical factors has already been incorporated into the new synergies screening stage of the regional eco-efficiency opportunity assessment methodology (Van Beers et al. 2007a), which comprises a set of related questions with a subjective scoring system to rank potential synergies in relation to their ease of implementation and nonmonetary benefits. Although this approach is useful to assess specific projects, it does not consider the overall regional IS supporting environment and does not lead clearly to strategies for overcoming barriers.

The lessons and experience from different examples of IS can help understand and describe the possible ideal circumstances to overcome nontechnical barriers. Moreover, a detailed approach that distinguishes different phases of regional development or regional maturity from an IS perspective could be, in the researchers' opinion, very beneficial in helping to assess the

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DOI: 10.1111/jiec.12159

Editor managing review: Olli Salmi

Volume 00, Number 0

progress toward a more resource-efficient, sustainable region. This idea is similar to the development of maturity models.

The core aim of the maturity model or grid is to measure and codify so-called capabilities, or typical behavior that reflects good practice in order to effectively achieve specified tasks and goals (Fraser et al. 2002; Wendler 2012). A maturity grid usually includes several key aspects that overview the area of interest, describing and interpreting the progress in each of these through several intermediate or transitional stages.

Over the last 20 years, maturity grids have been successfully applied to assess strategic and operative capabilities in an organization for quality management, product development, communication, data security, and risk management (Maier et al. 2009). They have not, however, been used at a regional scale and for interindustry cooperative initiatives.

The process of the development of an IS maturity model can be represented by several steps:

- First, the main barriers and enablers to IS have to be identified and standardized. These are the key elements within the maturity grid.
- Second, every element in the maturity grid has to be described in detail over its progression through several transitional stages. The descriptions aim to capture the essential aspects of the studied area in a precise and concise manner.
- Third, a general approach on how to use the maturity grid has to be developed to help users with the practical application of the tool in the regional case studies to ensure consistency, reliability, and comparability of the results.
- Finally, the maturity grid has to be tested on a real case study in order to verify its effectiveness and identify areas for possible improvements.

Barriers to Industrial Symbiosis

A range of issues in industrial ecology (IE) development at the regional level has been addressed in the existing literature, and, in most cases, these issues were considered as barriers, problems, or challenges only (BCSD-GM 1997; Brand and de Bruijn 1999; Heeres et al. 2004; Fichtner et al. 2005; Mangan and Olivetti 2010). Some researchers also admitted that every barrier category, apart from challenges, can represent drivers or enablers that stimulate IS (Harris 2004; Van Beers et al. 2007b).

Despite variation in classifications of IS barriers, most of the approaches can be taken down to a group of seven barriers presented in table 1, starting with the commitment to sustainable development (SD) and ending with the economic barriers. The proposed sequence of barriers reflects the logical process for a potential resource synergy to proceed with its implementation.

Despite the wide citation of IS barriers in the literature, there is still a lack of real cases describing the process of investigation and overcoming these barriers, and no methodology has been reported for analysis of the barriers in a consistent manner. The development of such a methodology, in the opinion of the researchers, could significantly contribute to better understanding of the complexity of IS as well as help with assessing and overcoming IS barriers in practice.

Development of Industrial Symbiosis Maturity Grid

The transformation of an industrial estate from a waste management focus to an IS focus requires close collaboration between industries in the area and the variety of synergy projects of different types (Golev and Corder 2012). The IS maturity grid has to reflect the barriers and enablers for synergy projects to mature and thrive, as well as stress the importance of evolutionary changes in eco-industrial development (EID) of a region.

The proposed maturity grid (table 2) includes seven IS barriers that are tested against five stages of maturity. Detailed descriptions are used to characterize every section in the grid. They are based on the researchers' experience in, and knowledge of, the field of IE, were initially assessed within a broader academic audience, and further tested with the case studies. The original maturity stages used in quality management—uncertainty, awakening, enlightenment, wisdom, and certainty (Crosby 1979)—were modified for the area of IS to not recognized, initial efforts, active, proactive, and forming the future.

Stage 1 (Not Recognized)

The first and lowest level of IS maturity means that the concept of IS has no recognition in the area. There are different economic, regulatory, communication and trust, and other barriers that prevent any collaboration between the industries. This usually results in no (or only fortuitous) synergies, with most waste streams not being reused. There is, however, the possibility of the potential development of eco-efficiency projects at a company or site level.

Stage 2 (Initial Efforts)

The second stage shows a progress in industries' understanding of the importance of environmental efforts, including the need for better collaboration between different companies. Some synergy projects may be already implemented, or at least the opportunities for the beneficial waste reuse are recognized by some industries. However, there are still significant barriers to developing these projects, unless there is an urgent need for it from an industry side, or direct requirement from a legislative perspective.

Stage 3 (Active)

The active stage signifies the landmark in the IS development. The industries show growing interest in collaboration with neighboring companies in different spheres, and there is evidence of previous successful work together; an interindustry

Table 1 Barriers and enablers to industrial symbiosis

Category	*Description*
1. Commitment to SD	Organizational strategy, goals, and performance measures have to motivate managers to develop and participate in the synergy projects, contributing to the company's and regional SD.
2. Information	The detailed qualitative and quantitative data on waste streams and local industries' material/water/energy requirements provide the starting point for the development of regional resource synergies.
3. Cooperation	The cooperation and trust between key players, sharing of information, and network development are crucially important factors for new synergy projects. A coordinating body (e.g., interindustry council) can significantly contribute to this.
4. Technical	Technical feasibility is an indispensable condition to proceed with a potential synergy. A lack of technical knowledge within the industries may be an additional barrier for a new project. This can be compensated by involving a consulting company or research organization.
5. Regulatory	The uncertainties in environmental legislation and difficulties to obtain approvals for waste reuse projects from the regulatory authorities may also be an obstacle for potential synergies. At the same time, compulsory legal requirements to recycle specific materials, higher taxes for waste disposal, and so on, are the drivers for synergy projects.
6. Community	Community awareness (of the environmental and economic impacts that industries generate) can be a strong driver to initiate or stop the development of different projects. Well-established communication systems between the industries and local community, as well as environmental education programs, help to ensure the legitimate status of new synergies.
7. Economic	Synergistic connections are expected to bring a positive economic outcome along with environmental benefits. Economic feasibility may result in increased revenue, lower input costs, lower operational costs, and diversifying and/or securing water, energy, and material supplies.

Note: SD = sustainable development.

organization or similar form of joint communication is already in place. At this stage, the progress in IS development may have occurred over several years, including the realization of new synergy projects, whereas several other opportunities are under investigation.

Stage 4 (Proactive)

At the fourth (proactive) stage, IS in the area can be viewed as mature. The detailed investigation for new synergy opportunities frequently happens, and a further search for new projects is considered standard procedure. The communication and information support between all the industries and interested stakeholders in the area is well established and maintained. There is an adopted and actively supported strategy for regional industrial development, including long-term projects to further decrease the associated environmental impacts.

Stage 5 (Forming the Future)

Finally, the highest stage in IS maturity describes the situation when the industries and all other stakeholders in the area are able, through continuous collaboration and trust, to form the desirable (sustainable) future. The long-term perspectives and benefits are the main driver and goal in the regional development.

The developed maturity grid (table 2) can help not only to monitor and assess the level of regional industrial collaboration, but also to indicate a potential path for further improvements and development in an industrial region, depending on where that region currently lies in the grid. This is illustrated with a case study in the next section.

Where an industrial region lies on the grid (in other words, the level of maturity) is determined from interviews with industry representatives and different stakeholders, such as government bodies, interindustry organizations, and community environmental groups, in addition to analyzing additional supporting and clarifying information and data. The assessment of IS maturity level requires an expert opinion with an understanding of IE concepts, and there are usually only a few people within industries (and other stakeholders) in the area of interest who have the necessary experience, knowledge, and appreciation of the regional context to answer the questions.

The general approach to perform an IS maturity study is presented in figure 1.

Every interview should include a series of open-based questions and general discussion about the region in regard to industrial collaboration and development. The answers to these questions are used to interpret the level of maturity in each

Table 2 Industrial symbiosis maturity grid

IS barriers	*Stage 1 (not recognized)*	*Stage 2 (initial efforts)*	*Stage 3 (active)*	*Stage 4 (proactive)*	*Stage 5 (forming the future)*
Commitment to SD	SD is not recognized as a part of business strategy and practice.	SD is a part of company strategy, but no indicators are used to measure the SD performance.	Some SD indicators are used and reported, but there is a lack of proven methods/skills to standardize this process.	The system of indicators and proven methods are used to ensure that the SD goals are effectively deployed to every level of the company and successfully achieved.	Long-term perspectives and benefits dominate in the decision-making process. Local industries cooperatively take the responsibility for the regional SD.
Information	There is no exchange of information between companies in the area. Minimum environmental data are released to the public domain.	Most companies release environmental reports that are publicly available, but there is a lack of detailed information on waste streams.	Environmental reporting for public interest is a standard practice. Some reports that combine the information in order to see the “full picture” may also exist.	Summary of the overall environmental situation in the area is released regularly. There is an agreed coordination mechanism (or body) for the environmental data sharing and analysis.	The database on existing waste streams in the area is regularly updated and well maintained. Any additional details can be easily obtained through existing communication systems.
Cooperation	Every company looks solely for its waste reuse opportunities. There is a lack of trust between companies that hampers any collaboration.	Cooperation between industries predominantly happens when they are facing serious challenges together.	There is growing interest (and trust) for cooperation with neighboring industries. Coordination for these initiatives is predominantly at the top management level.	Cooperation between companies in the area happens often in different spheres. Coordination for these initiatives gradually proceeds from the top level to lower levels.	Cooperation between companies is constructive and happens regularly at different levels. There is continuous effort to improve it.
Technical	The waste reuse opportunities outside of a single company are not considered to be worthwhile. Cost minimization for waste disposal is the preferred strategy.	Some opportunities for waste reuse between industries may exist, but only well-known and proven projects can proceed with implementation.	Several possibilities for waste reuse in the area have been identified, but there is still not enough information to proceed with these projects.	Opportunities for waste reuse were analyzed in detail by experts. The most promising projects have been realized; others are under further investigation.	There is a list of long-term research projects for the waste reuse and minimization; industries often proceed to the implementation as pioneers. The current level of technical expertise is at the edge of scientific progress.

(*Continued*)

Table 2 Continued

IS barriers	*Stage 1 (not recognized)*	*Stage 2 (initial efforts)*	*Stage 3 (active)*	*Stage 4 (proactive)*	*Stage 5 (forming the future)*
Regulation	Waste reuse opportunities are not well recognized in the current legislation. The regulation is more restrictive, rather than encouraging.	Recycling is announced in legislation as an important element, but no specific regulation exists. Decisions are usually made on a case-by-case basis.	Recycling and waste reuse issues are an integral part of current regulation. Several well-known examples are included in official documents to encourage the implementation of the best-known waste reuse practices.	Legislation recognizes both well-known and potential waste reuse options. There is continuous improvement of regulation for better environmental outcomes.	Recycling and waste reuse is the main focus of environmental regulation. Most recyclable wastes are forbidden for disposal (compulsory recycling). The taxation system makes the reuse option strongly preferable for most types of wastes.
Community	Community is not recognized as an equal part in negotiation process for industrial development, which mostly depends on the government policy and the interests of industry and investors.	Community opinion may be important in some situations; people are kept informed about most important environmental aspects.	Informing community about environmental issues is a part of business strategy. There is a well-established communication system. The feedback and any community member claims are well analyzed, responded to, and reported.	Contribution to community capacities is recognized as one of the most important outcomes of industrial development in the area. An official community body exists and effectively negotiates with industries and government; it may also participate in environmental assessments.	Community is an active power in the decision-making process for current and future industrial development in the region.
Economic	Maximizing of profit is the main driver for industrial development in the region.	Industries have a special budget for environmental projects to comply with current regulation. General opinion is that environmental projects sound good, but are too costly.	There is an understanding that wastes may be a valuable resource. The information on costs for the disposal of every ton of waste is well known and used in decision making.	Waste reuse projects have proven their efficiency. There is a continuous investigation for new opportunities. Long-term benefits and risks are considered as a priority for project approval. Some projects have been accepted even if they are not feasible from a short-term perspective.	Close collaboration with other industries in the area is seen as a key competitive advantage. "By the reuse of wastes we make profit, secure our resources base, minimize environmental risks, and ensure regional SD."

Note: IS = industrial symbiosis; SD = sustainable development.

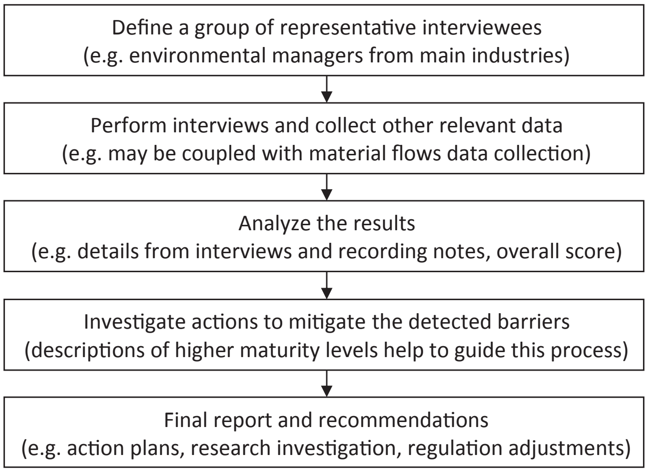

Figure 1 Flow chart for industrial symbiosis maturity study.

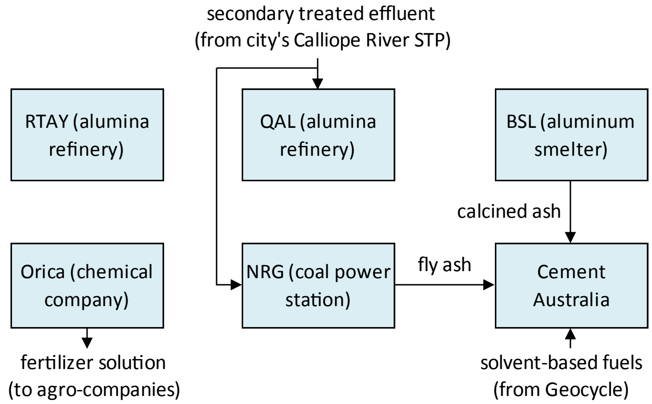

Figure 2 Main resource synergies in the Gladstone region. STP = sewage treatment plant; RTAY = Rio Tinto Alcan Yarwun Pty Ltd; QAL = Queensland Alumina Ltd; BSL = Boyne Smelters Ltd; NRG = NRG Gladstone Power Station.

of the seven themes for the region. During the discussion, the respondents can also be directly asked to choose the most appropriate position on the grid against every barrier.

Case Study Application

Given that the first practical application of the IS maturity analysis was expected to be a challenging task, it was preferable to choose a region with a proven record of waste and by-product exchanges between the variety of industries, whose managers are generally familiar with the IS concept. This enabled the interviewing process to be more effective and provided valuable critical comments from interviewees on the applicability of the developed maturity grid. At the same time, testing of the IS maturity grid with a less-mature case helped verify the tool's applicability, including clarification of the statistical toolset used to analyze the data and present the results.

The IS maturity grid, presented in the article, has been developed as a part of a Ph.D. project at the University of Queensland, Australia, and was tested on two heavy industrial areas: Gladstone (Australia) and Berezniki (Russia) (Golev 2013). The detailed results from its application to the first case study are presented in this section.[2]

Overview of Gladstone

Gladstone is the largest industrial area in Queensland, Australia. From a small remote town with a population of approximately 7,000 in 1963, Gladstone has become, over several decades, an internationally recognized Australian heavy industrial area, with a population of approximately 60,000 in 2011 (QTT 2012), hosting several of Australia's largest industries and potentially several others to come within the next decade. The current main industries comprise a coal power station, two alumina refineries, an aluminum smelter, cement producer, ammonia nitrate producer, and a demonstration plant for oil shale processing.

The regional resource synergies study implemented in Gladstone in 2004–2007, scoped as a technical investigation for industrial waste reuse opportunities, at the end of the project concluded that mainly nontechnical aspects prevented further uptake of the revealed new synergies (Corder 2008). However, no detailed investigation has followed until recently.

The IS maturity analysis in Gladstone was performed in February 2012. It is based on the qualitative data collected from interviewing industries' representatives (predominantly environmental managers), as well as representatives from the government body and interindustry organization. This analysis complemented the existing and new potential synergies investigation and formed an update for the development of regional synergies in Gladstone (Golev 2012). The existing synergies in the Gladstone region are shown schematically in figure 2 and further information is available in another work (Golev et al. Forthcoming).

Selection of Interviewees and Interviewing Approach

Because expert opinion and professional knowledge are crucial for understanding the different barriers to IS, it was decided that the site environmental managers would be the primary point of contact for the purpose of this analysis, along with chief executive officers (CEOs) and operations managers for small- and medium-sized enterprises (SME) and/or new and emerging industries in the area.

The list of interviewees includes the representatives of all main industries in Gladstone (apart from those who declined to participate at that time), plus two important stakeholders in the area—Gladstone Economic and Industry Development Board (GEIDB)[3] and Gladstone Industrial Leadership Group (GILG) (table 3).

The local representatives from alumina refineries (QAL and RTAY) decided not to participate in the interview. Because both sites are parts of the Rio Tinto Alcan Group, a relevant person (who is familiar with and experienced in Rio Tinto's

Table 3 List of interviewees

Organization	*Sector*	*Interviewee's position*
1. Cement Australia, Gladstone plant	Key industry	Environmental manager
2. NRG Gladstone Power Station	Key industry	Environmental manager
3. Boyne Smelters Ltd	Key industry	Environmental manager
4. Orica, Yarwun site	Key industry	Environmental manager
5. Queensland Alumina Ltd	Key industry	N/A (declined)
6. Rio Tinto Alcan Yarwun Pty Ltd	Key industry	N/A (declined)
7. Rio Tinto Alcan, Brisbane	Key industry	General manager
8. Queensland Energy Resources Pty Ltd	Emerging industry	Operations manager
9. J.J. Richards (waste management company)	SME	Operations manager
10. Gladstone Industrial Leadership Group	Interindustry body	Chief executive officer
11. Gladstone Economic and Industry Development Board	Government	Chief executive officer

Note: SME = small- and medium-sized enterprises; N/A = not available.

operations in Gladstone) from the company's main office in Brisbane was interviewed in order to cover all main industries in the Gladstone industrial area.

Eight interviews were performed face to face in the company/organization offices and one over the phone (because of the unavailability of the person at the time of the visit). Before the interview, every participant received an e-mail with a short explanation for the main aims of the research project and the interview structure.

The interviewing of industry representatives consisted of two main parts. The first part related to the general information about the company, as well as material flow data, aiming to update the information from the previous research project in 2004–2007. The second part was devoted to the analysis of IS barriers with the use of the IS maturity grid. Each interview took approximately 1 hour and was tape recorded for further analysis.

Assessing the level of maturity, interviewees were also allowed to choose two successive levels of maturity for some barriers if they considered that both were relevant to describe the existing situation in the area. In these circumstances, the final mark was calculated as average.

Interviews Results and Analysis

The answers from nine interviewed people are plotted in table 4. The average score for IS maturity is 3.01, which positions the Gladstone industrial area at the third (active) stage. Cooperation and trust among industries is the strongest characteristic of the area, with the score of 3.44. Information barriers received the lowest score (2.50), which likely indicates that lack of information sharing still exists, thus preventing uptake of new synergies and further development of IS in the area. All other barriers have relatively similar scores, varying from 2.83 to 3.28.

Table 4 also shows some variations in answers for the different types of barriers. The minimum variation (i.e., the greatest level of agreement) was for cooperation; all the marks were in the third and fourth squares. The information barriers section has the most variation (lowest level of agreement); the answers vary from 1 to 4.

As to the individual estimations of IS maturity in the area (from particular interviewees), they vary from 2.43 to 3.86 (median, 3.00). The standard deviation is 0.43, which gives the ±0.27 variance for the 90% level of confidence. In other words, for this study and its sample size, considering possible errors in answers from the individual interviewees, the average score lies in between 2.74 (3.01 [–0.27]) and 3.28 (3.01 [+0.27]) at the 90% confidence level. This confirms the location of the Gladstone industrial area at the third stage on the IS maturity grid.

The characteristic of Gladstone's IS maturity regarding every barrier category is provided below and also summarized in table 5.

Commitment to Sustainable Development

As identified in the interviews, all major industries in Gladstone have SD targets as a part of their corporate strategies and use the appropriate indicators to assess the progress. However, publically available information on this matter is limited. Four of six main companies (Cement Australia, Orica, BSL, and NRG) do not provide separate sustainability or environmental reporting on their operations in Gladstone.

For example, the recent Cement Australia's public report on energy efficiency specifies some details on energy consumption by different plants in Australia (CA 2012), whereas Orica's sustainability report has no details in regard to their Gladstone operations (Orica 2012). BSL and NRG are now a part of the Pacific Aluminium Group (www.pacificaluminium.com.au/), formed as a new Rio Tinto business unit in 2011. No sustainability reports have been issued for the group to date.

Table 4 IS maturity analysis: interviews' results

	Level of IS maturity								
IS barriers	*Not recognized*	*Initial efforts*		*Active*		*Proactive*	*Forming the future*	*Total answers*	*Score*
Commitment to SD			√√	√√	√√√	√√		9	3.28
Information	√√	√	√√	√√	√	√		9	2.5
Cooperation				√√√√	√√	√√√		9	3.44
Technical		√√	√	√√	√	√√√		9	3.11
Regulation		√√√√		√√		√√√		9	2.89
Community		√√	√√	√√√	√	√		9	2.83
Economic		√√√	√	√	√	√√√		9	3
Total answers	2	16		24.5		20.5	0	63	–
Score									**3.01**

Note: IS = industrial symbiosis; SD = sustainable development.

The Gladstone aluminum refineries, QAL and RTAY, publish their annual sustainability reports separately. Some key environmental and resource efficiency indicators are presented in the reports, although the level of information disclosure varies between the two companies (QAL 2012; Rio Tinto 2012).

It is also important to note that one of the interviewees stressed the priority of the corporate targets in waste minimization that possibly prevents collaboration in waste reuse with other industries, because the latter can negatively affect the existing corporate indicators (or the effect is negligible to justify a potential synergy project).

Information Barriers

The first step in identifying any new potential synergies is analyzing the information and data about existing industrial waste streams. However, in Gladstone, there is minimal public domain information. Moreover, an attempt to collect the 2011 material input-output information (as a part of a bigger project) directly from industries was only partially successful.[4] Some interviewees mentioned that even for companies that have existing synergy projects, relevant information and data were not necessarily readily available for investigating new potential synergies.

A more detailed reporting on the environmental situation, including a summary report on the level of solid waste generation, water effluents, and air emissions in the area, could be a benefit for different stakeholders in Gladstone. It could also assist with further investigation into regional synergy opportunities.

Cooperation Barriers

Most interviewees admitted an improvement in cooperation and trust among industries during the last several years and that it is relatively easy to work together in the area for commercial, as well as noncommercial, projects. Attempting to clarify how it has been achieved, several respondents partly referred this achievement to GILG's activities. Some interviewees from the Rio Tinto Group (which includes QAL, RTAY, BSL, and NRG) also mentioned the regular meetings within their joint working groups (on environmental and other issues). The rise in community awareness regarding the challenges that industrial development brings to the Gladstone region was also mentioned among the possible reasons that encourage industries to work cooperatively.

Technical Barriers

Most of the interviewed industry representatives in Gladstone were environmental managers, and not everyone was able to provide technical insights into the existing and potential waste reuse opportunities. Overall, the interviewees assessed the level of technical expertise in their respective companies at a relatively high level, although, in many cases, they also admitted that investigations for new technical solutions happen predominantly within the corporate research centers, rather than on sites; therefore, some regional synergy opportunities may be overlooked in these investigations, and the local operation

Table 5 Gladstone IS maturity analysis results

IS barrier	*IS maturity average and its range*	*Characteristic of Gladstone's IS maturity stage*	*Examples of comments from interviewees*
1. Commitment to SD	3.28 (2.5 to 4.0)	SD is a part of companies' strategy. The system of indicators and proven methods are used to ensure that the SD goals are effectively deployed to every level of the company and successfully achieved.	"The company does a lot to ensure that sustainable development is included in each of the business plans. We have targets for each department, targets for the site, continual improvement, etc."
2. Information	2.50 (1 to 4)	Minimum environmental data are released to the public domain. There is a lack of detailed information on waste streams.	"We are open to talk with other industries, but it is more ad hoc." "We release only general information and talk very little about our wastes."
3. Cooperation	3.44 (3 to 4)	There is a matured trust and interest for cooperation with neighboring industries. Coordination for these initiatives gradually proceeds from the top level to lower levels.	"We have good relations with all main industries due to the existing business links." "We have regular meetings with other industries . . . but waste has not been a 'big fighter' for them."
4. Technical	3.11 (2 to 4)	There are some opportunities for waste reuse between industries, but only well-known and proven projects can proceed.	"In many cases, we just send wastes to the dump, pay the money, and that is it."
5. Regulation	2.89 (2 to 4)	Recycling and waste reuse issues are an integral part of current regulation. Several well-known examples are included in official documents to encourage the implementation of the best-known waste reuse practices.	"Some positive changes started to happen just recently. Still, they [legislation andgovernment] do not give us any direction or encouragement." ". . . the biggest issue is going to be the condition in everybody's license that allows [us] to accept waste materials."
6. Community	2.83 (2 to 4)	Community opinion is important and people are kept informed about most significant environmental aspects. Some companies that are situated in a close proximity have a well-established communication system to receive and respond to any community member claims.	"Community is recognized here as being an important aspect." "Community consultations are performed only when and where there are some concerns about our activities from the local community."
7. Economic	3.00 (2 to 4)	There is an understanding that wastes may be a valuable resource. Industries have a special budget for environmental projects to comply with current regulation.	"Some environmental programs, that we implement, are not legally compulsory, but they allow us to keep (potentially) good relations with the community." ". . . we must provide a return for our shareholders."
Total	**3.01**	**Active stage**	

Note: IS = industrial symbiosis; SD = sustainable development.

managers may be limited in deciding which new technologies can be implemented at their site.

Several technically feasible opportunities have been revealed in the previous Gladstone regional synergies project (Corder 2005). Commenting on the lack of progress with these, apart from the low financial incentives, the interviewees appealed to the reliability and safety of the main industrial processes as well as to the importance of the company's reputation. If there is a risk to the stability of the existing industrial operations (when accepting waste product for reuse), or to jeopardize the reputation (when supplying waste product to others), it is very likely that industries would refuse to proceed with a project.

Regulation Barriers

Commenting on the regulation barriers, the respondents were critical about the existing environmental legislation. There are still some regulative barriers as well as a lack of incentives to develop new waste reuse projects. Ensuring the public safety, current environmental regulation often complicates and prevents the reuse of waste products in Queensland (Davis et al. 2009). However, a few respondents admitted a

Table 6 Recommendations for mitigating IS barriers in Gladstone

IS barrier	*Score*	*Score explanation*	*Key areas for barriers mitigation*
Information barriers	2.50	There is a low availability and sharing of information between different industries (and for public interest) that limits investigation and progress with new resource synergies.	There is a need for more detailed environmental reporting for public interest, including regular summary reports for the whole area. The summary reports should include a database on existing waste streams in the area (and potentially future waste streams), also providing information on their current and possible reuse options. An agreed coordination mechanism (or body) for the environmental data sharing and analysis would help to facilitate this process
Community related barriers	2.83	The local community is kept informed about main environmental impacts; however, it has not yet been recognized as an active and equal power in the decision-making process regarding future industrial development of the area.	Existing and future industries should recognize a contribution to community capacities as one of the most important outcomes of their industrial activities in the area. Existing (and new) community groups should state their vision in regard to future industrial development of the area and negotiate more effectively with industries and government.
Regulation barriers	2.89	Recycling and waste reuse issues are an integral part of current regulation, but there is still a lack of legislative incentives and guidance for the best environmental outcomes.	Legislation should recognize not only well-known, but also potential waste reuse options. A continuous review of the regulation barriers (in close collaboration with industry partners) is necessary. There has to be a clear promotion from a regulatory side for the best-known practices in waste reuse and recycling.
Economic barriers	3.00	There is still a dominance of economic drivers for the approval of new projects. Long-term environmental outcomes are predominantly treated on a regulatory compliance-only basis.	Industries have to accept a more proactive approach for the waste reuse projects, recognizing the long-term environmental benefits and risks as a priority for industrial development and project approval. Possible changes in the legislation, higher community concerns and pressure, and closer collaboration between industries may contribute to this transformation.
Technical barriers	3.11	There is a range of recognized opportunities for waste reuse, but there are just a few examples of successful synergy projects. Industries prefer to follow well-known technical solutions and do not risk proceeding with new synergies as pioneers.	Further expert analysis of the most promising synergy opportunities is needed. A creation of interindustry focus groups for a specific waste stream or cluster (e.g., alternative fuels and raw materials for cement) may facilitate this process. The companies have to announce a list of long-term research projects for waste reuse and minimization (including projects in collaboration with other neighboring industries).

(Continued)

Table 6 Continued

IS barrier	*Score*	*Score explanation*	*Key areas for barriers mitigation*
Commitment to SD	3.28	Industries use proven methods and indicators to assess and ensure a progress toward their sustainability goals; however, their sustainability performance and reporting scopes for public interest are still limited.	External reporting standards and scope have to be extended to meet growing public interest and modern environmental challenges. The companies SD commitments have to be clearly stated and represented by the appropriate indicators, including some indicators that can demonstrate a progress in the development of the whole industrial estate.
Cooperation barriers	3.44	There is a matured trust and interest for cooperation with neighboring industries. Coordination for these initiatives gradually proceeds from the top level to lower levels.	The positive experience in close cooperation between main existing industries (within GILG) has to involve and be shared with the existing SME and new emerging industries. There should be a continuous effort to improve the cooperation and trust between industries.

Note: IS = industrial symbiosis; SD = sustainable development; GILG = Gladstone Industrial Leadership Group; SME = small and medium-sized enterprises.

positive impact of the recent changes in the regulation, notably the introduction of Queensland's waste disposal levy in 2012.[5]

Community Barriers

Because modern Gladstone originated as an industrial center, this can explain the presence of general public support for industrial development (Greer et al. 2010). Nevertheless, the interviewees admitted that not all citizens are positive about the expected significant increase in industrial activities in the area.

Gladstone's population continues to grow quickly, in line with the industrial development in the area. This is one of the main social challenges. A lack of available housing for new workers as well as high rental prices are the most vital current issues. The local government admitted that "residents who don't have jobs with mining and LNG[6] companies will keep leaving Gladstone unless more houses are available" (Whop 2012).

Economic Barriers

Several interviewees pointed out that the long-term environmental priorities stated in corporate strategies help to offset the low economic returns allowing environmentally sound projects to proceed. Others were more critical, concluding that the short-term economic outcome is still the main driver because " . . . we must provide a return for our shareholders." There is a list of long-term environmental projects within the companies, with a significant allocated financial budget; however, the interviewees were unable to provide any example of a synergy-type project among these.

The existing pricing mechanism for waste products and supply arrangements can also be a barrier to remain for the synergies. The examples from Gladstone show that a waste product can be:

- supplied for free and directly reused in the process without additional treatment (e.g., fly ash as raw material for cement);
- delivered for free or for a smaller charge than a conventional product's or utility's price, but also requires some preprocessing, and/or technological adjustments, and/or investments in additional infrastructure (e.g., production of weak caustic soda from BSL's spent cell linings in the past as well as reuse of the city's secondary treated effluents for industrial operations);
- accepted by the customer for an additional fee to utilize it (e.g., spent cell linings from BSL as alternative fuel for cement).

No common approach or mechanism on sharing the benefits from the reuse of waste products adapted by the industries has been found. In some cases, it may lead to the cessation of a synergy as, for instance, the recovery of caustic soda from spent cell linings at BSL (supplied for free to QAL) was considered uneconomic and cancelled several years ago.

Another issue with new synergy exchanges is attributed to competition with raw materials suppliers (Bossilkov et al. 2005). In many cases, industries are not willing to risk their existing supply chains and substitute some of the original raw materials by waste materials. Nonetheless, sometimes this aspect can encourage greater interest in new synergy solutions, as in the case of growing industrial regions when there is a limit on different raw materials and utilities, such as water and energy.

Overall, the interviewed industry representatives and other stakeholders in Gladstone admitted that it was relatively easy to navigate through the IS maturity grid during the interviewing process. The results from this analysis give a better understanding of nontechnical barriers (existing and potential) that have to be considered for progression and implementation of new regional synergies in the area. Additionally, the results can help in developing mitigation actions to overcome the most significant barriers detected.

The local community can provide a strong incentive for industries to further investigate synergy opportunities. In 2009–2010, Central Queensland University (CQU) and GILG conducted a research study in Gladstone in order to investigate the community perceptions, concerns, and expectations from the industrial development in the area (Greer et al. 2010). In general, the results and conclusions from this study support the main findings from the IS maturity analysis.

CQU's report indicates that the main industries in the area are performing satisfactorily for maintaining their "social licences to operate." Most interviewees (Gladstone community members of various ages) share their concern for air quality, safety for all residents, recycling and managing of waste products in a sustainable manner, and infrastructural development and expect existing and new industries to meet these expectations. "The things they [industries] are going to give us are temporary and the environment should be something which many, many generations to come can enjoy" (Greer et al. 2010, 52).

Possible Actions to Mitigate IS Barriers in the Area

The main identified IS barriers for the Gladstone industrial area include information, community, and regulation barriers (table 4). The variation in scores—on the scale from 1 (lowest) to 5 (highest)—between different barriers is not high. However, the difference between the lowest score (2.44) for the information barriers and the highest score (3.50) for the cooperation barriers (and the variance in answers from different interviews for these two types of barriers) provides sufficient evidence to recognize it as statistically significant. A summary for every barrier score and the corresponding relevant key areas for improvement (barriers mitigation) are summarized in table 6.

In general, for a given level of maturity in the IS maturity grid (table 2), the possible actions and recommendations to mitigate existing barriers are described in the next higher levels of maturity. For example, if the information barriers are scored in the second stage of maturity, then the descriptions of the third and fourth stages of maturity provide the fundamental ideas on how to improve the situation. The recommendations in table 6 guide the progression of the Gladstone industrial area from its current maturity stage 3 (active) to stages 4 (proactive) and 5 (forming the future).

Some recommendations presented in table 6 are universal and can be suitable for any region with a similar IS maturity level, whereas others are Gladstone specific. Implementation of these recommendations, as well as further investigation of IS development in the area, would help to reveal more solutions and develop new approaches for overcoming IS barriers.

The Gladstone industrial area, having a recognized potential for further development of regional resource synergies, at the same time is likely facing significant increase in the overall environmental impacts resulting from new industries expecting to be established in Gladstone in 2014–2020 and beyond (Golev et al. Forthcoming). Apart from developing new technical solutions for waste minimization and reuse, there is also a need for better recognition of the nontechnical barriers that prevent higher uptake of these opportunities in both current and future industrial activities.

Conclusions

This article has presented a new qualitative tool for analysis of IS barriers—the IS maturity grid. The developed tool comprises seven IS barriers that are tested against five proposed stages in region's IS maturity. It highlights the importance of evolutionary changes in an EID of a region and offers guidance to overcome the barriers based on the current regional maturity stage.

The application of the IS maturity grid to the case study of Gladstone (Australia) helped to detect the most significant nontechnical barriers that affect the development of regional resource synergies, such as information, community, and regulation barriers. The results positioned the Gladstone industrial area at the third (active) of five stages of maturity. Cooperation and trust among industries was the strongest characteristic, whereas information barriers was the weakest and exhibited the greatest variation in interviewee responses. The IS maturity grid provided a straightforward approach to better understanding nontechnical barriers (existing and potential) for progression and implementation of new regional synergies in the Gladstone region. In addition, the IS maturity grid assisted in developing mitigation actions to overcome the most significant detected barriers.

Maturity grids are expert tools that usually require considerable practical experience to elaborate the descriptions for estimated parameters (e.g., IS barriers). Further application of the developed tool and/or its variations would contribute to refinement of barrier characteristics in the IS maturity grid and strengthen its effectiveness when applied to regional studies. A more formalized interviewing process, including detailed questionnaires and guidelines, could also contribute to a wider use of the developed tool. The main challenge, however, remains with the development and application of mitigation actions and strategies for IS barriers.

Notes

1. For the remainder of this article, we will only use the term waste, but equally the term by-product could apply.
2. The second case study (Berezniki, Russia) is not presented in the article. Despite some differences in the overall findings, both studies confirmed the appropriateness and effectiveness of the developed tool (Golev 2013).
3. The GEIDB closed on 30 June 2012. The roles and responsibilities of the GEIDB are being undertaken by the Department of State Development, Infrastructure and Planning.

4. See: Golev, A. 2012. A review of the regional synergy development in Gladstone: Research report. Brisbane, QLD, Australia: Center for Social Responsibility in Mining, Sustainable Minerals Institute, The University of Queensland.
5. This regulation was amended later in 2012 by the new Queensland government. See, for example, Powell (2012).
6. Several large LNG (liquefied natural gas) processing plants and export facilities have been proposed in Gladstone. These plants comprise the downstream sections of bigger projects that include coal-seam gas field developments in Central Queensland, as well as a pipeline component to deliver raw natural gas to Gladstone.

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