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Modeling and Evaluation of the Possibilities of Forming a Regional Industrial Symbiosis Networks †

Biljana Mileva-Boshkoska [1,2], Borut Rončević [1,3] and Erika Džajić Uršič [1,3,*]

[1] Faculty of Information Studies, 8000 Novo mesto, Slovenia; biljana.mileva@fis.unm.si (B.M.-B.); borut.roncevic@fuds.si (B.R.)
[2] Department of Knowledge Technologies, Jožef Stefan Institute, 1000 Ljubljana, Slovenia
[3] School of Advanced Social Studies, 5000 Nova Gorica, Slovenia
[*] Correspondence: erika.ursic@fis.unm.si; Tel.: +386-(0)-51-633-471

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Abstract: Industrial symbiosis (IS) is a term used to describe a network of diverse organizations that make use of different byproducts to improve their ability to achieve common goals, improve environmental conditions, and/or improve business and technical processes. In this paper, we propose a model for evaluation of the possibilities of the establishment of such IS on a regional level. This paper studied a benchmark of seven IS examples, which are used to build a qualitative multi-criteria decision model for evaluation of the development of IS network model. Through these examples, where two are the best known IS cases in the world, we demonstrate the importance of social actors' involvement in IS in their industrial or non-industrial technological processes.

Keywords: industrial symbiosis; industrial symbiosis networks; social forces; multi attribute hierarchical model; simulation; ecology

1. Introduction

Industrial Symbiosis (IS) emerged as a collective, cooperative, and multi-industrial approach towards economic and environmental sustainability. IS has been defined as bringing together "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and byproducts" (Chertow 2000). Both economic considerations, such as lowering costs for waste disposal, as well as by environmental ones, such as accessing limited water supplies, motivate IS. Firms operating within an Industrial Ecology (IE) paradigm use IS as a collective approach to joint competitive advantage—usually within the framework of a geographically delimited cluster or industrial district—and simultaneously realize environmental benefits. Different authors (Chertow 2007; Howard-Grenville and Paquin 2008, p. 158; Gingrich 2012, p. 44) define IS as an approach to IE; as a synonym for IE (Phillips et al. 2005, p. 242); as a subset of IE (Chertow and Lombardi 2005, p. 6535); as activity within IE (Rui and Heijungs 2010); as eco-industrial symbiosis (EIS), which represents local or regional circular economy and environmental approach (Hartard 2008); and as one of the levels of studying IE (Hartard 2008). Deutz (2014, p. 4) sees IS as a stream of untapped resources (including materials, objects and/or energy), starting with social actors that would have discarded these resources, and ending with social actors that use these resources as new resources. Some are also hoping to be recognized as environmentally aware by their social environment (Costa and Ferrão 2010; Costa et al. 2010; Eilering and Vermeulen 2004). Through such collaboration, social relationships among participants get better (Zhu et al. 2007). Examination of IS networks (ISNs), from an economic and especially ecological point of view, is now the subject of numerous multidisciplinary research studies, which mainly focus on waste management (CTTÉI 2013), industrial ecology (Chertow 2000; Ehrenfeld and Gertler 1997), circular economy (Laybourn 2015), supply chain management (Leigh and Li 2015), and economics (Chertow and Lombardi 2005; Fric and Rončević forthcoming).

Positive economic effects are demonstrated by lower waste/byproduct disposal costs, competitive advantages towards other economic actors and better reputation of the firm/economic actor. Firms hence participate in IS for exchange of resources, such as byproducts, materials, services, energy etc., in the framework of closed and sustainable cycles. This cooperation contributes to the reduction of required input of materials and energy, as well as a decrease of the output in the form of waste. Furthermore, the low price of waste as a material—if compared with no waste materials—increases economic effectiveness of individual organizations, which are recipients in the framework of ISNs. Open networks, on the other hand, allow entropy, which results in loss of energy, poor utilization of materials and consequently causes environmental damage (Chertow 2000; Chertow 2007). However, although participation in IS seems rational both from an organizational and societal point of view, and although we have sufficient technological and logistical knowledge to manage them successfully, IS could be further developed both on regional, national and international levels in terms of forming new IS relationships and networks.

Why is this the case? IS is not only a technological or logistical system; it transcends the boundaries of various systems, and it is also a social system. Hence ISNs may be considered to be social networks. This implies that nodes in IS networks—enterprises, households, policy actors—are social actors, operating in the context of bounded rationality, i.e., they are limited in their rational decision making not only by their own inherent organizational values but also constrained by the decisions of other organizations. Since exchange—the elementary activity in IS—is taking place between social actors and it requires cooperation, communication, and a certain level of trust, its morphogenesis can be study by sociological research. Our social research is based on Beckert's social fields theory (Beckert 2009), according to which social fields—in our case IS and its networks—are shaped by the three social forces. These are institutions (laws, central concern for law, the formal mechanism for political rule-making and enforcement), social networks (social structure made up of a set of social actors such as individuals or organizations, a set of the dyadic ties between these actors) and cognitive frames (social interaction, meaning-making technologies, and strategically-selective opportunities for reflection and learning) (Beckert 2009). However, one should avoid the pitfalls of sociological determinism and study the IS as a complex phenomenon, taking other factors into account as well, to allow informed conclusions and policy-making process. In this paper, we introduce a model to support the decision makers in the process of IS Networking (ISN). We propose a model that includes environmental, technological, organizational, economic, and social aspects of IS (Boshkoska et al. 2017).

Forming an ISN is a complex process and its success is highly dependent on establishing a synergy among several spheres including physical, social and organizational ones. Neglecting even one of them may lead to a significant time delay or even failure of development of a useful ISN. In this paper, we propose a model of an ISN that includes all three spheres to support the decision makers in the process of the development of an ISN. The model allows evaluation of the current state of the ISN based on the three spheres and contributes to clarification and finding weak spots for improvement of ISNs. Hence, the results from the evaluation of ISNs suggest to the decision makers which particular spheres, and which attribute needs to be improved to develop or obtain a better ISN. In practice, the model could also help firms, local and state institutions and the public sector in understanding the weaknesses of the current system, and to define weak spots for which solutions are required. The model can also support the decision makers in the process of improving the ISNs and its temporal as well as long-term behavior (Criado Pacheco et al. 2017).

The data collection of the study is based on a mixed methods approach, conducted by method of triangulation (qualitative-quantitative method) to ensure the validity of the study. This means that data obtained from seven IS cases from sources such as literature reviews, empirical data, and empirical data from articles with interviews-practitioners who work with the facilitation of IS exchanges. A theoretical framework obtained from the literature on IS guides the data collection in all parts of the study.

The main objective of the paper was the use of quantitative method of a multi-attribute decision-making program that is being able to "translate strategy into action". Consequently, the model is based on the DEX methodology and its implementation into the DEXi computer program (Jereb et al. 2003). DEXi is a stand-alone computer program for multi-attribute decision-making. It facilitates interactive development of qualitative multi-attribute and hierarchical decision models and the evaluation of options. DEXi has been used in many real-life decision problems in areas such as selection and evaluation of computer hardware and software, evaluation of firms and business partners, individual management, project evaluation, land-use planning, risk assessment in medicine and health-care (Jereb et al. 2003; DEXi 2017).

The structure of this paper is as follows: in Section 2 we describe the materials and modelling approach for development of a decision support model for evaluation of an ISN. We outline the key benefits of ISN model and support our statements by seven of the most famous examples of IS best practice. The obtained model and evaluation of seven ISNs is given in Section 3. In Appendix A, we provide a detailed description of the attributes, while in Appendix B we provide the utility functions of the aggregated attributes. Finally, in Section 4 we give our conclusions.

2. Materials and Methods

To build the ISN model, we used the available literature on IS from the Web of Science database and searched for publications that listed "IS," "Eco-Industrial Park," or the combination of "Industrial Ecology", and "IE" as a topic. From the available literature, we extracted seven relevant real-life cases of IS. Next, we used the model to evaluate ISNs located in Kalundborg and Aalborg in Denmark (Aalborg Kommune 2010), Rotterdam Europoort in Netherlands, Kwinana and Gladstone in Australia, Guayama and Barceloneta in Puerto Rico (detailed descriptions of the cases that we denote as options are provided in Section 3).

The modeling proceeded in five consecutive sub-stages (Beckert 2010):

1. Definition of the relevant attributes for three spheres: environmental and technological, organizational and economy, and social. The result was an ordered list of all 22 (13 + 9) attributes.
2. Developing attributes' hierarchy based on their interrelations and anticipated influence on the final proposed outcomes of the model. The process involved structuring, comparing, and aggregating the list of attributes using a "bottom-up" approach.
3. Implementation of the attribute hierarchy into a DEXi model. The result of this stage is the tree of attributes given in Table 1.
4. Definition of attributes' measurement scales and set of values that each attribute may obtain. The DEX method is a qualitative one and usually represents attributes whose values are represented by words, such as "impossible," "incomplete," or "possible "or other (see Table 1, column 2).

Definition of the utility function, in which we define an aggregation of several attributes into one attribute. The utility function of every aggregate attribute is presented in a table where rows can read as logical "*if* ... *then*" expressions.

The model is based on the qualitative multi-criteria method DEX. In DEX, the qualitative attributes build a hierarchical structure, which represents a decomposition of the decision problem into smaller, less complex, and possibly easier-to-solve sub-problems. There are two types of attributes in DEX: basic attributes and aggregated ones. Basic attributes are the directly measurable attributes, also called input attributes, which used for describing the options. The latter are obtained by aggregating the basic and/or other aggregated attributes.

Table 1. DEX model tree, scale attributes and short description of attributes.

Attribute	Scale	Description
ISN Development	**Partially developed**; mostly developed; ***fully developed***	Current ISN Development
├─**Environment and Technology**	**Weak**; moderate; ***strong***	Facets, location, diversity of industries, presence of river, sea, core businesses
│ ├─**Accessibility of material resources**	**Low**; moderate; ***satisfying***	Scarcity of resources
│ ├─Availability of resources	**No**; partially; ***yes***	Industrial water, energy, production materials (primary and secondary)
│ └─Origin of resources	**External**; mixed; ***internal***	How the available resources are connected: internal, external, mixed
│ └─**Proximity**	**Low**; moderate; ***satisfying***	Physical distance among industrial installations
│ ├─Distances	**Long**; medium; ***short***	Distances among firms
│ └─Installation/viability of heavy infrastructures	**Impossible**; incomplete; ***possible***	Vicinity of the main infrastructure suppliers to the IS area
├─**Organization and Economics**	**Low**; moderate; ***satisfying***	Economic benefits, profitability
│ ├─**Economy and economics**	**Low**; medium; ***high***	Yielding the benefits of industrial symbiosis
│ │ ├─Sustainable dynamics	**Weak**; partial; ***strong***	Create economic growth, while advancing social and environmental objectives
│ │ └─Reduction of raw material and cost saving	**Weak**; partial; ***strong***	Reduction, reuse and recycling; Income generating synergies
│ ├─**Learning organization**	**Low**; moderate; ***satisfying***	An approach to include innovative ideas of employees in the decision making process
│ │ ├─Participative management	**Weak**; partial; ***strong***	Involvement of employees into decision making processes
│ │ └─Innovative ideas	**Weak**; partial; ***strong***	Employees generate innovative ideas
│ └─Common IS platform	**No**; partial; ***yes***	Existence of a joint and comprehensive policy and communication platform
└─**Social Forces**	**Low**; moderate; ***satisfying***	Social factors shaping the topography of IS networks
├─**Institutions**	**Weak**; partial; ***strong***	Rules, ritualized behaviours
│ ├─Urban planning	**Low**; moderate; ***satisfying***	Local and/or regional spatial planning
│ └─Regulations for waste management	**Weakly enforced**; partially enforced; ***fully enforced***	Implementation of the waste management regulations
├─Cognitive frames	**Weak**; partial; ***strong***	Green values, public awareness and green procurement
└─Networks	**Weak**; partial; ***strong***	Social trust and ease of cooperation

Note: The green coloured word means higher value in the evaluation of IS cases, red colour stands for lower, and the black colour is medium evaluate attribute.

They represent the evaluations of the options. The hierarchical structure in DEX represents a tree. In the tree, attributes are structured so that there is only one path from each aggregate attribute to the root of the tree. The path contains the dependencies among attributes such that the higher-level attributes depend on their immediate descendants in the tree. This dependency is defined by a utility function represented in a tabular format such as the one presented in Figure 1. Utility function is the component of multi-attribute model that define the aggregation aspect of option evaluation. In Figure 1, the utility function gives the aggregation rules for the attribute "*accessibility of material resources*" based on the values of the input attributes "*availability of resources*" and "*origin of resources*". For instance, one may read from the utility function in Figure 1 that if the *origin of resources* is external regardless of the available *availability of resources (row number 3)*, then the *accessibility of material resources* that would be in line with the requirements for development of IS in the region is low. Also, if the *availability of resources* is none (regarded as "no" *in the model)*," then regardless of the value of the attribute "*origin of resources*," the possibility of development of a suitable *accessibility of material resource* is low (DEXi 2017). To have at least moderate *accessibility of material resource*, the actual *availability of resources* should be evaluated at lease as partial and the *origin of resources* should be at least evaluated as mixed.

	Availability of resources	Origin of resources	Accessibility of material resources
	43%	57%	
1	no	*	low
2	<=partially	<=mixed	low
3	*	external	low
4	*yes*	mixed	moderate
5	>=partially	*internal*	*satisfying*

Figure 1. Utility functions of the attribute "Accessibility of material resource".

The rows in the utility function may be present as *"if* ... *then"* decision rules. An example of such decision rule, given in the first row in Figure 1 is:

IF Availability of resource is "yes" **AND** Origin of resources is "mixed" **THEN** Accessibility of material resource = moderate.

The developed "ISN" model contains 13 basic and 9 aggregated attributes. Each decision alternative is firstly assessed with respect to each attribute, and these individual assessments are then aggregated into an overall evaluation of the alternative (DEXi 2017; Boshkoska et al. 2017). The green-higher values in the evaluation of IS cases are preferred. It follows that decision alternatives are hierarchical, and the best one is chosen in a transparent and justifiable way. Attributes in the decision model include a three of IS aspects: environment and technology, organization and economy, and social forces. The last one represents the main contribution to the DEX model in this paper given the fact that the social forces in IS have not been addressed before in the literature to the knowledge of the authors. The model tree, the scale values of all attributes and short description of attributes is given in Table 1, while the detailed descriptions of the attributes are given in Appendix A. The utility functions of all aggregated attributes are given in Appendix B. In Table 1 the scale values are color coded where the green color means most preferred value, and the red color means least preferred value. The proposed model is implemented using the DEXi software tool. The model evaluates the degree of compliance of the industrial areas with the IS prerequisites. They are intended to help decision makers in determining the facilitating mechanisms, the barriers that should be avoided, and provide recommendations regarding future operations to be undertaken for the improvement or development of a new IS network.

3. Modeling Results: Options Description End Evaluation

The DEX model tree and the results from the evaluation of the seven real cases of ISN are presented in Table 2 and graphically, using polar maps of the evaluation of the alternatives given in next polar maps bellow from Figure 2 to Figure 8.

Table 2. DEX model and evaluation of seven IS cases shows that three of the seven IS cases are evaluated with highest qualitative measure as "fully developed", while four IS cases are evaluated as "partially developed". Such evaluation is in line with the information from the considered literature.

Attribute	Kalundborg	Aalborg	Guayama	Barceloneta	Kwinana	Gladstone	Rotterdam
ISN Development	*fully developed*	mostly developed	mostly developed	*fully developed*	mostly developed	*fully developed*	mostly developed
⊢—**Environment and Technology**	*strong*	*strong*	**weak**	*strong*	**weak**	*strong*	**weak**
│ ⊢—**Accessibility of material resources**	*satisfying*	*satisfying*	**low**	*satisfying*	**low**	*satisfying*	**low**
│ │ ⊢—Availability of resources	partially	partially	partially	*yes*	partially	partially	partially
│ │ └—Origin of resources	*internal*	*internal*	mixed	*internal*	mixed	*internal*	mixed
│ └—**Proximity**	moderate	moderate	moderate	moderate	moderate	moderate	moderate
│ ⊢—Distances	*short*	*short*	medium	medium	medium	*short*	*short*
│ └—Installation/viability of heavy infrastructures	incomplete	incomplete	incomplete	incomplete	incomplete	incomplete	incomplete
⊢—**Organization and Economics**	*satisfying*	moderate	*satisfying*	*satisfying*	*satisfying*	moderate	moderate
│ ⊢—**Economy and economics**	medium	medium	*high*	*high*	medium	medium	medium
│ │ ⊢—Sustainable dynamics	partial	partial	*strong*	*strong*	partial	partial	partial
│ │ └—Reduction of raw material and cost saving	partial	partial	partial	partial	partial	partial	partial
│ ⊢—**Learning organization**	*satisfying*	*satisfying*	*satisfying*	*satisfying*	*satisfying*	*satisfying*	*satisfying*
│ │ ⊢—Participative management	partial	*strong*	partial	partial	partial	partial	partial
│ │ └—Innovative ideas	partial	partial	partial	*strong*	partial	partial	partial
│ └—Common IS platform	*yes*	partial	partial	*yes*	*yes*	partial	partial
└—**Social Forces**	*satisfying*	moderate	moderate	*satisfying*	moderate	*satisfying*	moderate
⊢—**Institutions**	*strong*	partial	partial	*strong*	*strong*	*strong*	partial
│ ⊢—Urban planning	*satisfying*	moderate	*satisfying*	*satisfying*	*satisfying*	*satisfying*	moderate
│ └—Regulations for waste management	*fully enforced*	partially enforced	partially enforced	*fully enforced*	*fully enforced*	*fully enforced*	partially enforced
⊢—Cognitive frames	*strong*	*strong*	partial	partial	partial	*strong*	partial
└—Networks	*strong*	partial	*strong*	*strong*	partial	partial	partial

Note: The green coloured word means higher value in the evaluation of IS cases, red colour stands for lower, and the black colour is medium evaluate attribute.

3.1. ISN in Kalundborg

The IS project in Kalunborg, Denmark, begun in 1972 and by 1994, 16 contracts had been negotiated. The extent of the material and energy exchanges in 1995 had been about 3 million tons a year. Estimated savings totaled US $10 million a year, giving an average payback time of six years (Kalundborg Symbiose 2017; Jacobsen 2005; Jacobsen and Anderberg 2005). The core participants were Asnaes, Denmark's largest coal-fired power station, an oil refinery owned by Statoil, a pharmaceuticals plant owned by Novo Nordisk, a Gyproc, Scandinavia's largest plasterboard manufacturer and the municipality of Kalundborg, which distributes water, electricity, and district heating to around 20,000 people (Kalundborg Symbiose 2017; Ehrenfeld and Gertler 1997). The symbiosis has grown over the years to include partners from other districts, including farmers who had put emphasis on reducing environmental costs. The environmental benefits of IS are quantified by measuring the changes in consumption of natural resources, and in emissions to air and water, through increased cycling of materials and energy. The economic benefits of IS are quantified by determining the extent to which firms' cycling byproducts capture revenue streams or avoid disposal costs; those businesses receiving byproducts gain advantage by avoiding transport fees or obtaining inputs at a discount (Uzzi 1996; Kalundborg Symbiose 2017). IS involves economic benefits for social actors involved, e.g., savings in production cost, savings in purchase of new materials, savings in management of secondary resources, and additional revenue from re-processing secondary resources into byproducts and primary resources (Ehrenfeld and Gertler 1997; Doménech Aparisi 2010; Doménech Aparisi and Davies 2011; Ehrenfeld and Gertler 1997).

According to the DEX model, the ISN in Kalundborg is evaluated as fully developed. The polar map of selected attributes for Kalundborg is given in Figure 2

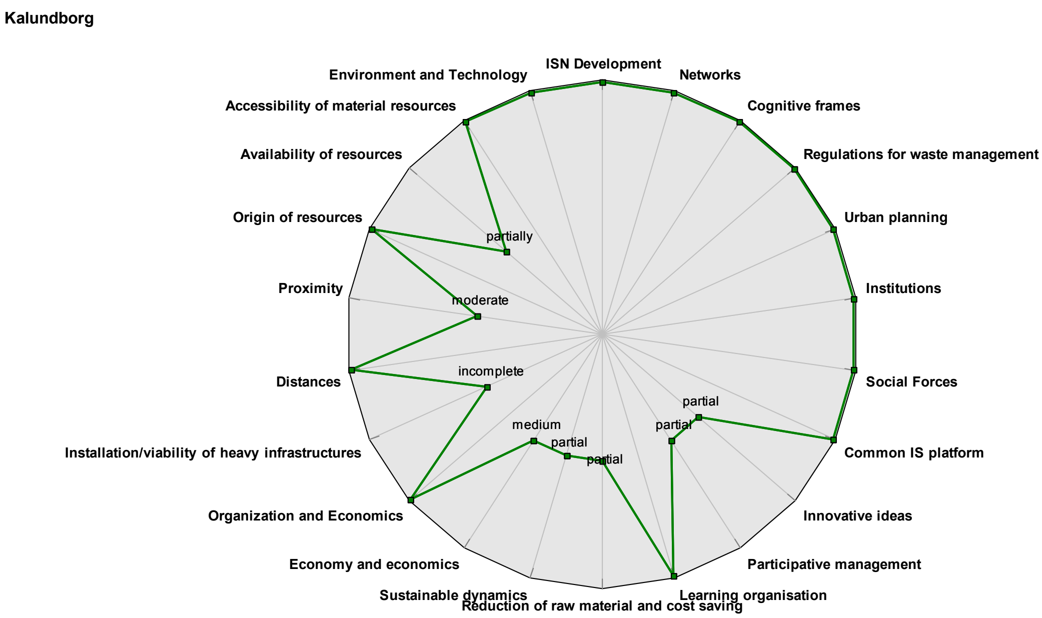

Figure 2. Polar charts of the selected attributes for ISN in Kalundborg.

3.2. ISN in Aalborg

Even though most of the traditional activities in Aalborg, Denmark, have been off-shored abroad for (mainly) cost salary reasons, heavy manufacturing activities still characterize the city economy such as the cement industry, power production plant, and harbor. Synergies of the industries in Aalborg happen within a radius of 1 to 2 km distance between firms (Aalborg Industries 2017) Aalborg, in north Denmark, is a mid-sized town that gathers all the prerequisites present in most of the IS cases around the world:

it has an opening on the sea, harbor activity, an important industrial area, manufacturing businesses, etc. However, very few symbiotic partnerships between firms are in place (Scrase et al. 2009).

According to the DEX model, Aalborg has a "partially developed" ISN due to the incompletion of the attribute installation/viability of heavy infrastructure, partial reduction of raw material and cost savings and partial common IS platforms. These results are in line with the literature, which states that because Aalborg East does not face too many problems with natural resource scarcity, firms are not significantly motivated to decrease their resource consumption. Furthermore, there was no data about input/output or massive material flows in this area, so firms tended to hold a skeptical or curious attitude regarding to what extent other firms would share information and knowledge within the area and protect their business confidentiality (Chertow and Lombardi 2005). Firms in this area had few extra-professional activities and relatively weak social links, which limited the space for developing deeper collaboration and mutual trust (Novokovic et al. 2012; Aalborg Industries 2017). As a result, very few symbiotic partnerships between firms were operating in this area, and firms' willingness to have industrial cooperation is l. The polar map of selected attributes for Aalborg is given in Figure 3.

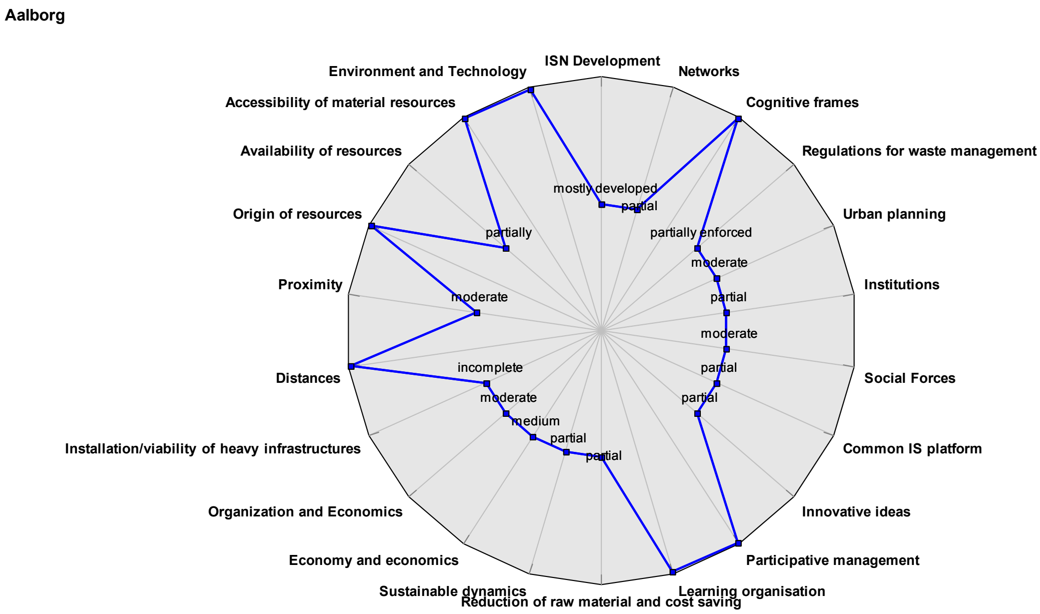

Figure 3. Polar chart of the selected attributes for ISN in Aalborg.

3.3. ISN in Guayama

An evolving network of interfirm exchanges in Guayama, Puerto Rico provides a tractable illustration to analyze the environmental and economic case for IS. Puerto Rico is a commonwealth of the United States (US), thus sharing most US laws and business practices. The municipality of Guayama, on the southeastern coast of Puerto Rico, measures 169 km^2, and has a population of approximately 42,000. Before 1940, Guayama was primarily an agricultural economy with some light manufacturing. After a period of light industrialization in the 1940s and 1950s, the current industrial profile began developing. Guayama hosts many of the same industries as Kalundborg: a fossil fuel power generation plant, pharmaceutical plants, an oil refinery, and various light manufacturers. Current exchanges in Guayama include the new AES coal-fired power plant using reclaimed water from a public wastewater treatment plant (WWTP) for cooling, and providing steam to the oil refinery. Additional steam and wastewater exchanges are under negotiation between neighboring pharmaceutical plants, the refinery, and the power plant. Beneficial reuse of the coal ash has begun as a means of stabilizing some liquid waste (Chertow 2000).

The case of Guayama was evaluated as "mostly developed" because of the partial availability of resources that are from mixed origin, partial reduction of raw material and cost savings and partial innovative ideas. In the cases of Guayama and Rotterdam it is known that there is a need for involvement of stakeholders in the IS communication platform (Baas 2008; Baas 2011), which is in line with the DEX model evaluations for the attribute "Common IS platform" as partial suggesting the possibilities for improvement. The polar map of selected attributes for Guayama is given in Figure 4.

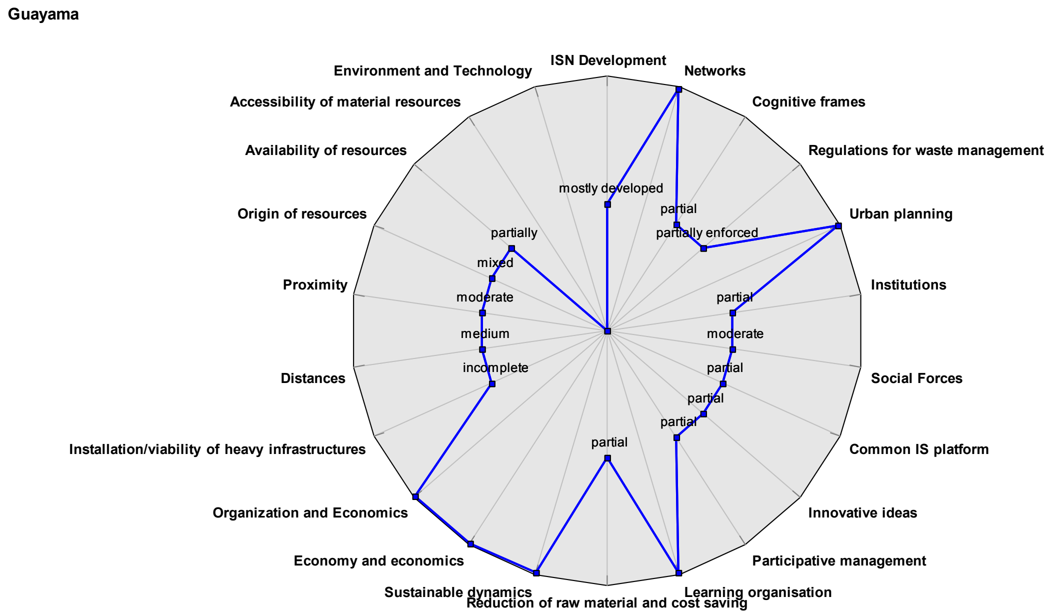

Figure 4. Polar chart of the selected attributes for ISN in Guayama.

3.4. ISN in Barceloneta

Barceloneta and its neighbouring municipalities, Arecibo and Manati, is often referred to as having one of the highest concentrations of pharmaceutical manufacturing facilities in the world, with 14 facilities located across the three municipalities. Despite food, chemical, packaging, electronic equipment, and metal fixture manufacturers and waste management firms, there are global leaders such as Abbott, Bristol-Myers Squibb, Merck, and Pfizer. Beginning in the 1950s, Puerto Rico, a US commonwealth territory, promoted generous tax benefits and low workforce costs relative to the continental US to attract manufacturing firms. Eight regional firms participate in the Barceloneta Wastewater Treatment Corporation Advisory Council, a joint agreement, started in 1978, to construct and oversee operation of the region's secondary wastewater treatment plant, which handles 31,415 m^3 per day (8.3 million gallons per day). The plant is owned and operated by the Puerto Rico Aqueduct and Sewerage Authority. Advisory Council members provided 70% of the plants' operation and maintenance costs, as well as technical assistance to the authority (Ashton 2008). The pharmaceutical facilities were financed to manage the wastewater treatment plant initiative. Managers in the participating firms met frequently to discuss common problems; initially these were focused on the wastewater plant, but later evolved to include other shared resource constraints. The Advisory Council has served to institutionalize cooperative resource management practices among the firms and deepen the social embedding of inter-firm relations (Corder et al. 2014; Granovetter 1985). ISN in Barceloneta is evaluated as "fully developed", however due to the medium distances the attribute proximity is evaluated as moderate because according to Velenturf and Jensen 2015, industrial ecologists commonly believe that trust and geographical proximity-vicinity are essential to the development of IS and consequently ISNs. Close geographical proximity and confidence among actors and firms are essential to the development of IS (Velenturf and Jensen 2015). According to Velenturf and Jensen (2015), to move IS research forward there is a need for additional research on the concept of proximity, with attention on institutional, geographical, cognitive, social, and organizational distances between actors (Velenturf and Jensen 2015). The polar map of selected attributes for Barceloneta is given in Figure 5.

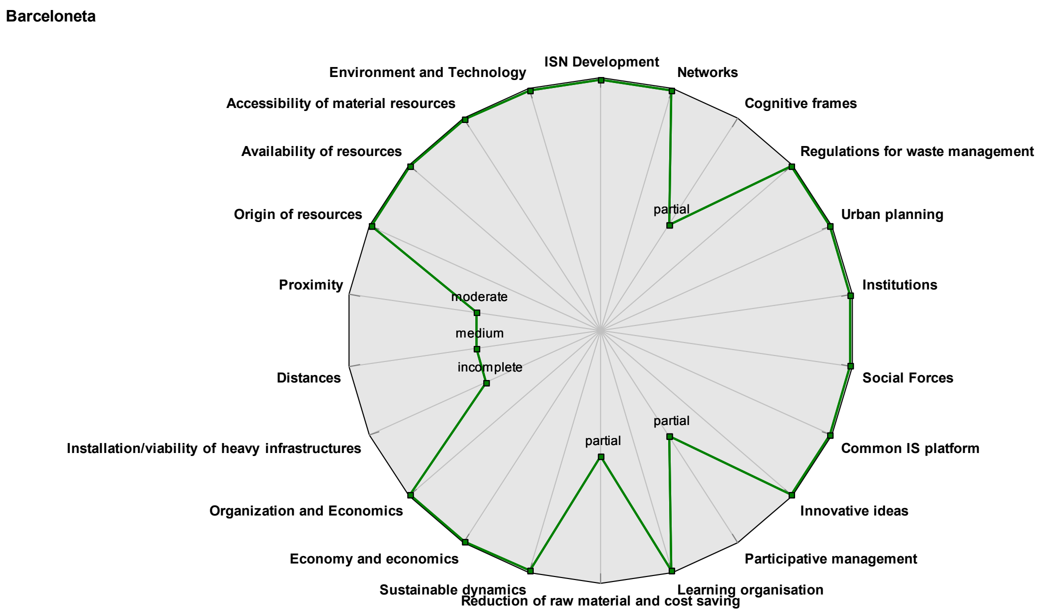

Figure 5. Polar chart of the selected attributes for ISN in Barceloneta.

3.5. ISN in Kwinana

The Kwinana Industrial Area of Western Australia is emerging as a world leading example of IS. The Kwinana Industrial Area (KIA) was established in the 1950s and is Western Australia's most significant heavy industrial region. The area of 120 km^2 is located approximately 40 km south of Perth. About 3600 people work in the area's core industries, and many more in related sectors and service jobs. The total economic output of the area exceeds a $4.3 billion annually (Harris 1987). The KIA is home to a diverse range of industries ranging from fabrication and construction facilities through to high-technology chemical and biotechnology plants and large resource processing industries, such as titanium dioxide pigment production and alumina, nickel, and oil refineries. The instance of IS has considerably increased since the late 1980s, providing economic, environmental, and social benefits to the firms involved, the neighboring communities and the state. Following the successful development and start-up of two co-generation plants in 1997 and 1999, the KIA decided to explore further opportunities for IS exchanges in the area.

Kwinana is "mostly developed" IS because of the low accessibility of material resources that are due to the partial availability of resources, which are from mixed origin, and incompleteness of installation/viability of heavy infrastructure. The case of Kwinana has moderate social forces and satisfying organization and economics. The limited competition between operating firms and the isolation of other major industrial centers in eastern Australia are believed to be a cause of such social forces and proximity between actors in Kwinana. There are rigorous regulations in Kwinana, as in Kalundborg, with regard to handling availability of resources to produce alternative fuels (Baas and Huisingh 2008). The polar map of selected attributes for Kwinana is given in Figure 6.

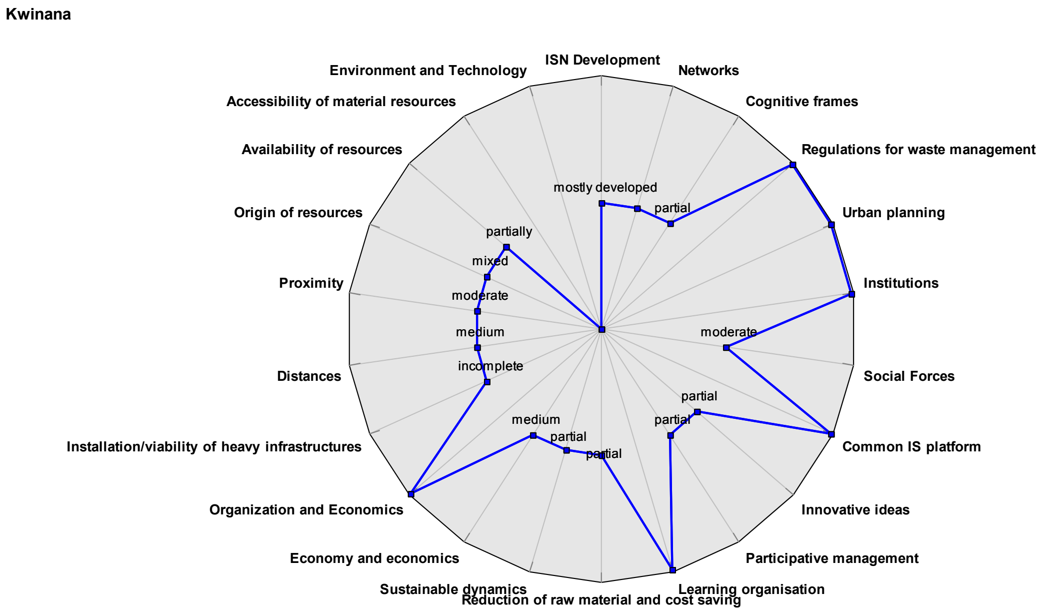

Figure 6. Polar chart of the selected attributes for ISN in Kwinana.

3.6. ISN in Gladstone

Gladstone is one of the main and largest mineral industrial clusters in Australia. It is located 540 km north of Brisbane, and 100 km southeast of Rockhampton and has a population of about 40,000 in the region that extends from Boyne Island in the south to Yarwun in the north. The Gladstone Area Industry Network (GAIN) was formed by the 9 members of the industries present in the region with a goal of improving the initiation of IS of large industrial area far away from the city and double the population compared to Kwinana. The district of enterprises is situated in Queensland, near the municipality of Gladstone and includes a coal power station, two aluminum refineries, an aluminum smelter, cement producer, and ammonia nitrate producer. There are 6 participant firms and the environmental benefits achieved by different symbiotic networks: approximately 10,000 tons per annum byproduct gypsum recovered for reuse, 170,000 tons per year CO_2 emissions reduction from one co-generation plant (Van Beers et al. 2006).

In Gladstone, the investment in water reclamation plant is a $29 million and 20% premium price on reclaimed water (Corder 2006; Corder et al. 2014). IS implementation activities are coordinated by the Gladstone Industrial Leadership Group and under the auspices and financial support of Centre for Sustainable Resource Processing. The district is mainly dominated by a single value chain, the alumina production (Gladstone Industry Leadership Group 2017).

ISN Gladstone is considered "fully developed". Its strongest aggregate attributes are: environment and technology, learning organizations, social forces and accessibility of material resources. The polar map of selected attributes for Gladstone is given in Figure 7.

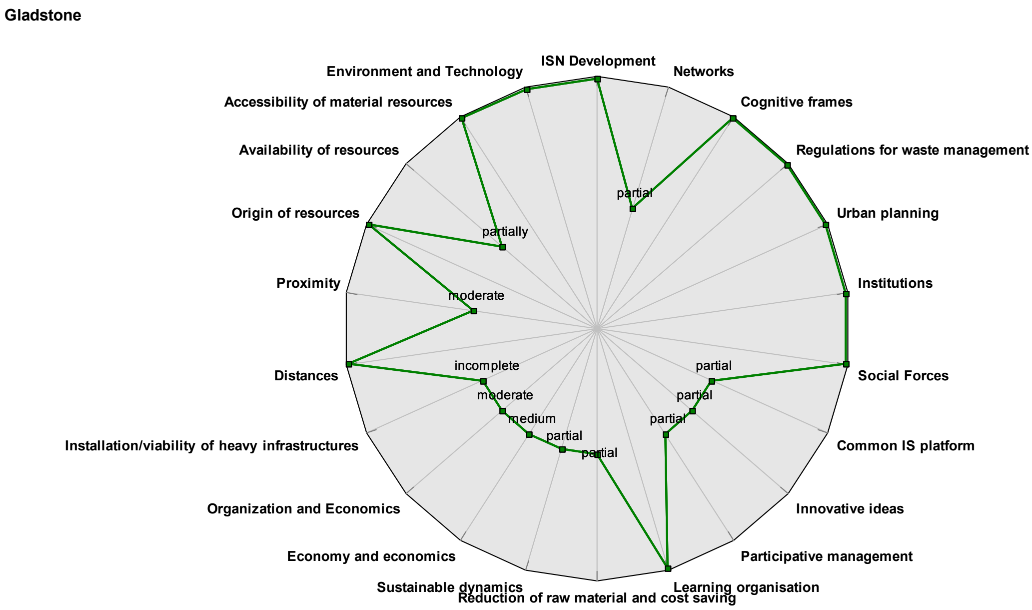

Figure 7. Polar chart of the selected attributes for ISN in Gladstone.

3.7. ISN in Rotterdam

The IS case Rotterdam Europoort is characterized by an IS organization located by the sea. The Eco-industrial park concept has been applied in the Rotterdam Harbor area by setting up an industrial ecosystem project. The Europoort/Botlek Interests (EBB) industry association has developed an intermediary role between government and industry. It defines goals and perspectives from the national environmental policy domain to its member firms. Even though the association does not have legal power, it has a position of "social control" to run the development in the area. Half the land area is looked after by Rotterdam Municipal Port Management (RMPM). Since 1998 the decisions and evaluation concerning different Industrial Ecosystem (INES) projects have been made by a decision-making platform that consists of members of national and regional industry associations, plant managers, national and regional governmental organizations, an environmental advocacy organization and academia (Baas 2011; Symbiosis 2010).

The attribute "environment and technology" is evaluated as "weak" due to "low" "accessibility of material resources". The learning organization is evaluated as satisfying, due to the moderate values of economy and economics and partial common IS platform. The organization and economics are considered "moderate". For Rotterdam, the evaluation for attributes "regulations for waste management" and "urban planning" are based on the comparison to the other six IS cases. We found that some of the "weak" impacts of environmental regulations in Rotterdam are caused by other dimensions of social embedding such as cultural embedding. This means that the effects of informal ISNs on innovative behavior and on innovation strategies of large firms have been found to be less common in comparison to the reported cases for other ISNs. Despite the dimensions of cognitive frames of embedded routines that are restricting new links in a holistic approach of Rotterdam Harbor region, there is a possibility for development of new concepts such as the design of compressed air systems for a group of firms (Baas 2011). Although the Rotterdam Harbor and industry complex is a heavily industrialized area, approximately 100 km^2 large, with about 1 million inhabitants in the urban surroundings, research projects such as the utilization of reduction waste heat, CO_2 and nutrients from the district heating firms in greenhouses, biofuel synergies, landfill and urban mining and planning only started in 2010 (Baas 2011). The polar map of selected attributes for Rotterdam is given in Figure 8.

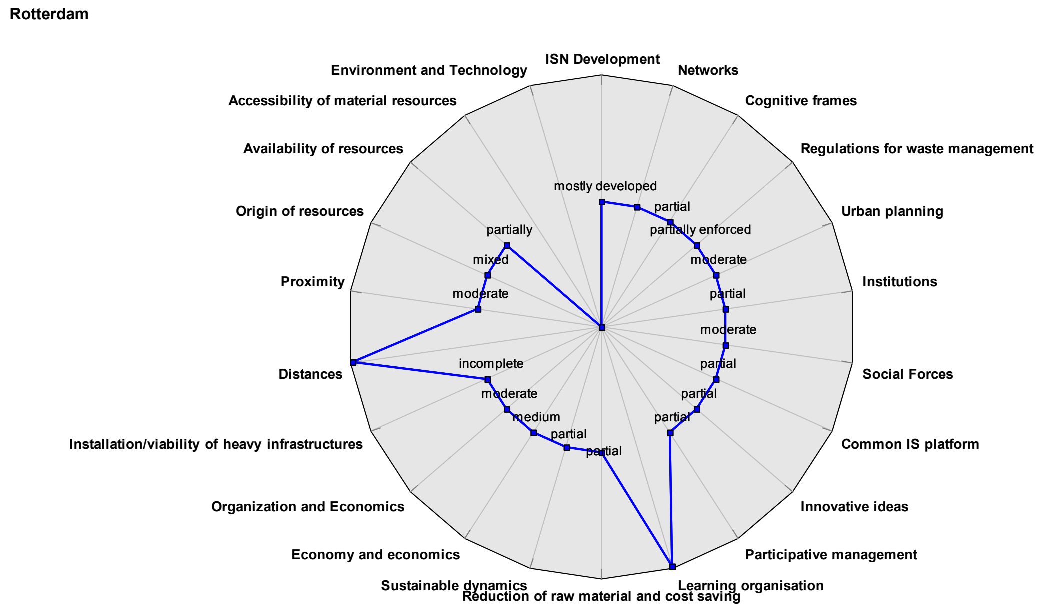

Figure 8. Polar chart of the selected attributes for ISN in Rotterdam.

4. Discussion and Conclusions

At this stage, a qualitative multi-criteria model for evaluation of the level of development of regional ISNs was developed. The model is based on the available literature for ISNs, from which we have extracted the most relevant and most general attributes. We have also defined the relations among attributes in terms of easily understandable "*if* ... *then*" rules.

To construct the model, we used seven real ISNs. The evaluation of the seven IS cases based on the developed model as well as consulted literature resulted in the following conclusions. Forming an ISN is a complex process that requires an extensive knowledge from social, organizational, environmental spheres as well as a good understanding of economy and technology. The developed model for evaluation of an ISN is designed through a set of indicators from each of the spheres and has a comparative and/or descriptive role to understand the requirements of development of an ISN. Since evaluation of ISNs based on one qualitative indicator leads to a high uncertainty in the evaluations, we used an approach in which we developed several indicators for the input attributes in the model. Based on the number of indicators that the ISN fulfills for the given attribute, we have performed more realistic evaluation of ISNs. Still, the evaluations could be changed by adopting new literature sources. Our belief with the use of the new model is that the decision makers could surpass the imposed disciplinary boundaries by the involved interdisciplinary research areas and enable them to evaluate and analyze the requirements for development of improvement of an ISNs.

One of the biggest barriers for increased IS activities is the lack of awareness about the potentially strategic business and development of the value of IS. There is also limited management attention given to the ISN concept. These can be overcome by helping decision makers understand the importance of the development of ISNs and the proposed model could be used in providing support to the decision makers in this context. The next challenge is identifying opportunities for creating regional ISNs. Creation of local dynamics and platforms that intensify communication among actors is one effective way of addressing this challenge. Further support can be provided by systemic assessment of the needs and capacities of all included actors in the process of development of a local ISN. Other challenges include the rate of return of required investments, access to finance, regulatory requirements, and concerns about operational disruptions. Some of these barriers can be addressed by public sector interventions.

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Appendix A. Description of Attributes

The topmost attribute, *ISN Development*, is an aggregated one that depends on the values of the *environment and technology*, *organization and economic*, and *social forces* attributes.

Environment and Technology fuses the availability and exchanges of material resources and the proximity of the physical plants. The longer distances between plants imply higher transportation costs. For example, if the exchange of material between plants involves transfers by pipelines, the capital costs of construction would increase in line with the distance of the plants. On the other hand, wheeled transports of materials regard less initial costs; however, the operating costs become more significant due to the increased noise, fuel usage, dust, and traffic. Because of that the ISN development is modeled through the feasibility of: developed or possibility for development of an accessibility of material resources in line with the IS requirements, availability of resources, distances in the area where ISN should be developed, and proximity-vicinity of the businesses (Doménech Aparisi 2010; Doménech Aparisi and Davies 2011; Ashton 2008; Almasi et al. 2011).

Accessibility of material resources is an attribute that describes the firms' access to industrial water, energy, and production materials (primary and secondary). Resource scarcity spurs resource efficiency and innovation. Resource efficiency refers to using the available and limited resources in a sustainable manner while minimizing impacts on the environment. Resource innovation means that firms focus on resource reduction and recovery (Corder 2006; Ashton 2008; Almasi et al. 2011).

Availability of resources is an attribute that describes the availability of resources in the region such as water, energy, fossil fuels, steam or production of raw materials (Cohen-Rosenthal and Musnikow 2003). Due to the increased concentration of industries with high usage of the material resources for their productive processes, the pressure for availability of primary sources is increasing. This attribute may get values of "no" meaning that the region does not have any available resources; "partial" meaning that the region has limited resources; or "yes" meaning that regain has available resources and these are not fully used by the existing industries (Almasi et al. 2011; Cavallo et al. 2012).

In this model, the attribute *availability of resources* may get values no, partially, and yes. It is measured on the bases of general characteristics of ISNs Development like:

1. High availability of water resources in the area.
2. Existing exchanges and reuse of different types of waste flows among firms.
3. There is an availability of critical resources such as energy, or particular raw materials.
4. There are public and private benefits shown as "spontaneous co-location" (Chertow 2007) of businesses in industrial districts, to give rise to numerous public, and private benefits including labor availability, access to capital, technological innovation, and infrastructure efficiency.
5. Availability of close port/s that are used for acquiring resources.
6. Availability of industrial land.

The value of the attribute Availability of resources is set as "yes" if the evaluated ISN satisfies 5–6 general characteristics described above, it has the value of "partially" if 3–4 general characteristics are satisfied and if it satisfies 0–2 general characteristics above, then it has an "no" value.

Origin of resources refers to the way of connection of the available resources. We divided the origin of resources in internal, external, or mixed. Internal available resources include land, water and all available natural resources among firms in the geographical connected IS. For example, when communities interact outside the political borders, they exchange and trade their internal resources to obtain external resources that are not available within their boundaries (political or natural) (Cohen-Rosenthal and Musnikow 2003). For mixed available resources, we simply meant the combination of internal and external resources available in each presented IS case (Cavallo et al. 2012).

Proximity. According to (Ayres and Ayres 2002), key ISN success factors are "collaboration and the synergistic possibilities offered by geographic proximity". They differ from one ISN to another and they have been largely discussed within the recent literature, often achieving slightly disagreeing results. Proximity considered as an important factor in the process of development of an ISN. In the process of considering economical and technical feasibility among firms, they firstly carefully analyze their neighbors' input and output flows, and try to find possible physical synergies. If they develop synergies with closely located industries, the infrastructure needed would be cheaper and their investment more profitable (Chertow 2007; Ashton 2008; Almasi et al. 2011). For example, IS ecologists generally believe that close geographical proximity and trust are essential to the development of IS. To move IS research forward, this article suggests engagement with research in economic geography on the concept of "proximity", which draws attention to the ways in which geographical, cognitive, institutional, social, and organizational distances between actors might affect innovation.

Distances are physical distances among firms. According to several IS cases, it seems that most synergies are taking place within a radius of 1 to 2 km distance between firms. Similar selection has been applied as a measurement scale to this attribute in the DEXi model {long, medium, short}. Having firms (Chertow 2007) concentrated in a small area having a short distance between them, can facilitate the feasibility of the IS process development. Long distances between firms can have an influence when making decisions (Cavallo et al. 2012).

In this model, the attribute *Distances* may get values long, medium, and short. When measuring distances, we considered:

1. Impacts of distance when making decisions among firms.
2. Metric distances between major cities and industrial centers in regional area.

Short distance refers to distances of up to are 2 km, medium distances are distances of up to 20 km, and more than 20 km are considered long distance.

The value of the attribute Distances is set as "short" if the evaluated ISN satisfies 2 general characteristics described above, it has the value of "medium" if we cannot confirm or deny any of two characteristics and if it satisfies none general characteristics above, then it has an "long" value.

Installation/viability of heavy infrastructures refers to the vicinity of the main infrastructure suppliers to the IS area, including knowledge and technical expertise. Different types of infrastructures ensure a good circulation of flows between firms such as roads among firms, environmental infrastructures, water supply sewer and waste management units, pipelines, heat exchangers, cooling systems, etc. These components must work properly in order to have successful IS system (Chertow and Lombardi 2005; Ashton 2008). It is important to take into consideration also the vicinity of engineers and people having specific knowledge of close setting, because it can facilitate social networks in the participating firms.

In this model, the attribute *Installation/viability of heavy infrastructures* may get values impossible, incomplete, and possible. It is measured on the bases of general characteristics of ISNs development like:

1. IS project does not have significant limitations of viability of transporting certain types of resources over long distances (such as steam or heat).
2. Sharing of access of heavy infrastructures (such as new waste exchange systems relying on pipeline or other heavy infrastructures; extensive roads, rails and port infrastructures to allow for reliable transport) is in place (to reduce atmospheric emissions).
3. Geographical dispersion of firms enforces laws and regulatory codes
4. Firms have an agreement to share the use of the installations.
5. The region has potential for renewable energy to a region's (country) natural capabilities.
6. There is a possibility for installation of heavy visible infrastructures.

The value of the attribute Installation/viability of heavy infrastructures is set as "possible" if the evaluated ISN satisfies 5–6 general characteristics described above, it has the value of "incomplete" if 3–4 general characteristics are satisfied and if it satisfies 0–2 general characteristics above, then it has an "impossible" value.

Organization end Economics refers to IS cooperation of firms with mutual benefit to cutting costs and improving the environment. This is an aggregated attribute that depends on *Economy and economics*, *Learning organization*, and *Common IS communication platform* among firms in the ISN. (Cohen-Rosenthal and Musnikow 2003) Organizations may form different networking relations to complement each other by sharing knowledge and information; to have common businesses by selling or purchasing; to share common facilities or even cooperate in technological innovations (Chertow 2007). ISN could provide innovations through implementing activities to eliminate common environmental impacts and develop organizational collaboration and learning strategies (Henriksen et al. 2013; Gladstone Synergies Project 3C1 Final Report 2017; Uzzi 1996; Golev et al. 2014). At organizational level, it is hardly possible to measure interactions between actors and structures (as the model indicates), because they are not an actor/structure. *Organization and Economics* attribute is composed of mechanisms that are considering IS organizations in a metaphorical way—theory suggests that such organization is seen as an organism adapting to its environment (Chertow and Lombardi 2005; Cavallo et al. 2012).

Economy and economics is one of the key motivation of firms to join the ISNs and hence to cooperate in resolving existing environmental issues. The motivational drivers led firms to establish environmental ISNs are basically the economic benefits such as cost savings, reducing costs by sharing investments in large joint infrastructural projects, ensuring availability of needed resources, such as water and energy, and implementing harsher legislative requirements (Aalborg Industries 2017; Laybourn 2015) The economic benefits of ISNs are measured by determining the extent to which firms recycle byproducts, for example in the form of financial savings through implementation of IS are based on reduction of various types of costs (cost of material, energy-related costs, waste-management costs, and costs of environmental legislation compliance). For example, when two firms cooperate in exchanging wastes, the economic benefits stemming from such cooperation can be quantified. The gross economic benefits stem from lower input purchase costs and lower waste disposal costs. There is different cost sharing policy that firm can use in exchanging wastes: firm X pays all the costs arising from IS, or firm Y pays all the costs arising from IS, or costs arising from IS are shared among firms.

Sustainable dynamics is an attribute that describes the possibilities to create economic growth, while advancing social and environmental objectives through an ISN. According to Schiller et al. (Schiller et al. 2014) "A sustainable community uses its resources to meet current needs while ensuring that adequate resources are available for future generations. It involves all its citizens in an integrated, long-term planning process to protect the environment, expand economic opportunities, and meet social needs."

In this model, the attribute *Sustainable dynamics* may get values weak, partial, and strong. It is measured on the bases of general characteristics of ISNs development like:

1. A firm's objectives are directed towards sustainable developments for the IS to have success.
2. Sustainable dynamism in the firms includes integrated policy, planning, and social learning processes.
3. Sustainable dynamics and objectives are successfully managed to be integrated in the policy programs of government.
4. Sustainable objectives are achieved by practical implementation of sustainable principles—decision-making processes.

Environmental, economic and social objectives have oriented firm's efforts in the reduction of main environmental impacts on a continuous process, contributed to reinforcement of the firms' commitments (Doménech Aparisi 2010). The value of the attribute Sustainable dynamics is set as "strong" if the evaluated ISN satisfies 4–5 general characteristics described above, it has the value of "partial" if 3–4 general characteristics are satisfied and if it satisfies 0–2 general characteristics above, then it has a "weak" value.

Reduction of raw material and cost saving means that firms on an individual level have outcomes in terms of reduction of raw material, reuse and recycle of products that leads to cost savings and positive impact on the environment. When being part of an IS system, the firm tends to reorganize their production process so that the wastes or byproducts of one firm become the raw materials for another. One example has been described by Kalundborg, where a $60 million investment in Eco-industrial network infrastructure generated a $120 million in cost savings over five years. The so-called "win-win" situation is transferring firm's outputs to others so avoiding landfills disposal costs. This exchange can be remunerated and contributed to a rise of the firms' incomes (CRESSI Publications Saïd Business School No. 5 2015; Jacobsen 2005; Jacobsen and Anderberg 2005).

In this model, the attribute Reduction of raw material and cost saving may get values weak, partial, and strong. It is measured on the bases of general characteristics of ISNs development like:

1. Re-use of raw material can significantly reduce the industry vulnerability with regard to raw material scarcities (for example water, greenhouse gases).
2. Initiatives are put in place to resolve the reduction of raw material and cost saving situation.
3. Providing real value of the money to the firm in some way, such as through cost savings or increased revenue.
4. Implementation of collaborative technologies for reduction, reuse, and recycling of raw material.

The value of the attribute Reduction of raw material and cost saving is set as "strong" if the evaluated ISN satisfies 3–4 general characteristics described above, it has the value of "partial" if 1–2 general characteristics are satisfied and if it satisfies none of the general characteristics above, then it has a "weak" value.

Learning organization is explained as a concept where one has an ease of making and breaking connections as conditions change. In other words, it enables including innovative ideas of employees in the decision making process. Firms' management is usually aware of the usefulness of networking as a way of obtaining knowledge and information sharing. New approaches and ideas for firms' management can be drowned from gaining new contacts to other firms. Networks could be created as a knowledge pool from which the existing and new firms could benefit (Corder 2006; Steward 2008; Almasi et al. 2011).

Participative management describes an approach that allows employees to participate with suggestions in the development of the firm. To recognize the employers' ideas, firms organize workshops and brainstorming sessions with different technicians and engineers to collect new feasible ideas concerning potential synergies (Chertow 2007; Ashton 2008). Employees who are not members of the management teams are included in the decision making process by allowing them to produce new ideas in the process of product reengineering.

Innovative ideas are attributes that describe cases when employees are allowed to produce new, innovative ideas in the process of product reengineering. Namely many firms are aware of the potential of their employees and customers' knowledge, experience and ideas that may lead to improved ISNs.

In this model, the attribute *Innovative ideas* may get values weak, partial, and strong. It is measured on the bases of general characteristics of ISNs Development like:

1. Accumulated know-how developed through long experiences and relationships of employees.
2. Sharing of information and know-how among employees.
3. Collaboration and dialogue in firms resulted in new ideas.
4. Encouraging creativity and innovation of employees.
5. Common cooperation is associated with development of ISNs of cooperative relationships between people, acting essentially as individuals, exchanging ideas, knowledge and advices in firms.

6. Firms considerate the order to further employee's efforts to improve, make progress and evolution in the environmental performance of the organization they represent.

The value of the attribute Innovative ideas is set as "strong" if the evaluated ISN satisfies 5–6 general characteristics described above, it has the value of "partial" if 3–4 general characteristics are satisfied and if it satisfies 0–2 general characteristics above, then it has a "weak" value.

Common IS platform: these platforms, called also pools or communications Centers, aim to provide communication as well as cooperation platform for the firms in the ISNs. These platforms offer the firms extra professional activities and better social links. They were developed to reach out beyond the existing ISNs and communication between managers, by measuring the in/out degree (ties claimed by others about the actor and ties claimed by the actor about others respectively). From literature, it has been found that some authors use these platforms to analyze the average degree (number of ties per firm), density (ratio of actual ties to all possible ties), and average constraint (measures how constrained each node is by its neighbors) (Jereb et al. 2003) of the ISN.

In this model, the attribute Common IS platform may get values no, partial, and yes. It is measured on the bases of general characteristics of ISNs Development like:

1. Existing institutional platforms and linkages, communication and trust, coordination.
2. Comprehensible databases; both existing and potential businesses can easily identify possible synergistic connections.
3. The available inventory and assessment of potential symbiotic connections (Rehn 2013).

The value of the attribute Common IS platform is set as "yes" if the evaluated ISN satisfies 3 general characteristics described above, it has the value of "partial" if 1–2 general characteristics are satisfied and if it satisfies none of the general characteristics above, then it has a "no" value.

Social forces consider different aspects from the social theory including *Institutions, Cognitive frames, and Networks* that are not the only devices to resolve coordination problems in market fields, however play a major role in defining the ISNs (Beckert 2009). While some firms have a great benefit from the existing network composition, institutional rules, and cognitive mindsets in the market field, others are disadvantaged. Hence, the IS actors (decision makers) are engaged in an ongoing struggle to change or to defend the social forces operating in the field (Fligstein 2002).

Social aspects in IS also involve groups, industries to exchange by products and sharing utility, and interactions among actors (Beckert 2010). Social platforms (e.g., environments/social clubs/associations etc.) that engage different industries to come together to share the common understanding and build networks between firms are important. To promote ISNs, it is important for institutions or external agencies (e.g., IS institutes/Eco-town Centers/universities) to link with the social platform of industry, so that they can establish a good relationship and trust with one another for easier information exchange and development of synergies. Also, holding periodical stakeholder discussions, public dialogue with industries promotes IS and facilitates match making. This will help to cultivate their interest and willingness to actively participant in potential synergies. Building a strong social cohesion among industries takes time. The model provides an insight of IS networking that presents social interactions as social forces—institutions (laws, central concern for law, the formal mechanism for political rule-making and enforcement...), networks (social structure made up of a set of social actors (such as individuals or organizations and a set of the dyadic ties between these actors) and cognitive frames (social interaction, meaning-making technologies, and strategically-selective opportunities for reflection and learning) (Chertow 2000; Chertow 2007).

Institutions are often defined as rules and shared understandings that structure market exchange, encompassing formal parameters such as labor laws, subsidies, intellectual property rights and industry standards as well as informal norms, routines, ethics, and conventions that shape the practice of market actors (Fligstein 2002). Actors that do not trade, but regulate markets implement some of these institutions. Other institutions are established by sellers, buyers, workers, cultural intermediaries, or consumers who populate a field and who have settled on arrangements to produce, distribute, evaluate, and consume certain products, either because of conscious agreements or because of what field participants perceive to be "normal" (Corder 2006). Institutions are considered as social forces and are primarily understood as cultural scripts providing orientation for actors under conditions of uncertainty. (Chertow and Lombardi 2005) The alternative concept of institutions, conceived as state-devised formal rules that regulate and constrain the behavior of economic actors (Black Sea Industrial Symbiosis Platform 2017) forms the conceptual background of historical institutionalism and comparative political economy but finds limited attention in the new economic sociology (Talent 1997).

Urban planning is a sub-attribute of *Institution* and describes the conditions of granting planning permissions, and organization of the overall land use, protection and use of the environment, public welfare, as well as providing a design of the urban environment. The *Urban planning* in terms of IS tells how and for what a specific area is used for. Also, such as where pipes and electricity should be placed, and is created when new industrial building areas are constructed. Urban planning can be altered by the municipality after conducting several legal steps. The openness and easiness to modify an urban plan to allow building of new ISN infrastructures heavily depends on the area and the preferences of the decision makers on a municipal level (Jereb et al. 2003). For example, when planning a new waste exchange systems or heavy infrastructures, changes in the urban plan need to be approved and followed by municipally permission and local population (Shi et al. 2010; Almasi et al. 2011).

In this model, the attribute *urban planning* may get values low, moderate, and satisfying. It is measured on the bases of general characteristics of ISNs development such as:

1. Existence of a controlled rural urban migration, urbanization with proper planning, and rapid industrialization with good infrastructure.
2. Existence of an on-site waste management plans.
3. Proper planning for required material quantities, on time passing of information on types and sizes of materials and components to be used.
4. Good supervision of the urban planning (Letcher and Vallero 2011).

The value of the attribute Urban planning is set as "satisfying" if the evaluated ISN satisfies 3–4 general characteristics described above, it has the value of "moderate" if 2 general characteristics are satisfied and if it satisfies 0–1 general characteristics above, then it has a "low" value.

Regulation and waste management describe the legislative matters setting limitations in terms of possibilities and quantities in regards to flows exchanges between IS firms (Schiller et al. 2014). Enforcing waste disposal regulations can trigger networking and synergies among firms, so that they can be able to cope with all imposed limitations. The process of obtaining permission is time consuming (Cohen-Rosenthal and Musnikow 2003). For example, the procedure of obtaining permissions can be described in four consecutive steps. First a draft proposal for a new local area change is submitted. Afterwards, the proposal has to be accepted by the City Council (or equivalent body). Next the new urban plan including the proposal is given to the published in order to obtain the public opinion. Finally, the municipality administration agrees on the plan changes and publishes it. Environment laws and regulations can be introduced to encourage industry to adopt environmental technology and form symbiotic linkages. IS becomes more economically feasible when enforces the legislation. Establishing relevant taxes, fees and levies are a motivation tool for development of an IS. The environment taxes on certain raw resources foster the development of synergies to consume fewer raw materials (Chertow and Lombardi 2005).

In this model, the attribute *Regulation and waste management* may get values fully enforced, partially enforced, and weakly enforced. It is measured on the bases of general characteristics of ISNs Development like:

1. Exists a governmental action and commitment for reform towards green growth.
2. Emergence of a variety of Eco-innovations as a result of regulatory and market-based instruments.
3. Enforcement of environmental taxes and regulations on harmful substances.

4. A literature evidence that government regulations and liability concerns are one of the reasons for action in developing synergy initiatives.

The value of the attribute Regulation and waste management is set as “fully enforced” if the evaluated ISN satisfies 4–5 general characteristics described above, it has the value of “partially enforced” if 2–3 general characteristics are satisfied and, if it satisfies 0–1 general characteristics above, then it has a “weakly enforced” value.

Cognitive frames: according to Beckert (Beckert 2009), cognitive frames are one of the three irreducible social forces that exercise their influence through constituting the perception and legitimation of institutional forms and network structures. In the social sciences, cognitive framing comprises a set of concepts and theoretical perspectives on how individuals, groups, and societies, organize, perceive, and communicate about reality. Moreover, they are shaped specifically within social networks (Almasi et al. 2011; Ashton 2008). Cognitive framing involves social construction of a social phenomenon—by mass media sources, political or social movements, political leaders, or other actors and organizations. In social theory, framing is a schema of interpretation—a collection of anecdotes and stereotypes—that individuals rely on to understand and respond to events (Beckert 2009).

In other words, people build a series of mental “filters” through biological and cultural influences. They then use these filters to make sense of the world. The choices they make are influenced by their creation of a frame (Social Constructionism 2016). The aim of changing can address cognitive frames among the marginalized themselves, or cognitive frames of groups that exert an influence on contextual conversion factors, or cognitive frames spanning across both groups. For example, despair about social mobility can erode the motivation of marginalized groups in striving for (educational) achievements and this is typically addressed by empowerment and education approaches (CRESSI Publications Saïd Business School No. 5 2015). This attribute may get values weak, medium, and strong and has been measured according to some general characteristics of ISNs that were elicited from the literature:

1. The changes of environment may lead to marginalization of the firms in cases when firms are not adaptable to the changes.
2. Some insights are present on the interrelation and dynamics among cognitive frames and other two social forces.
3. Highly innovative solutions that alter cognitive frames might outweigh long-established institutional incentives like tax exemptions.
4. There are present and implemented sanctions that are aimed to foster the integration of persons into the employment force in IS.
5. Sheared meaning structures might be incorporated in the notion of institution and therefore cognitive frames are not explicitly distinguished (Beckert 2010).

We set the value of the attribute Cognitive frame as “strong,” if the ISN satisfies 4–5 general characteristics above. If ISN satisfies 2–3 general characteristics above, then has a “medium” value and, if it satisfies the 0–1 general characteristics above, then the value is “weak”.

Networks are social relations (personal or organizational) between market actors (producers, consumers, suppliers, regulators, workers) and express the mental maps and the structure of the existing social relations (Beckert 2010).

The objectivity of networks is not constituted by the position of nodes and the structure of their connections as such, but by the dominant interpretations through which actors perceive the network structure. Networks generate trust, facilitate the exchange of information, or reduce risks. The opposite can be a comparison with ties that are founded solely on cost calculations. Network relations and based on the expectation of reciprocity (Granovetter 1985). In this model, the attribute *Networks* may get values weak, medium, and strong. It is measured on the bases of general characteristics of ISNs like:

1. Number of different public sectors or actors that can support IS developments in different ways.

2. Network is considered strong if public sector can set ambitious local policies demanding improved waste management and/or reduced emissions, creating the context for symbiotic exchanges.
3. Public sector can influence on the highly effective relationships and information brokers, by creating vital conditions for communication, familiarity, and trust among regional actors in IS.
4. The planning in IS, and procurement functions can also be adapted to create more fertile contexts for the development of ISNs.
5. Networks can support or hinder symbiotic relationships relevant to ISNs, with focus on the influence of the policy framework like the nature of inter-firm business models and governance mechanisms; and the role of public–private partnerships (Granovetter 1985).
6. IS networks being "embedded" (Baas and Huisingh 2008; Kalundborg Symbiose 2017) in social systems and, as such, decision-making processes are shaped by social relations (regulation systems, trust, beliefs, and knowledge are crucially influencing the direction and management of physical exchanges) (Jacobsen 2005; Jacobsen and Anderberg 2005).

The value of the attribute *Networks* is set as "strong" if the evaluated ISN satisfies 5–6 general characteristics described above, it has the value of "medium" if 3–4 general characteristics are satisfied and, if it satisfies 0–2 general characteristics above, then it has a "weak" value (Boshkoska et al. 2017).

Appendix B. Utility Functions

All utility functions that are used in the DEX model are given in Figures A1–A6.

From Figure A1 follows that the attribute *Proximity* is evaluated as "low" if *Installation of heavy infrastructures* is "impossible" or the *Distances* among firms are "long" and the *Installation/viability of heavy infrastructures* is at most "incomplete". Otherwise the *Proximity* is evaluated as "satisfying".

	Distances	Installation/viability of heavy infrastructures	Proximity
	29%	71%	
1	long	<=incomplete	low
2	*	impossible	low
3	long	*possible*	moderate
4	>=medium	incomplete	moderate
5	>=medium	*possible*	*satisfying*

Figure A1. Utility function of the aggregated attribute *Proximity.*

The evaluation of the attribute *Organization and Economics* is given in Figure A2. The attribute *Organization and Economics* is evaluated as "low" in cases when the *Economy and economics* is "low" and *Learning organization* attribute is evaluated mostly as "moderate", regardless of the value of the attribute *Common IS platform*. If attribute *Common IS platform* is evaluated as "no" (non-existent) and the *Learning organization* attribute is evaluated as "low", then regardless of the values of the *Economy and economics,* the attribute *Organization and Economics* is evaluated as "low". It is evaluated as satisfying when *Economy and economics* is evaluated as at least "medium", while *Learning organization* and *Common IS platform* have their most preferred values of "satisfying" and "yes", respectfully. If *Economy and economics* is evaluated as "high" and *Learning organization* is "satisfying", then regardless of the value of *Common IS platform,* the *Organization and Economics* is evaluated as "satisfying". However, if *Common IS platform* is "yes" than *Learning organization* should be at least "moderate" so that the *Organization and Economics* is evaluated as "satisfying". In all other cases the attribute is considered to be moderate.

	Economy and economics	Learning organisation	Common IS platform	Organization and Economics
	41%	41%	18%	
1	low	<=moderate	*	low
2	*	low	no	low
3	low	*satisfying*	*	moderate
4	<=medium	*satisfying*	<=partial	moderate
5	medium	<=moderate	>=partial	moderate
6	medium	*	partial	moderate
7	>=medium	low	>=partial	moderate
8	>=medium	<=moderate	partial	moderate
9	medium	moderate	*	moderate
10	medium	>=moderate	<=partial	moderate
11	>=medium	moderate	<=partial	moderate
12	>=medium	*satisfying*	*yes*	*satisfying*
13	*high*	>=moderate	*yes*	*satisfying*
14	*high*	*satisfying*	*	*satisfying*

Figure A2. Utility function of the aggregated attribute Organization and Economics.

The evaluation of the attribute *Economy and economics* is given in Figure A3. The attribute is evaluated as "low" if at least one of the attributes *Sustainable dynamics* or *Reduction of row material and cost savings* is evaluated as "weak", while the other one is evaluates as mostly "partial". On the other hand, if at least one of the input attributes is evaluated as "strong", and the other one at least "partial", then the attribute *Economy and economics* is evaluated with its most preferred value of "high". In all other cases the attribute *Economy and economics* is evaluated as "medium".

	Sustainable dynamics	Reduction of raw material and cost saving	Economy and economics
	50%	50%	
1	weak	<=partial	low
2	<=partial	weak	low
3	weak	*strong*	medium
4	partial	partial	medium
5	*strong*	weak	medium
6	>=partial	*strong*	*high*
7	*strong*	>=partial	*high*

Figure A3. Utility function of the aggregated attribute Economy and economics.

The evaluation of the attribute *Learning organization* is given in Figure A4. If *participative management* is "weak" and *innovative ideas* is at least "partial", then the *learning organization* is evaluated as "low". In case that the *Innovative ideas* is "weak" and *Participative management* is "partial" then the *Learning organization* is "moderate". In all other cases the attribute is considered to be "satisfying".

	Participative management	Innovative ideas	Learning organisation
	57%	43%	
1	weak	<=partial	low
2	partial	weak	moderate
3	*	*strong*	*satisfying*
4	>=partial	>=partial	*satisfying*
5	*strong*	*	*satisfying*

Figure A4. Utility function of the aggregated attribute learning organization.

The evaluation of the attribute *Social Forces* is given in Figure A5. If at least two input attributes are evaluated as "weak", regardless of the value of the third input attribute, the *Social Forces* are evaluated as "low". Similarly, if at least two input attributes are evaluated as "strong" at the third one as least "partial", then *Social Forces* are evaluated as "satisfying". In all other cases the *Social Forces* are evaluated as "moderate".

	Institutions	Cognitive frames	Networks	Social Forces
	33%	33%	33%	
1	weak	weak	*	low
2	weak	*	weak	low
3	*	weak	weak	low
4	weak	>=partial	>=partial	moderate
5	<=partial	partial	>=partial	moderate
6	<=partial	>=partial	partial	moderate
7	*	partial	partial	moderate
8	partial	<=partial	>=partial	moderate
9	partial	*	partial	moderate
10	>=partial	weak	>=partial	moderate
11	>=partial	<=partial	partial	moderate
12	partial	partial	*	moderate
13	partial	>=partial	<=partial	moderate
14	>=partial	partial	<=partial	moderate
15	>=partial	>=partial	weak	moderate
16	>=partial	*strong*	*strong*	*satisfying*
17	*strong*	>=partial	*strong*	*satisfying*
18	*strong*	*strong*	>=partial	*satisfying*

Figure A5. Utility function of the aggregated attribute Social Forces.

The evaluation of the attribute *Institutions* is given in Figure A6. *Institutions* are considered as "strong" if *urban planning* is considered at least "moderate" and *regulations for waste management* are "fully enforced". If *urban planning* is "low" and *regulations for waste management* are at most "partially enforced" or *urban planning* is at most "moderate" and *regulations for waste management* are "weakly enforced" then *institutions* are considered as "weak". In all other cases *institutions* are considered as "partial".

	Urban planning	Regulations for waste management	Institutions
	43%	57%	
1	low	<=partially enforced	weak
2	<=moderate	weakly enforced	weak
3	low	*fully enforced*	partial
4	>=moderate	partially enforced	partial
5	*satisfying*	<=partially enforced	partial
6	>=moderate	*fully enforced*	*strong*

Figure A6. Utility function of the aggregated attribute Institutions.

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