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Organising urban symbiosis projects

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Urban symbiosis is a strategy to create a more efficient metabolism of cities. However, urban symbiosis requires the integration of different systems, which is hard to achieve. Actors involved in existing systems can hardly develop 'the bridges' that are required to connect the thus far unrelated worlds of pre-existing systems. This paper analyses two cases of urban symbiosis and focusses on the process of building new actor networks. Urban symbiosis projects are generally complex and involve various stakeholders. The authors conclude that the introduction of additional actors or an additional institutional framework might be an effective means to create bridges between actors that could facilitate a more efficient metabolism of cities.

1. Introduction

1.1 Urban symbiosis, the integration of urban systems for sustainable development

Sustainable development poses a major challenge to urban systems: energy-generating systems should become fossil free and far more efficient; waste disposal systems should become recycling systems; sewage systems should recover resources; transport systems should require no fossil energy and less space, while producing less noise and emissions; and industrial systems should become more resource efficient, while producing less waste and emissions. This requires a major reconfiguration of all technological systems. In 1989, the term 'industrial ecology' was coined by Frosch and Gallopoulos (1989). A key element of industrial ecology is the metaphor that technological systems should acquire ecosystems-like characteristics. In an ecosystem, species feed on each other's waste. Technological systems should be organised so as to facilitate 'cyclic flows of materials within the entire industrial ecosystem' (Graedel, 1994: p. 26).

In order to make man-made systems compatible with natural systems, four rules for industrial ecology were proposed

1. work towards closed material loops
2. aim at dematerialising industrial outputs
3. make thermodynamically efficient use of energy sources
4. avoid upsetting natural cycles (Ayres and Ayres, 1996; Ehrenfeld, 1997; Tibbs, 1992).

These rules have consequences for the interrelation of systems. Rule 1 for example promotes recycling, which implies that production systems will cooperate with waste handling systems (industrial waste systems or municipal solid waste systems). Dematerialisation (rule 2) requires products to become smarter, which often implies adding additional features to the product and the production process. Rule 3 promotes a symbiosis of energy conversion processes – for example, in the form of combined heat and power systems. Rule 4 creates an additional limit, which might, like the other rules, increase the necessity to integrate different systems (e.g. creating a need for combined transport corridors).

Urban symbiosis focuses on the built environment and refers to initiatives that aim at closing material and energy flows within a given urban area. This approach has been spearheaded in Japan (see e.g. Fujita, 2006) and leads to the gradual integration of thus far unrelated urban systems. This implies that cities will become 'super systems', as change in one system can affect other parts of that system. A successful recycling scheme might for instance change the energy content of municipal solid waste and affect the waste incinerator that produces district heating.

Although promising, the integration of systems is hard to achieve in practice and often fails. Technical problems may occur, regulations may be in the way and costs are always an issue (Baas and Boons, 2004; Mirata, 2004). For example, Hemmes (2009) pointed out that the integration of various types of systems often does not fit policy frameworks. Besides this, when systems integrate, the actors involved become interdependent. Such interdependence might create a risk to the partners, especially in volatile markets when conditions can easily change and fast adaptations are required. This can lead to reluctance to integrate systems (Boons and Baas, 1997).

The driving force of urban symbiosis projects is often an attractive 'technological vision' such as, for instance, creating biofuel from sewage/organic waste. However, a successful integration of systems requires a high level of consensus among all stakeholders: regarding the technological content as well as regarding the roles of each actor and their interrelation. If the attractive technological vision is made immune for the demands of actors involved, the scope for negotiation is minimised and differences in perceptions easily lead to conflict. This links to the fact that the integration of systems requires crossing the boundaries of organisations or even sectors. Organisations may have different cultures, routines, priorities and time frames for planning that are hard to reconcile (Pandis Iveroth, 2014). A large part of the potential for symbiotic relations between urban systems is not realised due to the actors being unable to reach agreement.

Thus far, studying the integration of systems is a relatively new subject in innovation studies (Mulder and Kaijser, 2014). There are four ways in which processes of integration of urban systems might be different from 'normal' innovation processes.

- By its nature, urban symbiosis requires rearranging pre-existing socio-technical configurations (Vernay, 2013). This means that existing systems may have to be adapted before the integration can take place. This can be problematic, especially when systems are structurally incompatible. For instance, the integration of water management and electricity production, by means of a hydropower dam, often creates a problem of prioritising the supply of electricity to customers or optimising water flows/water levels (for agriculture or flood safety, etc.). Hence this integration needs adaptation of the behaviour of actors and/or additional technology, or even a further expansion of the network (Mulder and Kaijser, 2014). Sometimes the incompatibility of technological systems is even the result of deliberate attempts of actors to keep systems apart, such as for instance the Paris metro and the Paris region train system (Latour and Hermant, 2006).
- Urban symbiosis is often motivated by its public benefits (contributing to sustainable development, diminishing public nuisances). As such, actors representing the public interest have to play a role in the process.
- Unlike innovation in products, in urban symbiosis the emphasis is not on a 'novelty conquering the world', but on a rearrangement of actors in a specific local context.

This paper discusses two empirical case studies and shows that creating bridges between urban systems is crucial to the success of their integration. The first case study briefly analyses the introduction of biogas transport fuel derived from sewage/organic waste. The case shows that the bridge can be of a technical nature and its creation can be facilitated by the presence of a dedicated systems integrator, that is, an actor who is dedicated to the integration of the systems rather than representing the interests of one system. In the second case study, a project aimed at using a drinking water well for generating heat (for district heating) by using a heat pump is analysed. In this case, the bridge is of a social nature and its creation is facilitated by the presence of an institutional framework that created space for public actors to take on a proactive role.

2. Sewage biogas as transport fuel

2.1 Sewage

The high organic content of sewage was traditionally a problem. Cleaning sewage required considerable energy (in about 1990, depending on the size of the system, about 20–45 kWh per person equivalent per year; now about 5 m^3 of biogas can be produced per person equivalent per year) and therefore organic waste was to be kept apart from sewage and collected separately. Composting organic waste was the preferred solution. However, the situation changed over time. In the early 1990s, sewage treatment was increasingly efficient and first attempts were made to generate biogas in the treatment facilities (Knight, 2010).

In 1996, Stockholm City was engaged in a bid for the Olympic Games of 2004. It intended to create a 'Green Olympic village', Hammarby Sjöstad, which would be a key distinguishing element of its bid (Figure 1).

One central suggestion emerged: the idea to generate biogas from sewage and upgrade the gas to use it as a biofuel. The municipal company Stockholm Water had some experience in upgrading sewage gas and 20 vehicles were already powered by biogas produced by a pilot facility (Energy Cities, 1999). In order to be able to sell the upgraded biogas as a biofuel, oil companies had to participate. The oil companies were reluctant as there was at the time hardly any demand for biogas.

To overcome this problem, in 1997, Stockholm City decided to replace 300 of its own vehicles by clean hybrid vehicles. Most of these vehicles were running on upgraded biogas (Birath and Pädam, 2010). Financial support was also given to companies willing to develop tanking stations for biogas (Zero and Low Emission Vehicles in Urban Society (Zeus, 2000). OK/Q8, Statoil and Shell agreed to open one fuelling station each to supply upgraded biogas (Energy Cities, 1999), and Stockholm City took care that a 'tanker lorry' was developed to transport the biogas from the wastewater treatment plant where it was produced to these three tanking stations.

In 2002, the regional public transport company SL decided to join the initiative. It invested in hybrid buses and built a biogas filling station and a pipeline to connect it to the biogas production at the wastewater treatment plant (Baesen *et al*., 2005; Biogasmax, 2010).

At the beginning of 2004, Stockholm City took an additional policy measure to boost biogas demand: taxi drivers could obtain permissions for extra mileage under the condition that they would run on at least 80% renewable fuel (Birath and Pädam, 2010).

Although biogas as vehicle fuel grew rapidly, there were still few private end-users, and the biogas market for passenger cars did not increase fast enough to ensure profitability for fuel companies

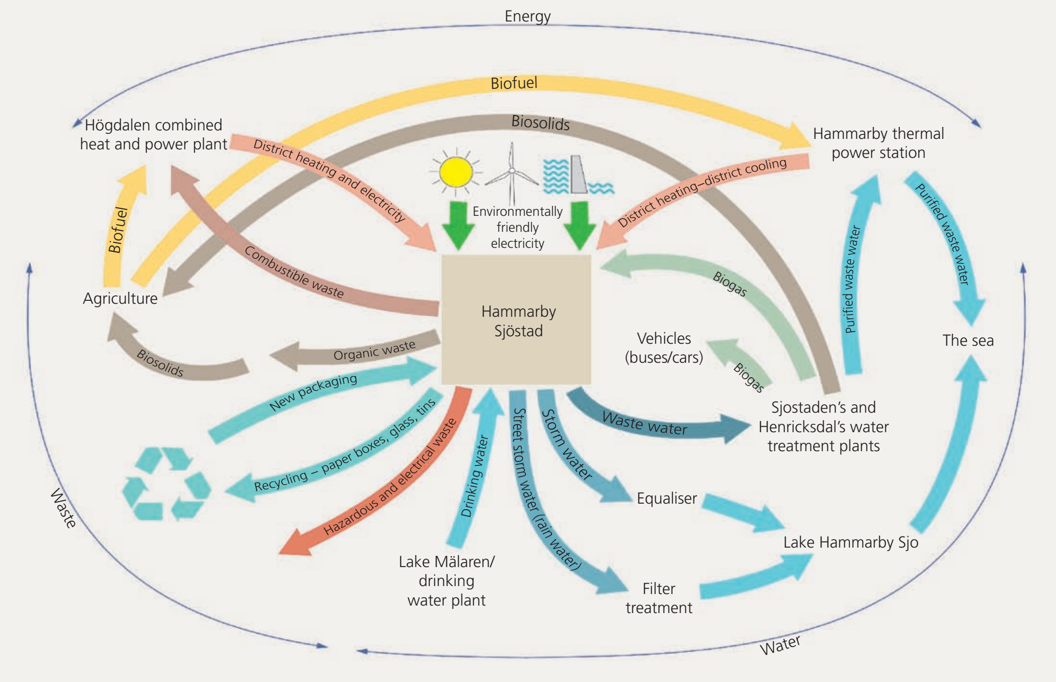


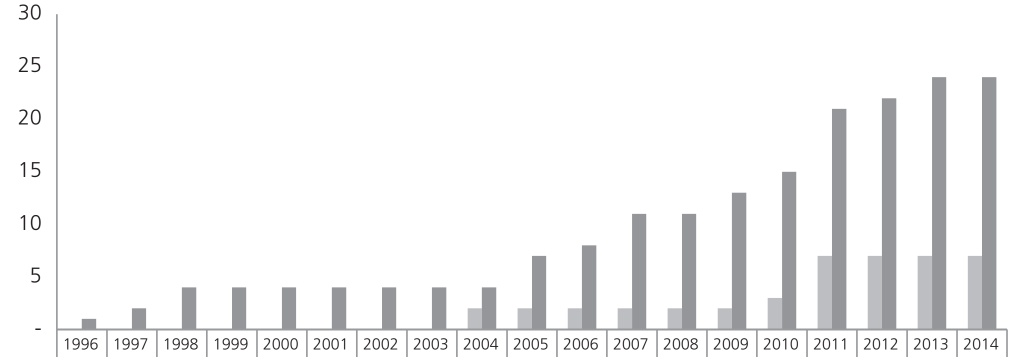
Figure 1. A cyclic metabolic model for Hammarby Sjöstad (Reproduced with permission from Rudden *et al.* (2015))

(Civitas, 2011). Stockholm City took a number of actions to boost the demand for biogas. In order to make clean vehicles more attractive, the city introduced a tax relief and special parking rates for owners of clean vehicles. To raise interest further a public relations campaign was organised. Moreover, the city planned four additional tanking stations for biogas (Plombin, 2003). However, the incentives were insufficient as drivers feared the limited geographical availability of biogas, and, for lack of a significant market, oil companies were not interested in expanding the number of biogas tanking stations: a 'chicken and egg problem'. One tanking station even decided to stop offering biogas (Baesen *et al.*, 2005).

Stockholm City ran out of policy tools to stimulate the use of biogas as biofuel and started looking for private investors to help expand the biogas infrastructure and overcome the chicken and egg problem. Most of the existing partners did not have the will and/or the capacity to develop the required biogas infrastructure. Stockholm Water aimed to be excelling in sewage treatment and had neither the resources nor the competences necessary to develop a biogas infrastructure, an activity that was too far from its core business. Besides, it was not used to market any product and the relations with its sewage customers were quite different from those needed for marketing biogas. This is a typical characteristic of an 'accumulative infra-system' collecting 'something' from distributed clients (Frantzeskaki and Loorbach, 2010). The oil companies aimed at showing their willingness to become 'green'. However, it was a side issue for them, and they were not much interested in supplying a fuel that required a new tanking technology, and that would only take market share from their existing products. Only one of the partners, the company AGA gas, a subsidiary of the Linde group involved in industrial gas transport and storage, showed interest (Civitas, 2011). The situation in Stockholm created new options for AGA gas to expand its portfolio. The company was also involved in setting up a biogas infrastructure in other parts of Sweden (Sjödahl, 2009). AGA gas negotiated the sole right on all biogas produced by Stockholm Water except for the biogas reserved for SL's buses (Biogasmax, 2010). It convinced oil companies to co-invest in four new tanking stations (Civitas, 2011) and invested in the tanker lorries necessary to distribute the biogas (Figure 2).

In 2006, registration of clean vehicles in Stockholm City really started taking off. The demand for biogas began to grow so fast that there was a shortage of biogas in 2007 (Birath and Pädam, 2010; Pandis Iveroth, 2014). Various wastewater treatment plants in the vicinity of Stockholm also started to engage in the production of biogas (Figure 3).

The success of biogas as transport fuel in Stockholm was ultimately the success of Stockholm City and AGA gas. First, the municipality was able to create the necessary conditions for a private actor to be willing to take the risk and invest in the missing biogas infrastructure. Second, AGA gas was at the right moment willing to break the deadlock that was created because of the chicken and egg problem. Gas being its core activities, AGA



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Non-public	-	-	-	-	-	-	-	-	2	2	2	2	2	2	3	7	7	7	7
Public	1	2	4	4	4	4	4	4	4	7	8	11	11	13	15	21	22	24	24

Figure 2. Number of biogas stations in Stockholm region (Source: Biogas öst, see http://www.biogasost.se/KartaStatistik/Tankst%C3%A4llen/Stockholm.aspx)

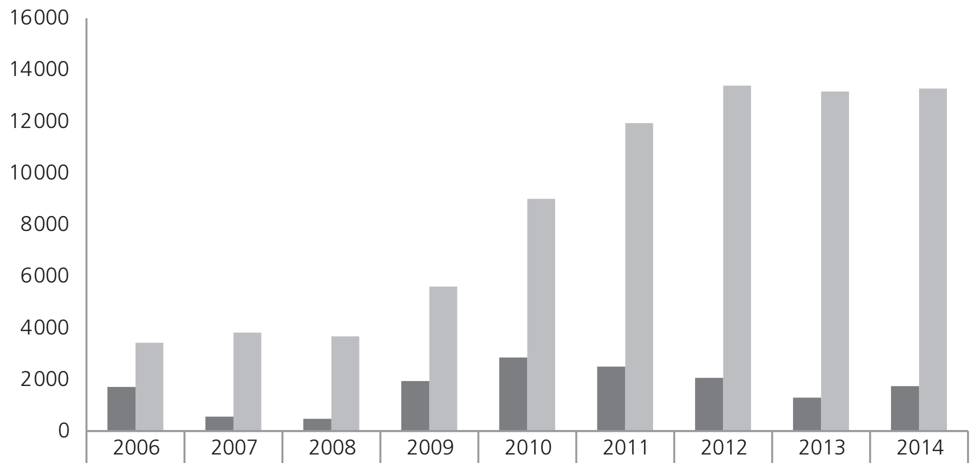
gas saw an opportunity to enter a new promising market: transport. With vested interest in the project, it became dedicated to the success of biogas as biofuel. It had both the will and the capacity to bridge the systems of sewage treatment and transport fuel, which made it the ideal actor to overcome the chicken and egg problem.

This case shows that a bridge, embodied by a biogas distribution infrastructure, was needed to be able to integrate wastewater transport and transport fuel. This bridge could be successfully developed thanks to the presence of a ‘dedicated systems integrator’. This actor did not have any stake in the two systems that were to be integrated. Instead, its interest was in making sure that synergies could be created between these two systems as they exchanged (by)products.

In the next case, it will be shown that a bridge can also be more a social construct that creates space for public actors to take on an active role and facilitate stakeholder negotiations.

3. Water as a heat source: a water company exploring expansion

EVA Lanxmeer is a new district of Culemborg, a small town in the central part of The Netherlands. This urban area has a peculiar history: it has been initiated by a group of committed citizens and renowned experts, organised in the EVA Foundation, who wanted to create an exemplar of sustainable urban development. They found in the municipality of Culemborg a partner willing to cooperate in the realisation of their ambitions. These ambitions included sustainable water and resource management and the active participation of future inhabitants who were considered to



	2006	2007	2008	2009	2010	2011	2012	2013	2014
New registrants	1714	556	476	1941	2851	2501	2059	1297	1746
Total	3422	3818	3671	5600	9001	11935	13381	13161	13268

Figure 3. Biogas cars in Stockholm region (Source: Biogas öst, http://www.biogasost.se/KartaStatistik/Gasfordon/Stockholm.aspx)

be experts of living. It is also the only urban area constructed in close proximity to a drinking water extraction plant.

In 1997, during one of the project meetings, the energy expert of the EVA Foundation heard that Waterbedrijf Gelderland (WG), the publicly owned drinking water company that exploited a nearby well, was planning to renew its installations. He suggested installing a heat pump in the new installations to use the extracted drinking water as a heat source for a district heating system (Sidler, 2011). (A heat pump can supply much more thermal energy than the electric energy it consumes. In EVA Lanxmeer, this is now approximately four times more (Thermo Bello, 2015a).) WG was attracted to the idea. As expressed by the energy expert: 'WG had a number of these pumping stations and wanted to be part of the game of renewables'. If a heat pump worked in Culemborg, it could also work elsewhere. WG nevertheless had one important condition: the initiative should have the support of the future inhabitants of the district (Goed, 2010; Sidler, 2011).

In the meantime, the inhabitants had started to organise themselves and had created the BEL, the association of inhabitants of EVA Lanxmeer. (All inhabitants would have to become members of the BEL. The association organises regular meetings and writes newsletters informing the inhabitants of events, developments or on-going issues in the district. Moreover, members of the BEL also wrote a 'bewonersboek' (residents' book) (BEL, 2003) explaining what EVA Lanxmeer is about.) It consisted of different working groups, one of which focused on the theme of 'energy and equipment'. This group helped the energy expert to conduct a feasibility study for district heating in EVA Lanxmeer. Additional cost calculations were carried out with the support of engineers from WG (Hanhart, 2010). In autumn 1999, a meeting was held in order to present the results. The majority of the inhabitants were convinced and voted in favour of developing a district heating installation in EVA Lanxmeer (VOEW, 2008).

In 2004 WG inaugurated the heat pump and started supplying heat to the dwellings in EVA Lanxmeer. The new district heating system suffered from various teething problems. The energy and equipment working group of residents offered some technical support. Despite minor disputes, the district heating system grew. New users were connected so that by 2006 about 165 dwellings and four businesses were served by the district heating system (VOEW, 2008). By that time, the largest part of EVA Lanxmeer had been built (Figure 4).

However, in 2006 the situation changed. Four years earlier WG had merged with WMO, another drinking water company, and Nuon-Water, the drinking water division of an energy company, and became Vitens. With 4 million customers, Vitens was the largest drinking water supplier of The Netherlands. Vitens' first priority was to refocus its activities in order to realise synergistic gains. The company still showed good will towards the small-scale EVA Lanxmeer heating project. However, the project lost its strategic position as creating a bridge that would allow the water company to expand into the district heating sector. In 2006 the company took the decision to sell its district heating assets. In search of an organisation that could buy the installations, Vitens

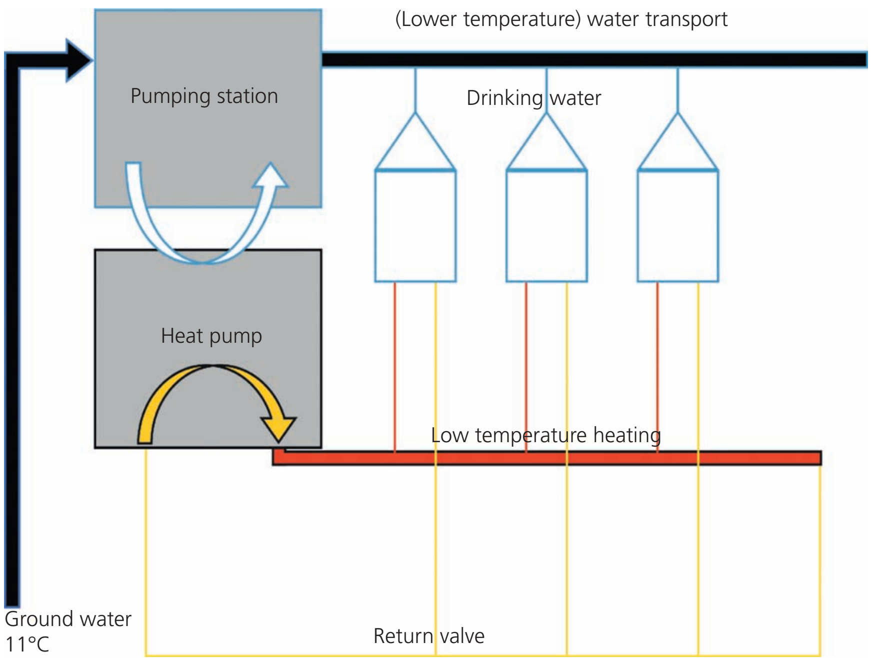


Figure 4. Schematic overview of drinking water/district heating system

preferred the initial partners. The municipality of Culemborg was considered first. However, it declined the offer as it considered it was not its role to operate an energy grid (Kaptein, 2010; Verschuur, 2010).

By October 2006, Vitens contacted the residents of EVA Lanxmeer to enquire whether they would be interested in taking over the district heating system (VOEW, 2008). The energy and equipment working group of the residents was eager to start joint entrepreneurial activities, and emphasised the importance of resident-controlled initiatives in EVA Lanxmeer (Verschuur, 2010).

An inventory phase was initiated during which the working group studied the feasibility of a ‘district-owned energy company’. In September 2007, the energy and equipment working group considered that a district-owned energy company could be created provided that the residents would support that decision (VOEW, 2008). To involve all the residents, an information campaign was set up. In October 2007, the plans were discussed at a district meeting. Debates focused on the control over this new company. Some wanted the BEL to be the owner. However, the energy and equipment working group argued that a few hundred owners would paralyse decision making and provide no influence on the larger energy consuming businesses in the district. These businesses represented about 70% of the total turnover of the district heating system. Therefore, they proposed a foundation to control and manage the system (Verschuur, 2011; VOEW, 2008). It was decided to complete a business plan and aim at raising more support for a district-owned energy company (Verschuur, 2011).

For this aim, a new entity was created: the Vereniging Ontwikkeling Exploitatie Warmtenet (VOEW) (organisation for the development and exploitation of a heating network). Between January 2008 and May 2008, 68 residents became members of the VOEW, 20 of which were actively working on the business plan. In the meantime, private companies also showed interest in taking over the system (Verschuur, 2010, 2011). However, Vitens remained loyal to the inhabitants of EVA Lanxmeer. VOEW summarised it as: ‘Vitens was our best friend’ (Verschuur, 2010, 2011). In May 2008, the business plan was presented and the residents were consulted. In one month and a half, about 40% of the residents expressed their views, 85% of them were positive. The interest of private companies to take over the district heating system created a fear of rising energy prices. Setting up a joint company and developing further entrepreneurial activities was regarded as a new challenge for the district. The VOEW created an option for residents to acquire more control over their district and work towards more ambitious sustainability goals (Verschuur, 2011).

In July 2008, VOEW decided to take over the district heating system. In November 2008, a new foundation Thermo Bello was created. The board of this foundation was composed of user groups (residents, local offices) and representatives of the energy companies that invested in Thermo Bello in order to learn from its experience (Verschuur, 2011).

In April 2009, Thermo Bello formally purchased the district heating system. Thermo Bello developed further plans to optimise the district heating system and expand it by connecting new consumers such as the local municipal swimming pool. Moreover, it also aimed at introducing more renewable energy technologies in the municipality of Culemborg. The company now (February 2015) delivers heat and hot tap water to 192 dwellings and eight businesses (Thermo Bello, 2015b). Various EVA Lanxmeer residents act as volunteers for Thermo Bello to contribute to the system’s high efficiency.

This case shows that the presence of the BEL was crucial to ensure a smooth transition from a situation in which district heating and drinking water were fully integrated and operated by one single actor to a situation in which there were two separate organisational entities benefiting from symbiotic relations. The BEL empowered the inhabitants to organise themselves and take on a proactive role in the district. It is thanks to the association that the working group on energy and equipment and later on the VOEW could exist and act as the dedicated systems integrator. They created a bridge between the water company, local businesses and the inhabitants of EVA Lanxmeer. In this case the bridge was not of a technical but rather of a social nature.

4. Discussion

This paper presents two cases of urban symbiosis and shows that creating bridges can be crucial to facilitate the integration of urban systems. Two types of bridges are presented: one of a technical and one of a social nature. Moreover, both cases show the importance of having a ‘dedicated systems integrator’.

In the biogas as biofuel case, the bridge represents an infrastructure that can physically connect two other systems. This bridge could not be created by the actors in the two systems to be integrated. Indeed, for Stockholm Water it implied competences that were very different from its core activities, both in technical and marketing terms. For oil companies, the integration did not represent a strategic issue and also required new technical competences. The bridge could be created thanks to the combination of two factors. First, it was due to the capacity of Stockholm City to create interesting conditions for a third party, AGA gas, to take the risk and make the necessary investments. Second, the bridge could be created because AGA gas had the technical know-how and saw a strategic opportunity in the initiative. Once it had decided to take the risk to invest in the biogas infrastructure, this actor became dedicated to its realisation and to making sure that the systems of wastewater treatment and transport fuel could be integrated.

In the case of EVA Lanxmeer, the bridge consisted of an organisation that empowered public actors to take on an active role. It was able to create links between private companies operating in the district and the inhabitants. It played a crucial role early on to raise trust and support for the district heating initiative among inhabitants and thereby the water company that would invest in the installation. Later on, it is because this bridge existed that a dedicated system integrator, in this case the energy and equipment working group followed by the VOEW, could emerge. Both were dedicated to the realisation of projects that ensured citizen control over the development in the district while keeping an open eye for the interests of investors and business located in the area. In fact the support of the residents, and the active role that some of them played, could not have been achieved by another actor.

4.1 Creating relations

The cases of biogas/biofuel in Stockholm and drinking water/district heating in EVA Lanxmeer show that the integration of urban systems for sustainable development is not just a matter of business opportunity: it is about being able to create relations between actors and manage their expectations and often conflicting interests. We have seen that actors capable of creating bridges have a crucial role to play. It is over-optimistic to suppose that these bridges can always be created by entrepreneurs that seek opportunity. The main reason for that is that the opportunity-seeking behaviour of an entrepreneur creates mistrust among potential partners. Several organisations were unable to play such a bridging role in actor networks that aimed to integrate systems. Barriers for actors to act as an urban systems integrator that can be identified in the cases include the following.

- Public organisations could not be involved in activities that were considered market driven (local authorities, both in Stockholm and Culemborg).
- Private organisations face difficulties in organising public activities (e.g. market-based companies would not have been able to acquire resident support in EVA Lanxmeer, market-based companies could not promote biogas as biofuel like Stockholm City did).
- Some of an organisation's existing activities could be negatively affected by urban systems integration (oil companies, Stockholm Water by risk of damage to sewage pipes).
- The size of an urban systems integration project might make it of minor significance to the partner organisations (oil companies initially in Stockholm, Vitens after the merger).

A condition for any new actor to join a network is that it fits existing relations in which the actor is engaged. AGA gas built on its existing gas actor networks, while the energy and equipment working group and the VOEW in the Culemborg case built on the relations it had with the district residents and the drinking water company.

However, besides these fitting relations, there were also inhibiting factors for each actor to play a bridging role. Actually, the number of actors that might play a bridging role might turn out to be very low. Moreover, as there are potentially only a few bridging actors, the process to involve a new actor might easily become a mutual bargaining game, which has a high risk of failure (Nash (1950) on mutual bargaining). Brokers might be effective in dealing with such bargaining problems, but it might be more than mere brokering; the integration of urban systems might require additional facilities, services, training and regulations. A dedicated intermediary organisation might accomplish these tasks. Intermediary organisations have been shown to be important for creating the required innovative capacity for transitions (van Lente *et al*., 2003). The case studies provide a clear indication that an absence of a dedicated systems integrator might play an important role in failure.

Public authorities are responsible for the common interest. In the integration of urban systems, giving this role of intermediary to the city authorities will not always work out well, as the city authorities are in general the key actor for planning and operating various infrastructures and for control and regulation of various sectors. The role of an intermediary organisation for urban systems integration could be incompatible with the interests of publicly controlled infrastructures companies, and requires activities that cannot be carried out by public administrations.

Further research is required both to confirm this hypothesis and design procedures on how projects with large importance for sustainable urban development could both be advanced and subjected to democratic control.

REFERENCES

Ayres RU and Ayres LW (1996) *Industrial Ecology: Towards Closing the Materials Cycle*. Edward Elgar Publishing, Cheltenham, UK.

Baas LW and Boons FA (2004) An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems. *Journal of Cleaner Production* **12(8–10)**: 1073–1085.

Baesen Y, Alexanderson S, Gspaltl P *et al.* (2005) *Evaluation Report – Clean Vehicle*. Trendsetter – program, Stockholm, Sweden.

BEL (2003) *Bewonersboek Lanxmeer*. BEL, Culemborg, Netherlands. See http://www.bel-lanxmeer.nl/html/werkgroepen/bewonershandboek/031120_bewonershandboek.pdf.

Biogasmax (2010) *Final Evaluation Report. Analysis of the Site Evaluation Activities (cross-site results, analysis and recommendations)*. Lille Métropole Communauté Urbaine and the European Commission, Lille, France.

Birath K and Pädam S (2010) *Clean Vehicles in Stockholm. Historic Retrospect 1994–2010*. The Environment and Health Administration in Stockholm City, Stockholm, Sweden.

Boons FA and Baas LW (1997) Types of industrial ecology: the problem of coordination. *Journal of Cleaner Production* **5(1–2)**: 79–86.

Civitas (2011) *Improving Biogas Refuelling Infrastructure*. Civitas. See http://www.civitas.eu/content/improving-biogas-refuelling-infrastructure (accessed 20/04/2015).

Ehrenfeld JR (1997) Industrial ecology: a framework for product and process design. *Journal of Cleaner Production* **5(1–2)**: 87–95.

Energy Cities (1999) *Biofuel Stockholm*. Energy Cities, Brussels, Belgium.

Frantzeskaki N and Loorbach D (2010) Towards governing infrasystem transitions: reinforcing lock-in or facilitating change? *Technological Forecasting and Social Change* **77(8)**: 1292–1301.

Frosch RA and Gallopoulos NE (1989) Strategies for manufacturing. *Scientific American* **261(3)**: 144–152.

Fujita T (2006) *Eco-Town Projects/Environmental Industries in Progress*. The Ministry of Economy, Trade and Industry, Japan. See http://www.meti.go.jp/policy/recycle/main/3r_policy/policy/pdf/ecotown/ecotown_casebook/english.pdf (accessed 29/08/2015).

Goed J (2010) Interview conducted by the author on the 5 May 2010. Vernay AL, Culemborg, The Netherlands.

Graedel TE (1994) Industrial ecology: definition and implementation. In *Industrial Ecology and Global Change* (Socolow R, Andrews C, Berkhout F and Thomas V (eds)). Cambridge University Press, Cambridge, United Kingdom.

Hanhart J (2010) Interview conducted by the author on 24 April 2010. Vernay AL, Culemborg, The Netherlands.

Hemmes K (2009) Towards multi-source multi-product and other integrated energy systems. *International Journal of Integrated Energy Systems* **1(1)**: 1–15.

Kaptein M (2010) Interview conducted by the author on 21 April 2010. Vernay AL, Culemborg, The Netherlands.

Knight H (2010) Bugs will give us free power while cleaning our sewage. *New Scientist*, 7 May 7.

Latour B and Hermant E (2006) *Paris ville invisible*. La Découverte-Les Empêcheurs de penser en rond, Paris, France.

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

Mulder K and Kaijser A (2014) The dynamics of technological systems integration: water management, electricity supply, railroads and industrialization at the Göta Älv. *Technology in Society* **39**: 88–89.

Nash J (1950) The bargaining problem. *Econometrica* **18(2)**: 155–162.

Pandis Iveroth S (2014) *Industrial Ecology for Sustainable Urban Development – the Case of Hammarby Sjöstad*. PhD thesis, Industrial Ecology, Department of Sustainable Development, Environmental Science and Engineering, KTH, Stockholm, Sweden.

Plombin C (2003) *Biogas as Vehicle Fuel. A European Overview*. Stockholm Environment Administration, Trendsetter/Civitas, Stockholm, Sweden.

Rudden PJ, O'Neill K, McEvoy B and Treanor A (2015) Environmental sustainability of European cities. *Proceedings of the Institution of Civil Engineers – Civil Engineering* **168(2)**: 75–80, http://dx.doi.org/10.1680/cien.14.00037.

Sidler D (2011) Interview conducted by the author on 12 April 2011.. Vernay AL, Zutphen, Netherlands.

Sjödahl R (2009) LBG Infrastructure in Sweden. *Proceedings of European Biomethane Fuel Conference, Göteborg, Sweden.*

Thermo Bello (2015a) *Techniek*. See http://www.thermobello.nl/techniek (accessed 29/08/2015) (in Dutch).

Thermo Bello (2015b) *Product*. See http://www.thermobello.nl/product (accessed 29/08/2015) (in Dutch).

Tibbs H (1992) Industrial ecology: an agenda for environmental management. *Pollution Prevention Review* **Spring**: 167–180.

van Lente H, Hekkert M, Smits R and van Waveren B (2003) Roles of systemic intermediaries in transition processes. *International Journal of Innovation Management* **07(03)**: 247–279.

Vernay AL (2013) *Circular Urban Systems – Moving towards systems integration*. PhD thesis. Delft University of Technology, Faculty of Technology, Policy and Management, Delft, The Netherlands.

Verschuur G (2010) *Thermo Bello: energie voor de wijk – Nieuwe Nuts in de praktijk*. Innovatie Netwerk, Utrecht, The Netherlands (in Dutch).

Verschuur G (2011) Interview conducted by the author on 24 February 2011. Vernay AL.

VOEW (Vereniging Ontwikkeling Exploitatie Warmtenet) (2008) Ontstaansgeschiedenis van het warmtenet in het algemeen t/m Oprichting VOEW. Vereniging Ontwikkeling Exploitatie Warmtenet (VOEW), Culemborg, The Netherlands (in Dutch).

Zeus (Zero and Low Emission Vehicles in Urban Society) (2000) *Refuelling Infrastructure, a Zeus Project Report Summary*. European Commission, Directorate-General for Energy and Transport, Stockholm, Sweden.

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