Journal of Cleaner Production 277 (2020) 122822

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Developing biogas systems in Norrköping, Sweden: An industrial symbiosis intervention

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A R T I C L E I N F O

Article history:
Received 7 January 2020
Received in revised form
15 May 2020
Accepted 11 June 2020
Available online 17 July 2020

Handling editor: Yutao Wang

Keywords:
Industrial symbiosis
Institutional capacity building
Anaerobic digestion
Facilitation
Eco-industrial park

A B S T R A C T

Biogas systems are often multi-functional and involve several actors in different sectors, requiring these actors to collaborate closely in order to implement such systems. In this paper, a study is presented where the theory of institutional capacity building is used to guide interventions with public and private actors to facilitate the development of local biogas systems in Norrköping, Sweden. The interventions were performed in the form of a workshop series, where local actors with potential to influence biogas developments actively took part. The workshop series generated knowledge on Norrköping's significant potential for both producing and using biogas, which was traced, in part, to its high concentration of bio-based industries and its good position as a hub for transports. The interventions also created a shared understanding that cooperation and coordination to distribute resources and knowledge about biogas, both geographically and across sectors, was critical for realizing this potential. The municipal organization was identified as an important actor for coordinating these efforts. Observations during the workshops and survey responses indicate that the interventions contributed to building institutional capacity and initiation of efforts to develop local biogas solutions. Ideas put forth in this study enable interventions to target the intangible internal capacities of emerging industrial symbiosis networks. In addition, institutional capacity building serves as a useful analytical framework capable of capturing progress within emerging networks in the short-term even when material, water or energy synergies are yet to be realized.

1. Introduction

A transition towards sustainable development requires continued implementation of innovative sustainable systems (Cohen, 2006). These systems need to be well integrated and multi-functional, addressing several sustainability challenges simultaneously (Matson, 2001). Otherwise, they risk creating unintended problem-shifting (Korhonen, 2004; Lindfors et al., 2019) and missing synergistic opportunities for increased resource efficiency and higher resource utility (Frosch and Gallopoulos, 1989; Graedel and Allenby, 1995).

However, the successful implementation of such integrated systems is difficult, as they often require the integration of several different socio-technical systems. Furthermore, sustainability challenges are usually *wicked* problems lacking consensus around what the problem or the solution is (Roberts, 2000). Hence, what is deemed good by one stakeholder may be seen as negative by another (Roome, 2001). Roberts (2000) suggests utilizing collaborative strategies in order to jointly define and solve wicked problems. In addition to the wickedness of sustainability challenges, it is rare to find cases where individual actors have the ability or authority to singlehandedly drive the implementation of potential solutions. Hence, it is necessary to involve several different actors that can combine their resources and capacities to enable the successful implementation of sustainable solutions. These groups of actors can form collaborative networks, which may lead to further sustainability-oriented cooperation after a particular solution has been implemented and the original task of the network is complete (Posch, 2010).

In order to understand how sustainability-oriented cooperation between different actors may emerge and be facilitated, we draw upon the industrial symbiosis literature. Industrial symbiosis is the process of connecting material, water or energy flows between individual actors—done either through by-product exchanges or utility sharing (Boons et al., 2017). Recently, industrial symbiosis

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https://doi.org/10.1016/j.jclepro.2020.122822

has been gaining increased attention and support due to its theoretical and practical benefits. Its theoretical elements have contributed to progress towards sustainable development (Posch, 2010) and especially played an integral part in advancing the circular economy concept (Saavedra et al., 2018), which offer influential visions of desirable future societies. Furthermore, these theoretical elements advance our understanding of the dynamics of the emergence, development and even eventual dissolution of resource collaborations (Boons et al., 2012). On the practical side, several studies of industrial symbiosis cases have reported improved environmental (e.g. Chertow et al., 2008; Park et al., 2016; Yu et al., 2015) and economic performance (e.g. Jacobsen, 2006; Kim et al., 2018; Park et al., 2016; Van Berkel et al., 2009a), and provided support for the theoretical promises of industrial symbiosis. Hence, the concept is well suited to understanding the complex nature of sustainability-oriented cooperation.

There are many industrial symbiosis studies focusing on the development and facilitation of by-product exchanges or utility sharing cooperation (e.g., Baas, 2008; Chertow et al., 2008; Doménech and Davies, 2011; Jacobsen and Anderberg, 2004; Mirata, 2004; Paquin and Howard Grenville, 2012). This study builds on an idea from this literature put forth by Mirata (2005), namely, that an initial focus on strengthening the internal capacities of actors to engage in industrial symbiosis often requires fewer resources and provides faster results. The strengthening of these internal capacities can be understood through the theory of institutional capacity building (originally Healey, 1998; Healey et al., 2003), as was first done in an industrial symbiosis context by Boons et al. (2011). This theory originates in the field of policy analysis and may be used to understand and analyze how actors come together to address issues of common concern (Healey et al., 2003). So far, institutional capacity building in the context of industrial symbiosis has aimed to map events of importance to the emergence of industrial symbiosis networks and explain how certain events impact particular capacities (e.g. Abreu and Ceglia, 2018; Boons and Spekkink, 2012; Spekkink, 2015). The utilization of the concept to guide interventions to facilitate the emergence of industrial symbiosis networks and initiatives is in its early exploration stages. For example, Park et al. (2018) used a framework of similar theoretical origin to guide their intervention in Colombia.

In this paper, we contribute to this emerging literature by applying the theory of institutional capacity building to guide an intervention aimed at facilitating industrial symbiosis within the field of biogas solutions. Biogas solutions serve as an interesting case since they both benefit from industrial symbiosis processes (Martin and Eklund, 2011) and are able to improve the environmental performance and competitiveness of industries where they are introduced (Broberg Viklund and Lindkvist, 2015; Hagman et al., 2018). Moreover, biogas solutions are often multi-functional systems spanning across several sectors—including waste management, heat and power production, agriculture and transport—involving many stakeholders at different points in the value chain. This means that biogas solutions are able to provide several products and services as well as integrate different sectors (Olsson and Fallde, 2015). The multiple products along with the necessity to involve actors from several sectors mean that biogas solutions are inherently fit for industrial symbiosis. Furthermore, Mirata et al. (2017) pointed specifically at the need for improved institutional capacity in the biofuel industry. Strengthening the institutional capacity in the biogas sector may contribute to closing the gap between current production and estimated potentials, which are, for example, that the production in Sweden would be able to increase by as much as five times from 2013 to 2030 (WSP, 2013) and that the production of biogas in Europe can increase by a factor of 1.8–2.5 from 2014 until 2030 (Kampman et al., 2017).

Departing from such a background, this paper aims to present and discuss how the theory of institutional capacity building can be used to guide facilitation of industrial symbiosis by enhancing the internal capacities of actors to engage in collaboration and cooperation. By this, it contributes to the, hitherto, sparse literature on how to conceptualize, capture and assess the internal capacities of actors to engage in industrial symbiosis initiatives. Furthermore, the paper aims to provide methodological insights on performing interventions to strengthen the internal capacities of actors.

This paper describes and analyzes a process where a series of workshops and interim activities were used as the primary means to strengthen institutional capacity for increased production and use of biogas in the municipality of Norrköping, Sweden. These workshops aimed to (1) create an arena for actors to meet and build relations, trust and find common interests; (2) disseminate and co-create knowledge around the potential for, and feasibility of, biogas solutions in and around Norrköping; and (3) identify and engage actors willing to take the lead in different initiatives as well as the leadership of the network as a whole. We present the background of this workshop series and its setup and discuss the results of these workshops so that others may replicate or draw inspiration from them for other kinds of industrial symbiosis interventions in other geographical and technological contexts.

2. Theoretical framework

In order to analyze the internal capacities of actors engaged in industrial symbiosis, we utilize the theory of institutional capacity building (originally Healey, 1998; Healey et al., 2003), as was first done by Boons et al. (2011) and then followed by others (Abreu and Ceglia, 2018; Boons and Spekkink, 2012; Park et al., 2018; Spekkink, 2015, 2013; Wang et al., 2017). Institutional capacity is described as the capacity of a group of actors to act collectively, and institutional capacity building involves the processes (within networks of actors) that develop this capacity. This capacity can be observed in the interactions between actors as a “force which is continually emergent, produced in the interactive context of its use” (Healey et al., 2003, p. 63). It is recognized to develop along three dimensions: relational resources, knowledge resources and mobilization capacity (Boons and Spekkink, 2012; Spekkink, 2016, 2015).

Relational resources are connected to the number of involved actors and the range of their involvement. This includes the quality of interactions between actors, which enhances mutual understanding and trust. Knowledge resources are characterized by the quality of knowledge and shared experiences within the group. It also includes the alignment of perceived problems and solutions amongst individual actors and the group’s ability to absorb and learn from new ideas. Finally, mobilization capacity refers to the ability of actors to engage additional actors who can support the realization of identified opportunities. Furthermore, Spekkink (2015) describes that the presence, or absence, of shared visions and leaders may be an important aspect of the dimension of mobilization capacity.

These three dimensions make up the institutional capacity of a group of actors, which in turn influences the opportunity sets available to individual actors in the group. For example, an actor may have a certain by-product that they currently deposit on a landfill. Such an actor must identify a potential user, possibly an actor within their network of relations (relational resources), and must be informed about if and how the by-product can be used in the potential user’s production processes. Both actors then need to know how the by-product can be used and what benefits, and possible barriers, can be linked to such an application so that feasible transaction opportunities can be recognized (knowledge resources). Finally, the recognized opportunities have to be desirable for all involved parties, and the necessary resources must be mobilized to implement the by-product synergy (mobilization capacity).

Boons et al. (2014) list *orientation, planning, feasibility studies, implementation, influencing other actors, declaration, establishing new organizations, strategic visioning* and *influencing the context* as activities that contribute to institutional capacity building by influencing all three dimensions. These basic interactions were used to guide the workshop series analyzed in this paper and are described in brief in Table 1. Moreover, these interactions may be performed by a few actors within a certain group or the entirety of the group, both build institutional capacity, although the extent to which institutional capacity is strengthened may differ depending on the range of actors involved in the interactions (Spekkink, 2016).

3. Background

Norrköping, the geographical setting of our study, is a Swedish municipality with 140 000 inhabitants (SCB Statistics Sweden, 2018) and a total area of 1600 km^2, located 160 km southwest of Stockholm, the capital of Sweden (see Fig. 1 for a map of Norrköping municipality and its location in Sweden). The city of Norrköping, centrally located in the municipality, is connected to the Baltic Sea via the bay Bråviken, which has one of the largest and deepest harbors in Sweden. It is also an important junction for road transports, situated by main highways extending both north-south and east-west and carrying significant goods and personal traffic. The area around Norrköping city consists mainly of farmland and forests. Notable industrial plants in Norrköping municipality include three paper mills and Sweden's largest producer of bioethanol. The current biogas production in the area is limited to the wastewater treatment plant, the landfill and a few industrial facilities where anaerobic digestion is used for internal wastewater treatment. Organic waste collected from the households in Norrköping is transported 40 km to the neighboring city Linköping, where it is used to produce biomethane for vehicles. The city buses in Norrköping run on biomethane from the local wastewater treatment plant, and there are four public fueling stations for biomethane in Norrköping (The Swedish gas association, 2019). In 2009, the city council of Norrköping adopted an energy plan for the municipality, which states that the energy efficiency should increase by at least 30 percent from 2005 to 2030 and that all the energy used in Norrköping should come from renewable sources, such as wind, solar and biofuels (Norrköping Municipality, 2016). This plan was one of the driving forces for the Norrköping municipal organization to participate in the workshops described in this paper.

4. Method

Against this background and guided by the theory of institutional capacity building, a series of workshops were orchestrated with the aim of building relational resources, knowledge resources and mobilization capacity related to biogas solutions in the municipality of Norrköping. The method used to design and organize the workshop series and the method used to evaluate the workshop series effect on the institutional capacity of the participating actors are described in this chapter.

4.1. Selection of participants

The workshops brought together actors with the potential to play important roles in this development. The workshop series was organized and led by a group of researchers at Linköping University. In addition to the research group, representatives from the municipality, the regional authority, local companies and associations active or interested in biogas solutions attended the workshops. The full list of participants in each workshop can be seen in Table 2. As for the reasoning behind the suite of actors involved in the workshops, companies with their core business in the production and distribution of biogas or biofertilizer were included as they held key knowledge about the technology under investigation. Public authorities, such as the municipal organization and the regional authority, were included as they have been identified in literature as possible institutional anchor tenants and network brokers (Burström and Korhonen, 2001). Furthermore, industries and organizations with significant organic waste flows were invited as they held access to the by-product under investigation. Many of the participating organizations and their representatives were already familiar to the research group, but not to each other. Moreover, none of the organizations had a similar overview of the local biogas area and the relevant stakeholders as the research group. The research group, therefore, held the initiative by inviting, planning, organizing and leading the workshops.

4.2. Design and realization

The workshops were carried out at intervals of about six weeks. Each workshop lasted for 4 h and consisted of discussions in small or large groups and presentations from the research groups. For the small group discussions, the participants were divided into three groups, with a mix of researchers, municipal representatives and representatives of the participating companies and other organizations. An overview of the workshop series process is illustrated in Fig. 2 along with what basic interactions, proposed by Boons et al. (2014), links to the activities in each workshop.

Table 1
Descriptions of the basic interactions proposed by Boons et al. (2014) as activites that may strengthen the institutional capacity of industrial symbiosis networks.

Interaction	Description
Orientation	Exploration and negotiation between actors that help them to develop common definitions of problems and solutions.
Planning	Formulation of concrete plans to realize the implementation of a certain common solution.
Feasibility studies	Performing joint research with the aim of exploring the feasibility of implementing a certain common solution.
Implementation	Actors working together to implement a common solution that they have previously planned.
Influencing other actors	Activities performed by one actor to influence another actor within the network to make that actor more likely to engage in future collective action.
Declaration	An actor, or several actors, formally declare the intention to act to solve a common problem, often involving the signing and publication of formal documents.
Establishing new organizations	Actors join together and establish a new organization devoted, at least in part, to furthering the industrial symbiosis network.
Strategic visioning	Actors establish joint strategic visions where they describe their common goals.
Influencing the context	Activities performed by one or several actors with the aim of influencing the contextual factors surrounding the network.

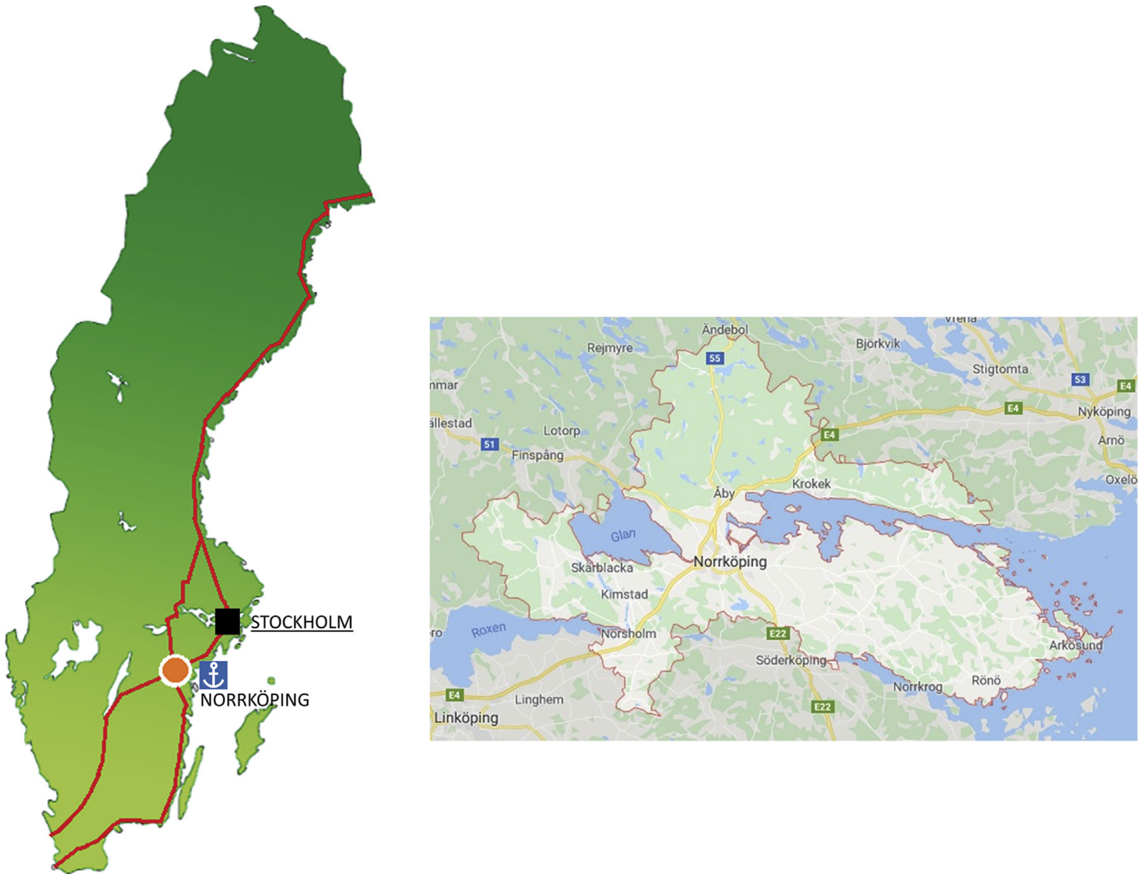

Fig. 1. Left: the geographical situation and main transportation routes of Norrköping. Right: Map of Norrköping municipality.

Table 2
Number of representatives from the participating organizations at the workshops[a].

Organization	Workshop participation		
	Workshop 1	Workshop 2	Workshop 3
Research group	4	5	5
Other researchers	3	3	6
Municipal organization—Business development	1	1	1
Municipal organization—Municipal board	1	1	1
Municipal organization—Water and waste department	2	2	
Municipal organization—Environmental controller			1
Regional authority		1	1
Regional biogas association		1	1
Regional network for fossil-free transports	1		
Waste management company	1	1	1
Biogas companies	4	3	4
Biofertilizer companies	2	2	1
Paper mill	1	2	1
Zoo		1	
Total	**18**	**22**	**21**

[a] In some cases there was an overlap between different roles of the same person/organization: researchers working part-time within biogas companies (1 person each on Workshops 1 and 3) and a waste management company producing biogas (1 company, Workshops 1–3).

The first workshop focused on getting the participants to familiarize with each other and with biogas solutions in Norrköping municipality. It started with a brief introduction presenting the aims of the workshop series followed by presentations from each participating actor about their relation to biogas solutions in Norrköping municipality. This helped lay the groundwork for building relational resources as participants started to communicate with, and develop a mutual understanding about, each other. The first workshop also contained a discussion on who the potential users and producers of biogas in Norrköping municipality were to further build relational and knowledge resources. Finally, discussions were also held with the aim of identifying synergistic benefits that may arise from cooperation between actors, aiming to identify previously unexploited opportunities.

In the period between the first and second workshops, the research group compiled the results from the previous workshop and performed inventory and analysis of potential areas of production and use of biogas in Norrköping. This study falls into the

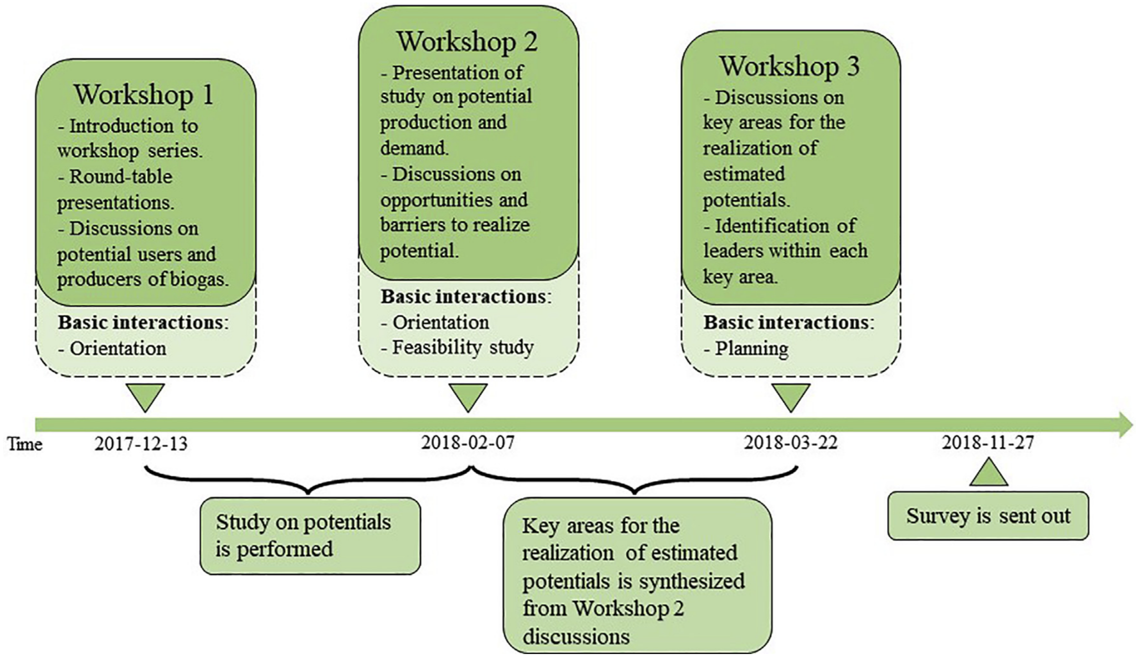

Fig. 2. Timeline of the workshop series process. The basic interactions found in the dotted line boxes underneath each workshop description relate to the categories of suggested by Boons et al. (2014).

feasibility study interactions in the categorization by Boons et al. (2014). The biogas potentials were estimated through a combination of literature and document studies, data on agricultural production on the regional level and communication with local companies that either possessed potential substrates or had a potential interest in using biogas. Numbers for recent years were collected and scaled up according to expected increases in population, production and traffic work until 2030, assuming unchanged fuel efficiency. On the use side, the main focus was put on transports, as that is the dominant sector for the use of biogas in Sweden (Eriksson and Harrysson, 2017). More detailed information about data sources and assumptions is provided in Appendices A and B. The potential production and use of biofertilizer, the main by-product from biogas production, was not quantified in the same way as the production and use of biogas, but only qualitatively discussed in the workshops.

At the second workshop, the research group presented the study on the potential production and demand for biogas in Norrköping municipality with the aim of increased knowledge resources. Following this presentation, participants in the workshop discussed opportunities and barriers to the realization of these potentials. Between the second and third workshop, the research group synthesized the material from the discussions during Workshop 2 into a list of key areas within biogas production and use to be developed in order to realize the estimated potentials. These key areas were then used as the basis for discussion during Workshop 3 in order to identify which actors were needed in each area and which of them could take leading roles. The aim of these discussions was to build mobilization capacity by identifying leaders and planning for resource mobilization and eventual implementation.

4.3. Evaluation method

The outcome of the workshop series was evaluated through a survey among the participants and observations made during the workshops and after the workshop series concluded. The survey aimed to assess how the workshop series had affected the relational and knowledge resources and mobilization capacity of the participating organizations. It was conducted through an online questionnaire, which consisted of five grading questions and eleven free text questions. Seven of the free text questions were constructed in such a way that they were answered with either “not sure”, “no”, “not yet”, “somewhat” or “yes” and, as such, are referred to as yes/no questions from hereon, although the respondents were encouraged to motivate their answers and these questions therefore sometimes captured more detailed information. The answers to the questionnaire were given and handled anonymously. The survey questions and the respondents’ answers are included in Appendix C.

Observations complemented the structured evaluation based on the survey. Each attending member of the research group took notes during the workshops and the research group discussed notes, impressions and observations between the workshops as well as upon completion of the workshop series. These discussions aimed to validate and cross-check observations and to formatively evaluate the workshops in order to improve upcoming workshops. After the workshops, the research group continued observing the participants through continued contact. In some cases, members of the research group were invited as experts in follow-up meetings, in-depth feasibility studies and other activities which sprang out of the workshop series.

5. Results

In this section, we present at first the results from the workshop. These results consist of both the potential production and use of biogas in Norrköping (2030), which was the outcome of Workshops 1 and 2, and the key areas identified between Workshops 2 and 3 and further discussed in Workshop 3. More details on these parts can be found in Gustafsson et al. (2018). Second, we present the results of the survey sent out after the workshop series concluded and observations made during and after the workshop series are presented. The indicated impact of the workshop series on the institutional capacity of the participants identified in the surveys and the observations is then discussed more thoroughly in Section 6.

5.1. Local biogas potential

As shown in Fig. 3, the potential for producing biogas in Norrköping was estimated at 500 GWh per year by 2030. Out of this, industries (three paper mills and one grain-based bio-refinery) account for 30 percent of the potential and the agricultural sector for just over 60 percent. Realizing all this potential would mean a roughly tenfold increase of the current biogas production in Norrköping. In Fig. 3, the substrate sources are arranged with the existing ones to the left ("sewage" until "existing industrial production") and the ones that are considered most difficult to realize to the right.

For the use of biogas, the potential demand by the year 2030 was estimated to be 2600 GWh per year, out of which 1000 GWh per year is found within the shipping sector, as is shown in Fig. 4. This can be compared to the potential production of up to 500 GWh, indicated by the dotted line in Fig. 4. Road transports, which are divided into city buses, regional and intercity buses, taxis, municipal and regional cars, private cars and heavy-duty transport vehicles, account for approximately 1500 GWh per year of the potential, while the rest is found in industrial processes. Currently, the use of biogas in Norrköping is limited to city buses, garbage trucks and heat and power production. Furthermore, almost 25 percent of the locally produced biogas is flared in sites spread across the municipality, each producing amounts too small to be economically feasible to recover.

Regarding biofertilizer, the demand in Norrköping is currently lower than the production capacity. It should, however, be possible to replace other fertilizers with biofertilizer to a much higher degree. Apart from agricultural land, it can also be applied in forests, municipal parks and private gardens.

5.2. Key areas and actors, drivers and barriers

The inter-sectoral discussions conducted at the workshops resulted in a list of prioritized areas for facilitating an increased production and use of biogas in Norrköping. It was found that a combination of activities and initiatives from different actors, and collaboration between actors, would be required to realize the biogas potential in Norrköping. These were distilled into six prioritized actions shown in Table 3, along with actors that may play leading and supportive roles. Since resources and the knowledge about biogas are spread geographically and across sectors, cooperation among actors and coordination of efforts were also identified as being very important. The municipal organization was recognized for its potential to play a key role in several of the identified areas (Table 3, Actor 1) and act as a hub in the coordination of local biogas activities (Table 3, Action 1). Biogas companies could also take an active role in many areas, not least by providing the necessary specialist knowledge that many of the substrate owners lack. The research group would probably continue to be a useful resource for the development of biogas solutions in Norrköping, although with a much less active and driving role than during the workshop series.

While the total potential for biogas production in Norrköping was estimated to be quite high within individual substrate categories, the geographical dispersion of the substrates was identified as a significant challenge. This concerns particularly the agricultural substrates, which are spread over numerous farms and fields across the whole municipality. To overcome this challenge, a system for centralizing the upgrading the raw gas to vehicle gas (Table 3, Action 2) would be important. Such a centralized system could help to overcome challenges with profitability usually associated with small production facilities (Raven and Gregersen, 2007; Skovsgaard and Jacobsen, 2017). This key area is closely linked to another, namely, the expansion of biogas production at industrial plants (Table 3, Action 5), which could increase the amount of raw gas production in the area and further increase the chances that a centralized upgrading facility could be economically feasible.

The production of biogas is largely dependent on the demand. Representatives for industries handling potential biogas substrates also pointed at the demand as one of the keys for them to initiate biogas production in their facilities. The municipality, the regional

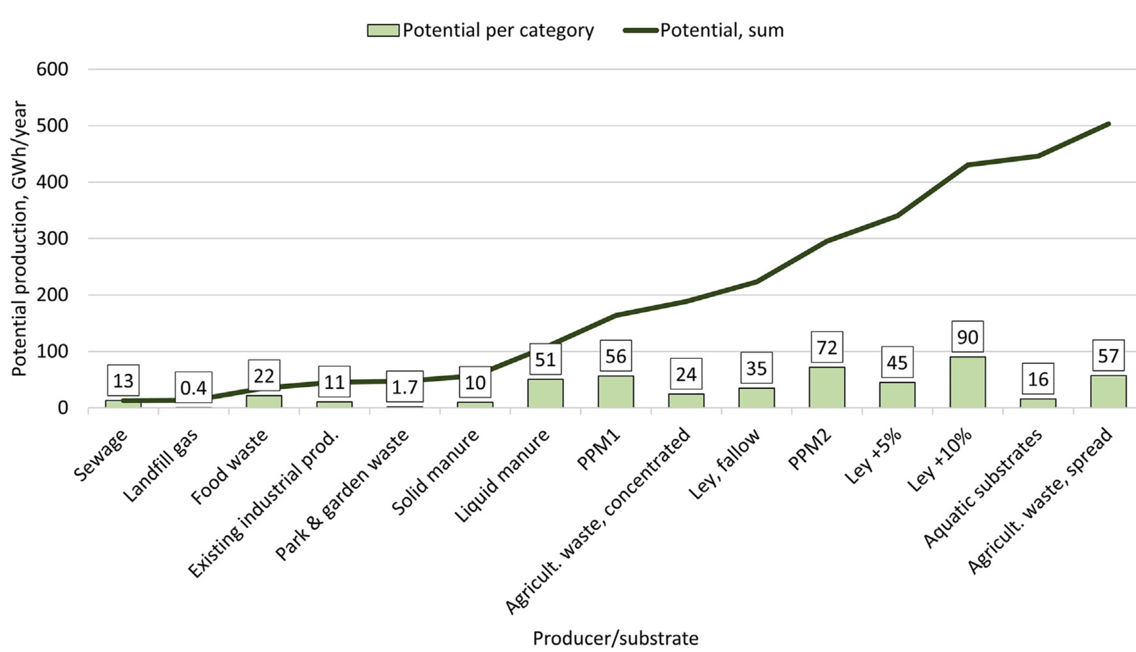

Fig. 3. Potential production of biogas (GWh/year) in Norrköping, the year 2030. The substrate sources are arranged with the existing ones to the left ("sewage" until "existing industrial production") and the ones that considered the most difficult to realize to the right.

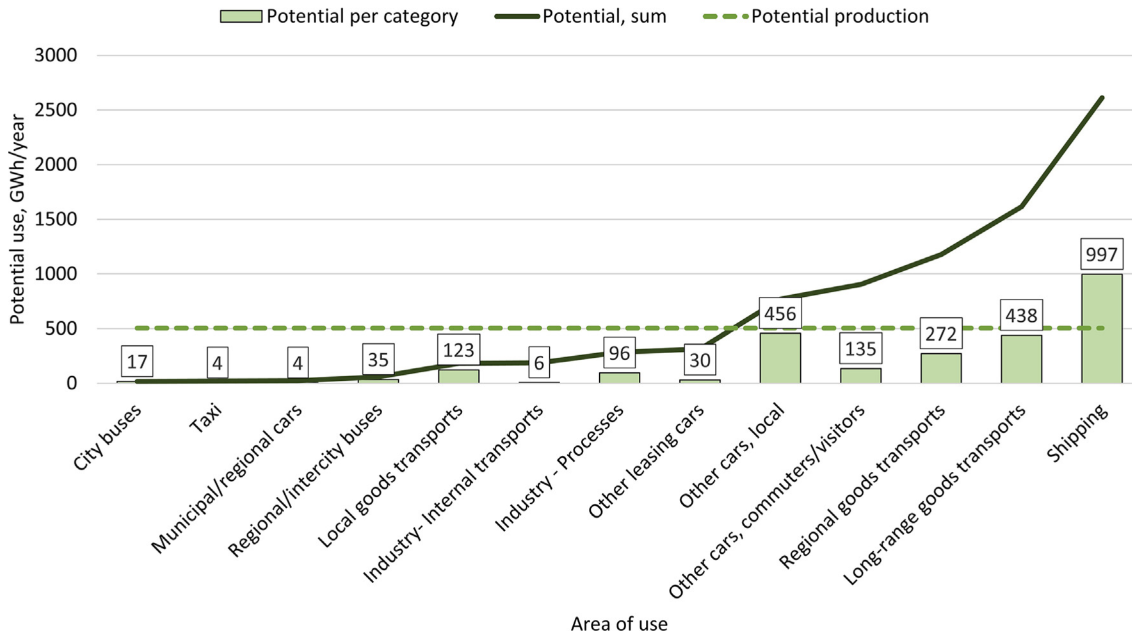

Fig. 4. Potential use of biogas (GWh/year) in Norrköping, the year 2030. Analogous to Fig. 3, the existing areas of use are positioned to the left, and the areas considered the most difficult to realize to the right, with the same reasoning regarding the actual order and degree of realization. The potential production is indicated by the dotted line.

Table 3
In the columns, the key areas identified during discussions in Workshop 3 and in the rows the actors taking leading roles, indicated by X, and taking consultatory or supportive roles, indicated by (X).

	Action					
Actor	1: Establishment of a municipal biogas coordinator	2: Joint centralized upgrading	3: Supportive procurement efforts	4: Establishment of new filling stations	5: Biogas production at bio-industrial plants	6: Establishment of liquid biogas production
Municipal organization	X	X	X	X		X
Regional authority	(X)		X			
Biogas company 1		X		X		X
Biogas company 2				X	X	X
Biogas company 3				X		X
Paper mill 1		X			X	
Research group	(X)	(X)			(X)	(X)

authority and other transport buyers could help with increasing and stabilizing the demand by specifying requirements in transport procurements towards biogas vehicles (Table 3, Action 3). Placing filling stations in strategic locations, for example, near the highway (Table 3, Action 4), and producing liquid biogas for heavy transports (Table 3, Action 6) were viewed as key areas to encourage the use in vehicles, and thereby stimulate the demand.

5.3. Survey results

From the organizations participating in the workshop series, ten unique responses were provided to the survey. All the respondents answered each of the five grading questions, while the response rate on the eleven free text questions varied between 70 and 90 percent. All questions and answers can be found in Appendix C.

In the answers to the grading questions, which are shown in Fig. 5, 90 percent of the respondents reported having gained some or a lot more knowledge about biogas solutions in general and in particular, about drivers, barriers and the potential for biogas production and use in Norrköping. This indicated that the workshop series had led to an increase in the knowledge resources of the participating actors. The same number of respondents (90 percent) said that they had gained more understanding of the role of their organization in the development of biogas solutions in Norrköping, indicating an increase in both knowledge resources and mobilization capacity as they became aware of how development may happen (knowledge resources) and what their role may be (mobilization capacity). Moreover, 60 percent answered that the workshop series, to some extent, had increased the commitment of their organizations to local biogas solutions, leading to a higher mobilization capacity in the network due to actors having a higher willingness to act if needed.

In Fig. 6, the answers to the yes/no questions are shown. Within these questions, 89 percent of the respondents answered that they had gained new contacts through the workshop series, and 78 percent that previous, already existing relations had been strengthened. These responses give indications that the relational resources had been strengthened. A majority among the

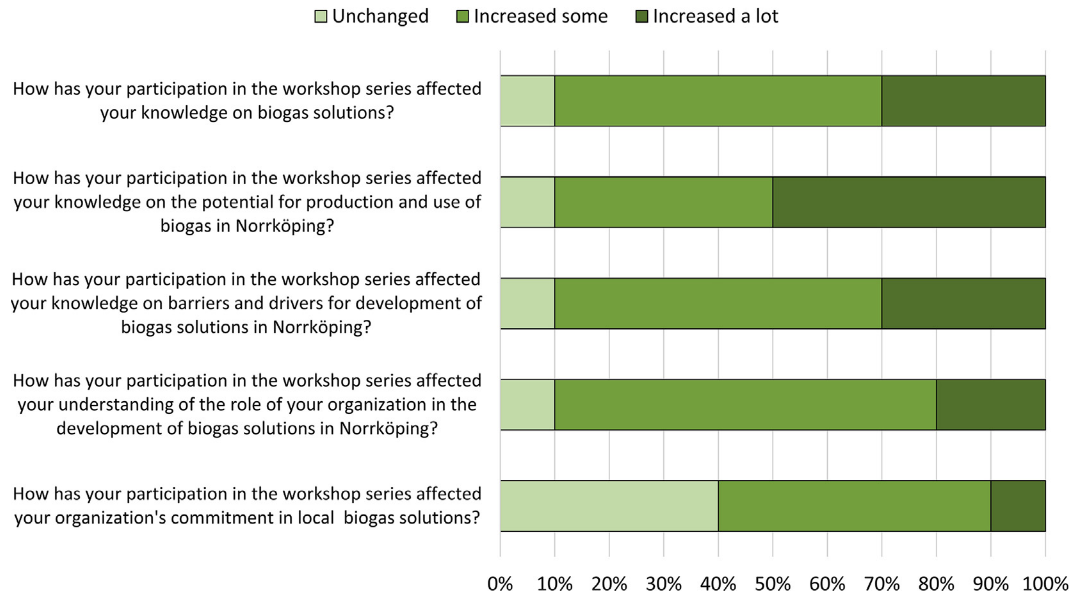

Fig. 5. Distribution of answers to the grading questions of the participant survey.

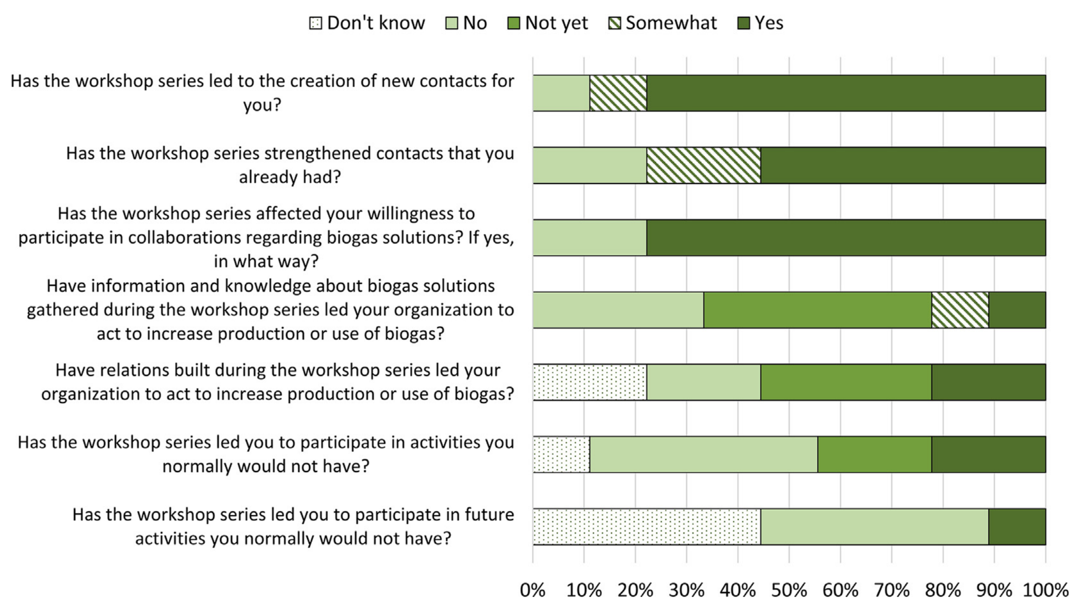

Fig. 6. Distribution of answers to the yes/no questions in the participant survey.

respondents (78 percent) declared that the workshop series had made them more willing to participate in biogas collaborations in the future, and 22 percent reported having initiated action already. However, for questions regarding the impacts of the workshop series “not yet” was the dominating answer, meaning that it is still too early to capture the full impact of the workshop series. The response frequency on the yes/no questions was 90 percent (of the ten answers).

5.4. *Observable outcomes*

In addition to the outcomes captured through survey responses, a couple of interesting developments have taken place since the workshop series concluded in the spring of 2018. Firstly, the municipal organization has shown increased involvement in a regional competence center for biogas research, indicating an increased interest in the subject. Secondly, the municipal organization has started a focused feasibility study, investigating the potential to produce biogas in a nearby agricultural area. Thirdly, a substrate-owning actor pursued discussions with biogas producers to apply for funding for a biogas production facility at their location. However, due to the limited biogas production potential, no biogas producer was interested, and the substrate-owning actor is now going to apply for funding on their own. In conjunction with this decision, the substrate owner has contacted other substrate owners who currently produce biogas in order to begin talks of joint upgrading. That is, to pipe the raw biogas from each production facility to a common upgrading facility where carbon dioxide and impurities can be removed and the biogas (now with a high methane content) can be used as a vehicle fuel. This initiative could be a way for the actors currently flaring their gas to reach a volume where upgrading is economically feasible.

6. Discussion

The aim of the workshop series was to build institutional capacity in the region of Norrköping within the area of biogas solutions. Therefore, our discussion mainly focuses on the impact of the workshop series, and related activities, on institutional capacity. The interactions and activities during the workshop series all influenced the institutional capacity of the group of participating actors in various ways. Interactions and activities of this kind should be a part of the repertoire of any actor seeking to build institutional capacity and facilitate the emergence of industrial symbiosis networks. Our experiences showed that universities might have a, potentially unique, capacity to drive this kind of industrial symbiosis intervention. While other organizations may find it difficult to justify organizing collaborative and explorative efforts like the workshop series, universities have the relations and legitimacy to be able to do so. Below, we discuss how the interactions and activities of the workshop series strengthened capacity within different institutional capacity dimensions.

The workshop series built a temporary arena where actors with common interests could meet, connect and interact. The relations formed through both informal and formal discussions contributed to the building of relational resources amongst the involved actors. Indications of this can be seen in the survey, where the majority of the respondents answered that the workshop series had led to actors establishing new contacts, strengthening pre-existing contacts and increasing their willingness to participate in other collaboration efforts. For example, responding to the question about whether they had strengthened any pre-existing contacts, one actor stated: “Yes, [it was] good to get to know each other better by doing something constructive together”. Furthermore, survey responses indicate that both formal and informal discussions in connection with the workshop have led to an increased level of trust and familiarity between the actors, which is widely acknowledge to be critical to the success of industrial symbiosis processes (Boons and Spekkink, 2012; Doménech and Davies, 2011; Hewes and Lyons, 2008; Jacobsen and Anderberg, 2004).

Regarding knowledge resources, many actors report an increase in knowledge related to biogas solutions in Norrköping after attending the workshop series. Prior to the second workshop, a feasibility study focusing on the supply and demand potential for biogas in the region of Norrköping was performed in a bottom-up manner, which was specifically aiming to increase the knowledge resources of the actors involved. This kind of bottom-up feasibility study is an important complement to the more common top-down national or continental studies, as bottom-up studies commonly have higher transparency and traceability (Offermann et al., 2011), enabling the understanding of what biomass resources to mobilize through which individual actors (Kautto and Peck, 2012). During the feasibility study, many workshop participants were involved as information sources, and as relations were already in place, accessing information that would otherwise be difficult to obtain was possible. As a result, the relevant actors’ knowledge of significant production and usage potential was enhanced, aiding them to better recognize important opportunities linked to biogas solutions. Most survey respondents reported that the workshop series had led to increased knowledge about biogas solutions in Norrköping. Furthermore, one actor stated: “… I have been even more convinced that an investment in biogas in Norrköping would require cooperation between several actors”, indicating that knowledge has also been enhanced regarding how to realize this potential. This can also serve as an indication of enhanced mobilization capacity, as the actors started to recognize ways forward towards implementing biogas solutions in Norrköping.

Similarly, the third workshop enabled actors to align their understandings of problems and solutions in relation to biogas in Norrköping by creating a consensus on key areas to prioritize. The fact that some actors have already taken steps to act to increase biogas production or use in Norrköping, and the majority has plans to act in this manner speaks to the success of the third workshop. Even if we do not know if the actors chose to act according to the key areas identified in the workshop, it seems to have provided a fertile ground for ideas on various actions to grow. Mobilization capacity was further enhanced through the collective identification of various leaders and the establishment of the municipality as the central actor and leader of the network. As identified in the literature, regional and local public organizations can often play an important role as network brokers within industrial symbiosis networks (Burström and Korhonen, 2001; Spekkink, 2016). Furthermore, the consensus on what key areas to prioritize, which actors to involve, and who would take the lead within each key area can be recognized as having contributed to mobilization capacity. The workshop series did, however, lack any dedicated efforts to develop a common vision for biogas in Norrköping, which could have served to build further mobilization capacity. Indeed, one of the respondents even acknowledged this by noting: “What is missing in Norrköping is not mainly knowledge but that we decide on a common pathway”.

Compared to some of the more extensively documented industrial symbiosis facilitations, the workshop series requires little investment in terms of money and time. For example, the Korean Eco-Industrial Park Development Program budgeted 810 million dollars for the entire 15-year program (Park et al., 2016), while the workshop series only spanned about three months and required little resources. Focusing on the internal capacities of the network provides a way of facilitating industrial symbiosis emergence without requiring large investments and continuous programs, although it is important to understand the limitations and strengths of different types of facilitation in order to choose the type best suited for a given context. Mirata (2004) suggests a categorization of five determinants to the success of industrial symbiosis initiatives, namely, technical, political, economic, informational and organizational determinants. Programs such as the Korean Eco-Industrial Park Development Program have been able to directly influence determinants, such as the economic and technical determinants, which interventions like the workshop series cannot. Focusing on building institutional capacity mainly influences the informational and organizational determinants, which enables groups of actors to develop new ideas that may influence all determinants favorably. Indeed, we have already observed outcomes of this kind in the form of increased interest for biogas solutions from one actor and other actors are calling for joint meetings on how to realize collaborative biogas solutions, although the emergence of material, water or energy exchanges, as well as joint service provision, are yet to be realized. This is to be expected since material synergies of this kind usually have long incubation times (Jacobsen, 2009) and macro-level conditions may also have to improve before any biogas solutions are realized. Hence, it is too early to say whether the workshop series will lead to the realization of any collaborative biogas systems in Norrköping, but they contributed to creating more supportive conditions for such collaboration.

The long incubation time of material synergies often means that it is quite difficult to evaluate the success or failure of industrial symbiosis interventions. Usually, this evaluation is done after longer programs are finished, as is seen in the Eco-Town Program in Japan (Van Berkel et al., 2009b) and the Korean National Eco-

Industrial Park Program (Park et al., 2016). This evaluation is useful when designing new programs (or new phases of programs), but it is insufficient if the goal is to improve interventions while the program is running. For this purpose, evaluations need to be done during programs and closely in tangent with the finalization of different specific interventions or projects. With the use of the institutional capacity building framework, one can evaluate interventions at a much earlier stage, looking at the internal capacities of the network. This makes it possible to continuously improve the interventions in a formative way. It signifies a way to capture the intangible parts of the industrial symbiosis network and can show the impact of industrial symbiosis interventions, even in the absence of tangible physical exchanges.

7. Conclusion

In this paper, we presented a workshop series that was an intervention aiming to facilitate biogas solutions in the Swedish municipality of Norrköping. We utilized the theory of institutional capacity building to guide and evaluate the intervention. The workshop series enabled different actors to familiarize, learn together and strategize, without requiring much investment from participants or the organizer. The workshop series created an arena were actors could meet and discuss a topic of common interest. The discussions in Workshops 1 and 2, accompanied by the feasibility study on the potential to increase use and production of biogas in Norrköping, helped participants to enhance both knowledge and relational resources. The results from the feasibility study indicate a significant potential for increasing the local production and use of biogas. Guided discussions among relevant actors made actors recognize that in order to realize this potential cooperation between actors and coordination of efforts is needed, as resources and the knowledge about biogas are distributed both geographically and across sectors. Discussions during the second workshop further increased knowledge on opportunities and barriers related to unlocking the production and use potential, which led to synthesis of six key areas to facilitate biogas solutions in Norrköping. These key areas were discussed during the third workshop and actors that were able to take leading roles in different areas were identified. This led to an increased mobilization capacity by appointing leaders and building consensus on ways to realize the key areas of development. The municipal organization was identified as a particularly important actor in this work, which could act as a hub for many of the local activities related to biogas, coordinating substrate owners, biogas companies and biofertilizer buyers. Results from the participant survey indicate that interactions and activities enabled by the workshop series were effective in strengthening institutional capacity among participating actors. Furthermore, observed activities of the involved actors following the workshop series show that efforts have been initiated towards developing the local production and use of biogas in Norrköping.

However, the workshop series presented in the paper is just one way to conduct this type of intervention, and the theory of institutional capacity building may be used to guide other kinds of interventions as well. Ultimately, the context and maturity of the network being targeted by the intervention should guide what kind of intervention, and what interactions, are best suited. For those seeking to facilitate emergence or growth of industrial symbiosis through interventions, the results and discussions of this paper provide valuable insights. For example, the paper presents how the theory of institutional capacity building may be used both to guide the setup of interventions aimed at strengthening internal capacities within networks and to evaluate interventions. The theoretical framework enables a short-term evaluation that is able to capture the intangible progress within the social process of industrial symbiosis emergence.

Nonetheless, using institutional capacity building to guide and evaluate industrial symbiosis interventions or other collaborative sustainability efforts remain a relatively unexplored area. More studies in other technical, political and geographical contexts are needed to validate preliminary conclusions and to show when conclusions may be transferable and generalizable. Furthermore, research on how to better capture changes in the institutional capacity of groups of actors is needed. As institutional capacity appears in the interactions between people, it is difficult to capture in a way that allows for comparison and ranking. Research here could aim to present methods to evaluate not only if institutional capacity has been strengthened but also to what extent and how different activities and events influence such change, both in individual actors and groups of actors.

CRediT authorship contribution statement

Axel Lindfors: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Marcus Gustafsson:** Methodology, Investigation, Writing - original draft, Writing - review & editing. **Stefan Anderberg:** Methodology, Investigation, Writing - review & editing. **Mats Eklund:** Conceptualization, Project administration, Writing - review & editing. **Murat Mirata:** Conceptualization, Methodology, Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to thank the participants in the workshop series for contributing to valuable discussions and the progress of the study. We would also like to extend our gratitude to Jonas Ammenberg at Linköping University for his work prior to, during and after the workshop series. Finally, gratitude is extended to the anonymous reviewers that contributed to the finalization of this paper by their insightful comments and suggestions.

This research has received funding from the Swedish Biogas Research Center, which in turn is funded by the Swedish Energy Agency, Linköping University and its members.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122822.

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