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Knowledge sharing in smart grid pilot projects

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ABSTRACT

The major role that the electrification of the energy system is projected to play in the transition to a sustainable economy increases the pressure on the electricity grid and thereby creates a demand for the implementation of smart grid technologies. The interdependencies present in the electricity system require, and have led to, the wide-scale adoption of pilot projects to develop knowledge about the application of these technologies. While the knowledge sharing that stems from these projects is one of the justifications for subsidising these projects, it has remained largely a black box. Based on the analysis of interviews with the project leaders of sixteen smart grid pilot projects, complementary secondary data sources and a survey, we studied knowledge sharing at four levels: intra-organisational, intra-project, inter-project and project-external knowledge sharing. At each level we observed specific sublevels, mechanisms and barriers, resulting in complex knowledge sharing dynamics. While the projects succeeded in developing knowledge, knowledge sharing between projects run by different consortium partners rarely occurred and project-external knowledge sharing was primarily unidirectional and involved generic knowledge. Based on the results a set of recommendations was developed that can stimulate the knowledge sharing and thereby increase the value generated by these projects.

1. Introduction

The electrification of transportation and the incorporation of electricity from renewable sources into the energy mix is increasing the pressure on electricity distribution grids (Dyke et al., 2010). The implementation of smart grid technologies, also known as smart energy systems, has been projected to play a pivotal role in enabling the grid to cope with these new challenges (Coll-Mayor et al., 2007). However, the current electricity system is characterised by difficulties arising from interactions between a heterogeneous set of demand- and supply-side actors in a distinctive regulatory and market context. This system not only poses pure technological challenges, but also relies on interdependencies between system components (Markard and Truffer, 2006), which hinders even the small-scale application of innovations, such as smart grid innovations. To overcome this challenge, actors need to collectively develop and share knowledge and innovations, what for smart grid innovations often happens in pilot projects (de Reuver et al., 2016; Planko et al., 2019, 2017).

Pilot projects are used to experiment with and demonstrate new technologies (Billé, 2010; Turner and Müller, 2003) in a relatively protected environment. A pilot project typically takes place on a small scale and aims to develop knowledge about the new technology as well as to create insight into how the new technology will fit into society (Markusson et al., 2011). The knowledge developed during the pilot project, consisting of both experience and expert insights, is of strategic importance for other actors facing similar issues (Davenport and Prusak, 1998). The idea behind the use of pilot projects is that when they are successful, the project can be followed by a scale-up and a large-scale implementation of a new technology. The sharing of the acquired knowledge with other actors in the sector should enable this larger-scale implementation of the piloted technologies. While this sharing might be deliberate in some cases, unintended spillovers are inevitable, generating additional returns that are not captured by the investing actors (Breschi and Lissoni, 2001), resulting in a market failure. This market failure of underinvestment in knowledge development resulting from public returns outweighing private returns (Martin and Scott, 2000) has been addressed through the provision of public funding to consortia for the execution of pilot projects (Klette et al., 2000). Even though governmental funding programmes typically aim to realise knowledge sharing, they often lack a clear notion of what kind of knowledge

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spillovers they aim for and how they should occur. Furthermore, it is also not always required to include a section on knowledge sharing in the project application, leaving knowledge sharing largely a black box. Therefore, it could be anticipated that knowledge sharing, despite its importance, receives little priority in demonstration projects (Hart, 2018).

The lack of understanding knowledge sharing dynamics is not surprising given the complexity of knowledge sharing as a concept. Knowledge sharing might entail recombining the knowledge of multiple partners or exchanging or disseminating knowledge (Nahapiet and Ghoshal, 1998). In the context of this study, actors in pilot projects can share different kinds of knowledge (Hau et al., 2013) via several mechanisms (McDermott and O'Dell, 2001) while being constrained by a variety of barriers (Riege, 2005). The literature on knowledge sharing, however, does not systematically discuss this. Understanding this process is critical, since lack of knowledge is a bottleneck for the further development of smart grids (Muench et al., 2014), and knowledge sharing could pave the way for further large-scale implementations of piloted technologies (Nemet et al., 2018). In this paper, we aim to differentiate between intra-organisational, intra-project, inter-project and project-external as four distinct levels of knowledge sharing in pilot projects. At each of these levels, different mechanisms and barriers to knowledge sharing are at play. We aim to provide insight into the knowledge sharing dynamics present at these four levels.

Considering the limited existing knowledge on these dynamics, an explorative approach was adopted in which the project leaders of sixteen smart grid pilot projects in The Netherlands funded by the Netherlands Enterprise Agency (RVO.nl) were interviewed. These interviews provided insight into the knowledge sharing dynamics at these four different levels of knowledge sharing. The findings show that at all these levels, a variety of mechanisms and barriers play a role in explaining the knowledge sharing. It is remarkable that inter-project knowledge sharing with unconnected projects (that do not have project partners in common) rarely occurs. Moreover, project-external sharing is primarily unidirectional and involves only generic knowledge. By providing insight into these areas, this research contributes to the literature on knowledge sharing in general and to the literature on knowledge sharing of pilot projects in particular. The findings enable policymakers, both inside and outside the energy sector, to develop deliberate knowledge sharing policies to facilitate the sharing of knowledge developed in government-funded pilot projects. This paper provides a review of the literature on knowledge sharing at the four identified levels, followed by an explanation of the methods and data and a combined results–discussion section. The paper ends with concluding remarks and policy recommendations.

2. Literature review

2.1. Knowledge sharing

Knowledge sharing refers to the process by which knowledge is exchanged between two or more actors (Sharratt and Usoro, 2003). This knowledge can be codified or tacit. Codified knowledge is knowledge that can be formally articulated and written down, whereas tacit knowledge consists of experiences, routines and developed skills which are stored in people and processes (Polanyi, 1966).Tacit knowledge is understood to provide organisations the foundation for a sustainable competitive advantage, since it is difficult to articulate, to write down and to copy (Cavusgil et al., 2003; Zack, 1999). Another distinction that can be made is between generic and specific knowledge. Generic knowledge is the knowledge that forms the basis of most products and services in a specific sector (Pemberton and Stonehouse, 2000), whereas (organisation-)specific knowledge is the knowledge that allows organisations to deliver products or services that have an edge over those of its competitors, and it is thereby part of the organisation's core competencies (Stonehouse and Pemberton, 1999).

We differentiate between four different levels at which knowledge sharing can be observed in pilot projects: intra-organisational, intra-project, inter-project and project-external. Literature (e.g. Easterby-Smith et al. (2008)) has shown that there are differences between intra-organisational (level 1) and inter-organisational (levels 2–4) knowledge sharing because boundaries are different. This is also the case for our set of levels and this will impact upon the success of knowledge sharing, upon what can and will be shared at these four levels as well as the specific barriers.

For intra-organizational as well as for inter-organizational knowledge sharing, scholars have looked into factors that enable or hinder knowledge sharing, which have been categorised for instance into individual, organizational and technological factors (see for instance the literature review of Riege (2005) and the conceptual paper of Nooshinfard and Nemati-Anaraki (2014)).

For the pilot project setting, however, we distinguish more levels and the literature has not yet discussed the knowledge sharing at all our four specific levels. For each of these different levels we will explain what, based on the available literature, we expect the benefits are of successful knowledge sharing, and what kind of knowledge will be shared as well as what barriers can be expected.

2.2. Knowledge sharing at different levels

Organisations, which can be seen as collections of individuals that share particular objectives, can benefit from intra-organisational knowledge sharing as it helps to achieve these objectives (Ipe, 2003). Typically, only a fraction of the organisation's members are directly involved in a pilot project, while the relevant organisational expertise and knowledge is likely to be spread wider among other colleagues, urging the organisation's members involved in the project to draw on the knowledge of their colleagues for the execution of the project. Similarly, the relevance of the knowledge generated in the pilot project for the organisation and its members inform the decision to participate in such a pilot project. Hence, successful sharing of project knowledge increases the benefits that organisations can gain from their participation.

The intra-organisational setting facilitates frequent interactions, which offers the organisation's members a context that is conducive for the sharing of tacit knowledge (Zack, 1999). This setting is also likely to have limited competition concerns about sharing specific knowledge.

Possible barriers are formal hierarchical structures, power dynamics and costs. The formal hierarchical structures can hinder the informal social interactions between departments that play a crucial role in knowledge sharing (Tsai, 2002). Power dynamics between subsidiaries in multinational companies can influence the knowledge sharing between subsidiaries (Birkinshaw and Hood, 1998). Furthermore, the employee-level costs involved in sharing knowledge with colleagues creates an intra-organisational version of the knowledge as a public good dilemma. Resolving this requires organisational incentives and culture that enables intra-organisational knowledge sharing (Cabrera and Cabrera, 2002).

2.2.1. Intra-project knowledge sharing

The increasing complexity of knowledge-intensive sectors and the reality that expertise is distributed across organisations requires organisations to become involved in collaborative knowledge development processes (Powell et al., 1996), such as pilot projects. Therefore pilot projects are usually executed by consortia of organisations with varied sectoral and institutional backgrounds. This offers the consortia access to non-overlapping, complementary knowledge bases (Sakakibara, 2003), while at the same time reducing the risk of opportunistic behaviour due to the absence of competitors (Doz et al., 2000). Thus, successful knowledge sharing within the project increases the benefits of the project and the project partners involved.

Intra-project knowledge sharing within these consortia takes place to

enable the combination of different knowledge bases (Nahapiet and Ghoshal, 1998). In order to be successful also tacit and specific knowledge needs to be shared.

Possible barriers are related to coordination costs and the unwillingness to share tacit knowledge, Although including more partners can further extend the knowledge base (Liebowitz and Suen, 2000), coordination costs are likely to outweigh these advantages (Camacho, 1991). In order to have successful intra-project knowledge sharing, the sharing of some specific tacit knowledge will be required. This is not necessarily something organisations are keen to do. However, it is likely that they do not necessarily need to open their entire knowledge base to their partners, but instead limit their access to the extent that is needed for the execution of the project.

2.2.2. Inter-project knowledge sharing

Pilot projects are usually part of larger, topic-defined programmes, and meanwhile, international, national and regional funding programmes might be funding similar projects. These projects are likely to encounter similar challenges, and the consortia might learn from each other's solutions (Kasvi et al., 2003), possibly in a reciprocal way (Bock et al., 2005). This is what we label knowledge sharing at the inter-project level. Successful knowledge sharing between projects might realise synergies for the consortia, yet are also likely to generate social returns through knowledge spillovers.

Inter-project knowledge sharing takes place to learn from other projects how to address particular challenges. Therefore the knowledge is likely to be context-specific.

A possible barrier is the unwillingness to share knowledge with other projects because it is unclear how the project will benefit from it. Moreover, the sharing of the specific knowledge might require intensive collaboration, and therefore investments in time, to facilitate the exchange of knowledge between the projects.

2.2.3. Project-external knowledge sharing

The final level is project-external knowledge sharing. Successful knowledge sharing with external parties will mainly create social returns. It could however also result in some private benefits. For universities and research organisations it is the default to disseminate the knowledge to their respective communities. While the majority of their readers is from within the academic community, scientific articles are still considered one of the most important channels through which university knowledge reaches industry (Bekkers and Bodas Freitas, 2008). Also the increased citation of scientific articles in industry patents suggests a readership in industry circles (Narin et al., 1997). Furthermore, the rising trend of open access publishing (Laakso et al., 2011) is also understood to contribute to the dissemination of research outside the academic community (Davis, 2011). Other project partners might share knowledge to further the transition from which they will benefit (Van de Ven, 2005), while some partners use it to strategically influence policy (Austen-Smith, 1993).

Given that project-external knowledge sharing is about external dissemination of project knowledge it is most likely to be codified and general.

Barriers to project-external knowledge sharing are a lack of financial and human resources. However, the external dissemination of the knowledge developed in the pilot project is usually obligatory upon receiving public funding. Nowadays, most funding bodies require projects to include a strategy in the project plan describing how the project knowledge will be made available to external actors, often complemented with a set of compulsory project deliverables (European Commission, n.d.). Including a knowledge dissemination strategy allows projects to reserve resources, both in funding and time, to invest in these dissemination activities.

A concrete model of knowledge sharing for our four levels is missing in the literature. Therefore, we aim to unravel the knowledge sharing dynamics present at these different levels by exploring for each of the levels the different mechanisms through which knowledge sharing takes place as well as the barriers.

3. Methodology and data

3.1. Research design and empirical context

The study uses a qualitative research approach, focussed on Dutch smart grid pilot projects, to further our understanding of how the knowledge developed in pilot projects is shared. Since the early 2010s RVO.nl has executed several smart grid subsidy programmes, including the Innovation Programme Smart Grids (IPIN), which ran from 2011 to 2016 and funded twelve pilot projects, followed in 2012 by similar programmes which funded fifty pilot projects through the Top Consortium for Knowledge and Innovation (TKI) Switch2Smartgrids (and its successors). Public-private consortia can submit a project proposal and compete for a subsidy within these programmes. At the time of the data collection (spring 2016), the majority of the TKI Switch2Smartgrids programme projects had just begun, which made them unsuitable to include in our study. From the twenty-five pilot projects that were suitable for our study, seventeen accepted the interview invitation. The main reason for non-participation was time constraints. Subsequently, one project was excluded from further analysis when it turned out during the interview that the pilot project was due to some delays still in a too premature phase, resulting in a final sample of sixteen projects.

3.2. Data collection

For each pilot project, data were collected through desk research and semi-structured interviews. The desk research preceding the interviews, which employed both internal RVO.nl internal and publicly available data, provided a general understanding of the technical nature of the projects as well as familiarity with the different actors in the smart grid sector. This facilitated an atmosphere during the interviews in which the project leaders were comfortable sharing in-depth insights about the knowledge sharing of their respective projects. Moreover, for each project the knowledge sharing sections of the final project report have been studied.

We conducted the 1-h, semi-structured interviews with the project leaders, assuming that they are the most informed team members regarding the strategic and general developments within their projects, although realizing that the insights into intra-organisational knowledge sharing of other consortium partners would therefore be limited. On two occasions an additional project member joined the interview. Providing anonymity and conducting the interviews in Dutch (the native language of the project leaders) allowed the project leaders to talk without constraints.

To complete the picture of the context and background of the projects, the project leaders were first asked about the functioning of their project, the collaboration within their consortium, and the role they fulfilled within the project. Subsequently, the project leaders were asked about how they defined knowledge; this was done to ensure that the interviewee and interviewer shared a similar understanding of this core concept. Next, we asked the interviewees what they meant by 'knowledge sharing' with regard to their project, which often resulted in elaborate answers which addressed all the four levels of knowledge sharing discussed in the literature review. The questions that followed zoomed in on inter-project and project-external knowledge sharing by asking to what extent such knowledge sharing occurred, in what ways, with whom, why and more. At the end of each interview, the role of RVO.nl in the sector was discussed, and the interviewees were offered the opportunity to discuss any additional topic they considered to be relevant.

In addition, a survey was conducted to capture the perspective of external actors on the receiving end of project-external knowledge sharing. The main topics covered in the survey were the demand for

knowledge about smart grids, the applied knowledge search strategies and the specifics of potential interactions with the pilot projects covered in this study. The sample for the survey was drawn via a web search and the scraping of overview websites, sampling organisations similar to the project participants, but who were not participating in one of the subsidy programmes. The list of organisations was subsequently discussed with field experts to ensure that these organisations belonged to the target audience for project-external knowledge sharing, resulting in a final list of one hundred organisations. These organisations were approached and reminded to participate in the survey; ultimately, 30% completed the survey. Field experts indicated this percentage to be a good response rate, and since there were no clear biases in the non-response, the results can provide general insight into the demand-side of project-external knowledge sharing.

Additionally, during the time of the data collection, one of the authors participated in conferences and meetings intended for actors in the Dutch smart grid domain. Participation in these events not only offered a deeper understanding of the sector, but also enabled informal discussions about knowledge sharing dynamics with various stakeholders. When these stakeholders or one of the interviewees mentioned interesting developments, further desk research or discussions with stakeholders were initiated.

3.3. Data analysis

The analysis consisted of three steps. First, using NVivo we distinguished the sections covering the different knowledge sharing levels in the interview transcripts. We then coded the mechanisms and barriers present at each level, which also lead to the identification of the sublevels. Second, for each level we examined the statements made by the project leaders to obtain holistic coverage of the level. Subsequently, we zoomed in onto the sublevels and its mechanisms, as well as the barriers present at the level. In the final steps the resulting analysis was complemented with the survey data and data from the knowledge sharing sections of the final project reports, either as additional insights or as context for the interview findings.

In writing-up the research, the interview quotes were anonymised, translated to English and used to support our findings. Anonymous letter codes were used to refer to the interviewees. Square brackets indicate clarification additions or anonymisation edits in the quotes.

Finally, to validate and contextualise our findings and policy recommendations, a previous version of this paper was discussed with a group of policy officers. Our results were considered to be relevant by them, and no radical or surprising additions were made following the discussion.

4. Results and discussion

4.1B. ackground information on the pilot projects

The scope of the pilot projects (hereafter referred to as ‘projects’) asked for such broad expertise that the median consortium size was six partners, including organisations from multiple sectoral and institutional backgrounds. During the formation stage, most consortia aimed to cover all the areas of expertise required for the execution of the project. This resulted in the participation of an electricity distribution company in most of the projects. Since the liberalisation of the Dutch electricity market, these government-owned companies have been responsible for maintaining and upgrading the grid in their area, making them key players in both enabling and benefitting from the smart grid innovations developed in these projects. However, also their vast financial resources made these actors attractive as consortium partner: ‘many actors see [distribution company] as a big bag of money with whom everyone therefore wants to collaborate’ (Project M). Other project participants came from the private domain (e.g. multinationals and SMEs), knowledge institutes (e.g. universities and research organisations), and the public domain (e.g. municipalities and cooperatives). On average, the projects received approximately 700,000 euros in subsidies, which covered 43% of the total project budgets on average, and ran with a mean duration of 38 months.

4.2. Knowledge sharing strategies

While the project plans were explicit about the technical objectives, most lacked a deliberate knowledge sharing strategy. Some project leaders were well aware of the knowledge sharing sections included in European Union’s Research and Innovation programme funding applications but did not include such a section in their own applications because it was not required by RVO.nl at that time. The presence of a section on knowledge sharing or an overview of publications in eleven[1] final project reports indicates that throughout the duration of the programmes, RVO.nl has placed greater emphasis on the importance of knowledge sharing.

There were some projects in which there was someone responsible for external communication, and/or knowledge dissemination was (part of) a work package. However, the absence of a deliberate strategy meant that often no specific financial or human resources were reserved for knowledge sharing. There were quite some differences between project leaders in how they handled this situation. While some indicated that knowledge sharing should be a general task for all consortium partners without someone carrying the final responsibility, other project leaders assumed that it was one of their responsibilities.

A few project leaders adopted a proactive role in sharing knowledge, while others were more passive and waited until people came to them with requests. This might partially be explained by the personal characteristics of the project leaders; in general, those with a management background were more interested in interacting and sharing, while those with a technical background tended to be more interested in the execution of their project, and they thought less about the other aspects of the project. Another explanation might lie in the incentives for knowledge sharing present in the project leader’s organisation: project leaders working for organisations that were destined to benefit from the large-scale adoption of smart grids, or the sharing of knowledge in general, were more engaged in sharing.

4.3. Knowledge sharing at different levels

This section zooms in on intra-organisational, intra-project, inter-project and project-external knowledge sharing. The dynamics at these levels are addressed by discussing the sublevels, the mechanisms and the barriers present at each level.

4.3.1. Intra-organisational knowledge sharing

Several project leaders mentioned the organisational level as an important level to share knowledge from the project: ‘I am sometimes more occupied with telling about our project within our organisation than that I am doing so externally’ (Project R). At the intra-organisational level, three sublevels were identified at which knowledge sharing took place (see Fig. 1). We identified knowledge sharing within the local branch (Sublevel 1.1), knowledge sharing with other national branches (Sublevel 1.2) and knowledge sharing with foreign branches (Sublevel 1.3).

The first intra-organisational sublevel was knowledge sharing with colleagues at the same geographical location (Sublevel 1.1). This meant not only disseminating knowledge internally, but also drawing on the available expertise. As Project Leader L noted, ‘We are really technical, and the core [of the project] is ICT, and we have an entire department that always can help us.’ While the leader of Project L referred to this as

[1] For two projects, a final report was unavailable, and in three final reports, knowledge sharing was not explicitly mentioned.

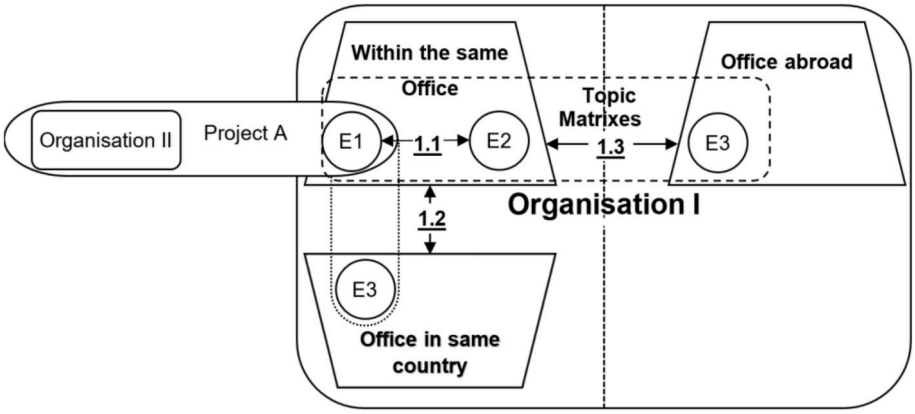

Fig. 1. Sublevels for intra-organisational knowledge sharing.

simply asking for advice from colleagues, in Project K '"another colleague was included in the project than originally planned'. Although intra-organisational knowledge sharing was prevalent in many organisations, smaller organisations were by default limited in the extent to which this could take place.

Second, several larger organisations also created a setting in which knowledge could be shared with colleagues of offices located elsewhere in the country (Sublevel 1.2). This sharing was often done on an informal basis: people knew each other on a first-name basis, and when in need of knowledge, these colleagues could be contacted with little effort. According to Project Leader L, when data on future energy prices was needed, 'One connection, and I have all the prices.' For Project Leader R this was not limited to a 'mouth-watering' interest of knowledge available at other national branches: this project leader also tried to influence the direction of the research at another branch: 'We try to influence their research in a way that it really helps us. Those batteries, we can really benefit from that, we can make progress on this topic (…) we have contact about it.' In other instances, colleagues from different branches were together involved in a project, which facilitated the joint development and exchange of knowledge.

Third, multinational companies, in addition, enabled knowledge sharing with their colleagues abroad (Sublevel 1.3). Part of this knowledge sharing took place through formalised matrix structures in which employees working on similar topics met regularly to discuss recent developments: 'We have so-called matrixes (…) I am part of the green mobility programme (…) We exchange between all countries what we are doing and the progress is, in order to not replicate knowledge that is already developed abroad and vice versa' (Project R). Participation in pilot projects offered the local branches prestige within the larger organisation and allowed them to take the lead on topics: 'We as the Netherlands really take the lead; everything related to e-mobility is then also done in the Netherlands (…) Other people look to our project to see what they can learn from it' (Project R). On other occasions interactions with colleagues abroad enabled the re-use of knowledge, where in some cases the context was more favourable to particular smart grid applications, such as regions that are more vulnerable to blackouts. The strong knowledge base of the larger multinational companies allowed project participants to search internally for the necessary expertise to meet the challenges that could not be solved by the people directly involved in the project.

There was one recurring barrier to intra-organisational knowledge sharing: a lack of awareness of the knowledge and relevant colleagues within the organisation. Project Leader B, employed by a university that was involved in several projects, had little knowledge about other similar projects in which the university was participating: 'I have not heard too much about that project (…) But you do not know what you do not know until you do.' This lack of connection between different parts of the organisation was the case not only for the universities, but also for the multinational partners. Project Leader E, who was employed by a multinational company, expressed similar feelings: 'You should not overestimate how close we are connected as a multinational company; we are still really a national organisation.'

4.3.2. *Intra-project knowledge sharing*

Most consortia had a contract and guidelines for intra-project knowledge sharing, specifying, among other issues, how to treat each other's intellectual property. Furthermore, direct competitors were excluded during the formation of the consortia: 'There were no partners that were competing with each other. Everyone had their own role, and that was really clear' (Project C). The intra-project knowledge sharing was seen by Project Leader R as beneficial: 'You are forced to cooperate in a context in which you encounter things you will not know, because as regular companies you are usually really doing your own thing. I see that by all means as an import form of knowledge development.' At the intra-project level, we identified two sublevels at which knowledge sharing took place (see Fig. 2). We differentiated knowledge sharing within work packages (Sublevel 2.1) from knowledge sharing at the project level (i.e. between work packages or between project partners in general) (Sublevel 2.2).

First, the consortia divided the responsibilities into work packages. Although it was possible that certain work packages were the sole responsibility of a partner, many work packages involved collaborative efforts and thereby created both an interface and a necessity for knowledge sharing to enable the combination of different knowledge bases (Sublevel 2.1). To structure this collaboration, work package leaders organised monthly meetings to discuss their progress on their objectives, although the frequency of these meetings differed depending

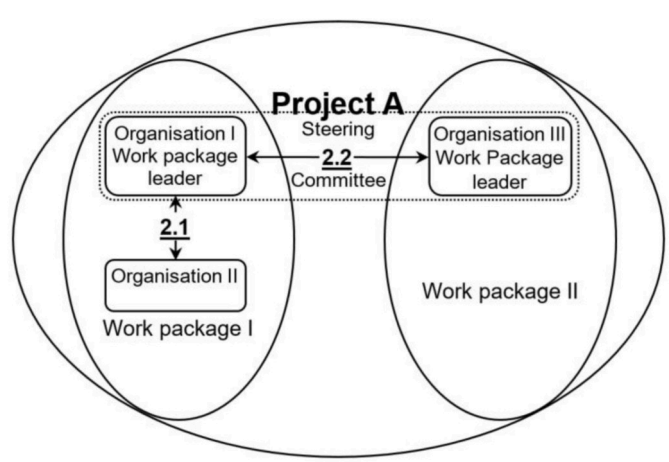

Fig. 2. Sublevels for intra-project knowledge sharing.

on the project stage. The project execution often required the exchange of knowledge with a tacit dimension, which might explain why project leaders preferred face-to-face meetings: 'We came to the conclusion fairly quickly that we had to be close to each other because we did a lot of work packages together; let us make sure that we see each other regularly at least and not everything has to be done by phone or email' (Project K).

Second, the collaboration in projects required also the exchange of insights between work packages to realise the project goals (Sublevel 2.2). Regular meetings for all work package leaders, which were sometimes attended by advisory board members, were organised to discuss the overall progress and inter-work package collaboration of the project. The project leaders also made clear that the project partners were selected to complement each other's knowledge while at the same time avoiding too large of a consortium. This facilitated knowledge sharing within the project. Project Leader K stated, 'I notice that with very large European projects, everyone is going to do his or her own thing, and that there was little cohesion. This project – because it had a nice size, and because not too many people per organisation participated – you could just sit together and just share with each other.' Although knowledge sharing at the project level often happened without a clearly defined strategy, there were exceptional cases in which such an in-depth strategy was developed. In one case, the project collaboration resulted in the project leader being recruited by one of the other consortium partners once the project was complete. Project-internal knowledge sharing also took place with citizens that were involved, sometimes even as a formal project partner, because the new technologies (i.e. smart dishwashers) were installed in their homes. Project Leader J stated, 'It is ideal to have a partner like [anonymous university], who takes responsibility for engaging with the residents, organising resident evenings to discuss this topic (…) We had a good student who acted as an independent party and formed a bridge between the residents and us, the technicians.' Further information to these involved citizens was also provided through brochures, presentations and websites clarifying how to use the technologies and their relevance.

The project leaders were generally satisfied with intra-project knowledge sharing, and the interviews indicated that the partners were often open and willing to share their knowledge with their project partners. Respondent E even said, 'We share everything.' Nevertheless, they also encountered barriers to knowledge sharing at this level. As mentioned above, one of the conditions for knowledge sharing at this level is the absence of direct competitors. However, in the emerging market of smart grids, future market roles are not yet clearly defined, and the projects can help to explore these roles: 'Every organisation was allowed to explore its future role. An electricity distribution company wants to go in one particular direction, but an energy supplier wants to go in a different direction' (Project C). Nonetheless, this was also a potential source of conflict: 'They start activities that are the same as ours, and that is sometimes a concern for us' (Project E). It was also observed that the different interests of organisations sometimes limited the knowledge shared: 'I truly believe that these parties have also gained knowledge in this project which other parties would be interested in, but they simply do not share it because it might give them a commercial advantage' (Project F). Moreover, in other situations organisations preferred to pursue their own interests, leading them to neglect their interest in the overall project idea: 'A lot of these projects provide (…) additional income for companies: (…) you take the money, you execute your part, the framing that it is one project is often wrong and everybody goes afterwards their own way' (Project O). In other cases, the way organisations pursued their own interests was more nuanced, such as when organisations quit their involvement in a project after the initial meetings because the knowledge developed in the project was too abstract and 'too much long-term for some parties to be relevant' (Project K).

Another barrier was personnel turnover, resulting in a lack of continuity in the knowledge generated in the collaboration. While the consortia indicated that they had benefited from the involvement of PhD and master's students, these students' departure from the project upon graduation resulted in the loss of their developed expertise. In one project this happened prior to graduation, when a talented PhD student was acquired by a multinational abroad. Moreover, the passing away of key employees and the bankruptcy of leading project partners harmed knowledge continuity. Consortium C attempted to ensure continuity by codifying knowledge for internal use: 'During the project a considerable number of people were replaced. After all, it was three years, and every new work package leader needs to familiarise themselves with how things were done before (…). If you codified this part, it can take away a part of this pain.' Project Leader E considered it merely an individual responsibility to safeguard the continuity: 'maintaining the thread, I am the one who has been there from when it started with a few colleagues (…) I am the one securing the original idea (…) I absorbed the input of the work packages, I fitted that into the bigger picture'.

4.3.3. *Inter-project knowledge sharing*

When discussing knowledge sharing at the inter-project level, several project leaders were visibly annoyed by how it functioned: 'We [the companies involved in Dutch smart grid projects] sometimes invent the same wheel in multiple places' (Project J). We identified three sublevels at which knowledge sharing took place between projects (see Fig. 3). We distinguished between knowledge sharing with unconnected projects (Sublevel 3.1), knowledge sharing via partners present in both projects due to overlap in consortia (Sublevel 3.2) and building further on the generated knowledge in follow-up projects (Sublevel 3.3).

First, sharing knowledge with unconnected projects, so other projects led by consortia of different partners, was a primary aim of the funding programmes (Sublevel 3.1). These exchanges tended to be initiated via face-to-face interactions during the smart grid conferences organised by RVO.nl. Although the project leaders were generally positive about these events, they observed that the knowledge exchanged remained generic: 'Everything is presented to a broad audience, which makes it very generic' (Project L). While agreeing with this point, Project Leader H also acknowledged the value of interactions with participants from other projects: 'During the coffee breaks, you hear a lot of interesting information that people do not share formally but are willing to share informally. If you publish a paper on behalf of a project, you should treat the feelings of oversensitive partners with care, because that paper will still be available ten years later.' In a similar vein, congresses were seen as useful for establishing contacts, which could lay the foundation for future contact: 'If you see each other at least every once in a while at a congress, and if you then have a query, the telephone can be used.' Project Leader L indicated that while the general events were too generic, project websites could be used to obtain information about ongoing sector developments: 'I look at the results. I am curious about what they have achieved, in case I might ever have a similar project, *I will look* closely at how they did it.' While this could be done by reading a final project report, direct contact seems to be preferred: 'If you know someone, then I am inclined to call him; hey, explain this'. Some project consortia explored possibilities for collaboration: 'One project in particular was appealing to us – that was [anonymous project]. We found that really interesting, and we visited that company twice, a collaboration or the intention to, and we have considered applying it [the idea of the other project] in one of our projects' (Project B). However, the interactions between unconnected projects remained superficial, and we did not observe cases of in-depth knowledge sharing or collaboration between unconnected projects.

Second, knowledge sharing between projects with overlapping consortia was more prevalent (Sublevel 3.2). In one of these cases, a research institute applied the same IT solution in multiple projects, benefitting from the knowledge generated in all these projects. Sometimes, this also resulted in joint publications, in which the knowledge developed during several projects was brought together. Considering that participation in multiple projects is a precondition for assuming this

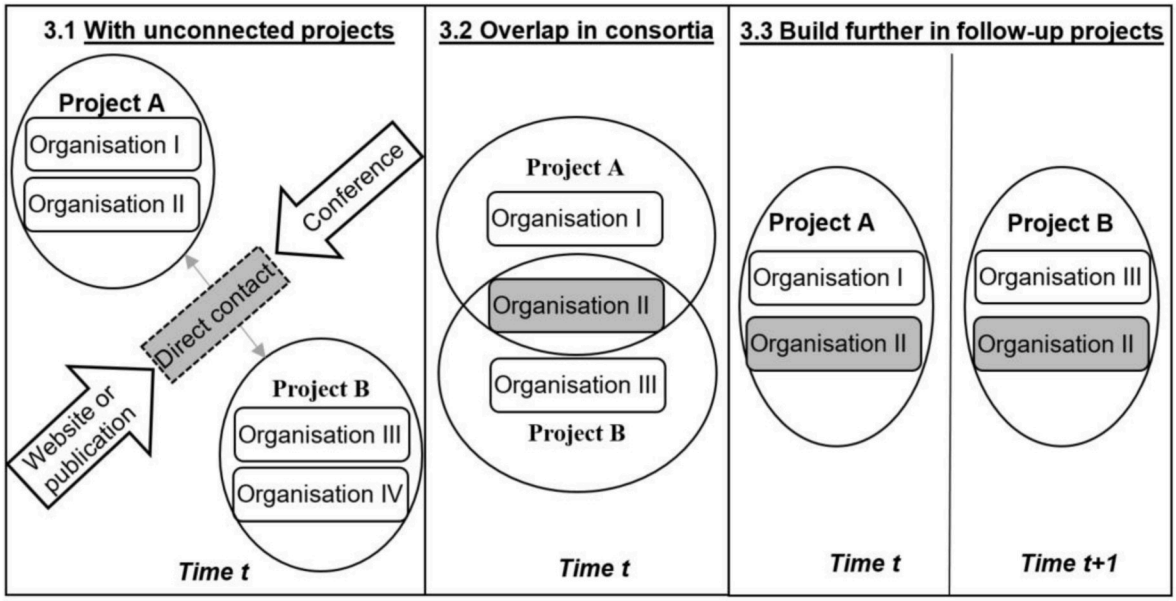

Fig. 3. Sublevels for inter-project knowledge sharing.

bridging role, only the larger research institutes, multinationals and electricity distribution companies were able to do this. The latter also played an active role by organising joint knowledge sharing sessions for the consortium partners of their projects. The project leaders indicated that they benefited from these sessions, which allowed them to go more in-depth than at the large-scale conferences: 'That was really useful. That allowed in-depth knowledge sharing; sharing of generic information is already happening enough. I am a technician, and want information on a detailed level, and not too generic' (Project L).

Third, eight consortia discussed or initiated follow-up projects to further build upon the knowledge developed during the current project (Sublevel 3.3). In most of these cases, the same consortium reapplied the knowledge in a new project, although there were also cases in which consortium partners formed new consortia for this purpose.

There were quite some differences in the frequency of knowledge sharing and the barriers at play within the different sub-levels of inter-project knowledge sharing and the barriers at play for the different sub-levels. While for projects with overlapping consortia or follow-up projects, knowledge sharing happened naturally, none of the projects realised in-depth knowledge exchange with unconnected projects. The reason for this could be that the latter requires more deliberate planning, which is difficult for consortia to do while under pressure to complete their own objectives. This could also be why most project leaders, although they indicated that they were open to sharing knowledge with other projects, expected the other side to take the initiative: 'On the one hand, it would help them if they would know what we are working on, but I am not going to take the initiative. [Anonymous] is located close to the German border. There is not really a need for me to go there, but we can give them some advice on their issues' (Project A). However, proactively offering help was sometimes not appreciated, as in the case of Project K: 'With some issues there were possibilities of which we thought we could assist, but I saw that quite some projects had a pretty closed vision of doing their own thing: "yes, this could be interesting, but we are not going to do this together."'

Several project leaders also expressed a lack of interest in the other projects: 'The other projects were not that interesting, that was about smart grid and sharing with horticulturists … mwah …. that is not so interesting, our project is special in focus' (Project B). When project leaders knew about other projects with whom there were no formal ties, informal networks seemed to play a role: 'I know one of these projects quite well because a friend of mine is involved in it' (Project N). In addition to the lack of interest, some project leaders expressed that inter-project knowledge sharing was not relevant because they saw themselves as frontrunners: 'We were far ahead in comparison to the other projects. For us knowledge sharing was helping them, and we have been reluctant in that. On the one hand, you do not want everyone coming up with the same solution, because you do not know whether it is the right one. On the other hand, you do not want to spend your time helping others, while we also had ambitious plans to realise' (Project C).

4.3.4. *Project-external knowledge sharing*

The knowledge sharing at the project-external level was quite diverse in its mechanisms, audience and content. There was no real consensus in the interviews or in the final project reports about what was understood as external knowledge sharing, although there was importance given to codified knowledge and a process characterised by dissemination with unidirectional knowledge-sending. We identified two sublevels at which knowledge sharing took place (see Fig. 4). We distinguished between knowledge sharing carried out by the project leader from the project level (Sublevel 4.1), and knowledge sharing carried out by the individual organisations within the project (Sublevel 4.2).

First, when discussing project-external knowledge sharing, most project leaders referred to the knowledge that was shared from the project level (Sublevel 4.1). They saw it as their main responsibility that the compulsory deliverables such as the final report and progress reports were written. These reports were available for nearly all the projects after their completion. While the progress reports were limited in scope, most final reports provided in-depth insight into the project's findings. Many project leaders saw these documents merely as boxes to tick and as an obligation coupled to receiving the funding, complaining that the time invested in these reports could hinder project completion.

In contrast, most project leaders were proud of and willing to invest time in publications for trade magazines. In addition, a couple project leaders were invited to join advisory boards, using these opportunities to stay up to date on and to influence policy in their desired direction, such as by asking for attention to be paid to the value of flexibility for the grid. In a similar vein, Project K aimed to influence other actors: 'Communication is as important as the technical content of the project because you want to push people to do something and not only present something technical.' Furthermore, (local) newspaper articles and videos were targeted to create awareness among the general public of the developments happening in their environment without addressing all the

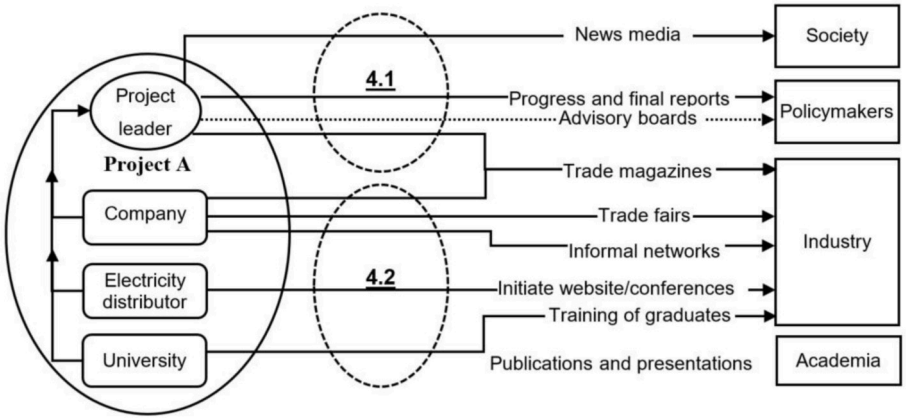

Fig. 4. Sublevels for project-external knowledge sharing.

project details. Project Leader L said, 'It is a constant process; I am not at my desk for six months, and only then do I start communicating (…) When I have found something, and I am with the client, and it is discussed, it is immediately shared (…) It is not that you are going to wait for a report to be approved; that is a continuous process.'

Second, knowledge sharing activities were also deployed by the other consortium partners (Sublevel 4.2). Some consortia saw publications as a shared responsibility: 'These publications are always [written by] a combination of partners' (Project C). This contrasts other projects, in which the partners have their own publications, which is indicated in the final report with each partner's list of publications. The focus areas of the types of partners also resulted in different forms of knowledge sharing. The universities and research institutes, pressured by the publish-or-perish culture in academia, often engaged in knowledge sharing by writing and presenting scientific and conference publications in English, targeting a global academic audience. The universities also shared the knowledge developed in the projects with their students (e.g. in courses and especially by means of graduation projects), and they are thereby said to be contributing to the training of 'the experts of tomorrow'.

Private companies, in contrast, were mainly interested in displaying their skills and products to potential customers. By appearing in trade magazines and presenting their products at trade fairs, these companies were considered to have disseminated market knowledge: 'I would like to present our story in Africa and China (…) I want to market this project' (Project P). Project Leader P also actively shared in-depth knowledge with an American company in their network to support the US implementation of a product developed in the project for which there was not yet a viable business case in the Netherlands. Actively sharing knowledge not only with companies but also within the sector helped several project leaders establish a good reputation and a strong position within the sector. Acquiring a position within the sector also motivated some firms to share knowledge, as they were convinced that this would allow them to position themselves well in the new configuration of actors in the sector; new business models were a concern for later.

The electricity distribution companies were in a different position, as regulations and bureaucracy limited their possibilities to experiment with new technologies. Nevertheless, as the main beneficiaries of the adoption of smart grids, they played a facilitating role for knowledge sharing within the sector. The electricity distribution companies, often in collaboration through the industry body Netbeheer Nederland, organised conferences to which industrial, societal and policy actors were invited. They additionally started the initiative energiekaart.nl, a knowledge portal which aims to provide a comprehensive overview of all smart grid initiatives, technologies and experts in the Netherlands.

Considering the barriers, knowledge sharing at the project-external level was not something that simply occurred; it required deliberate coordination and planning. As Project Leader K noted about not meeting the idea to send frequent newsletters: '(…) we send four or five, because it are things you need to think about, and on that the planning was not strict enough.' Some projects (e.g. Projects F, H and O) had work packages designated for knowledge sharing. Although the project leaders were usually expected to take the lead on knowledge sharing initiatives at the project-external level, they depended on input from the other consortium partners. In some cases the partners were unwilling or unable to invest resources in writing sections for project reports, while in other instances the partners were willing to share knowledge, but the project leaders noticed that they were only sharing part of the knowledge. Most project leaders understood that the partners were not going to share all the knowledge developed prior to the project, but they also stressed the importance of project-external knowledge sharing and that this was necessary to justify the subsidies they received.

Some project leaders pointed to lack the financial and human resources for project-external knowledge sharing, which they explained by not including it in the project planning and budgeting. Many of them, also referring to experiences from other projects, explained that knowledge sharing was not a top priority. This was especially the case for projects that were behind schedule and needed to focus on delivering the project on time. Sometimes these consortia were also reluctant to share because they preferred not to disclose the failure of some of their technologies or a lack of results in general.

Furthermore, the focus of universities on publishing led to a neglect of other knowledge sharing activities; this appeared to be the case with PhD students whose top priority was finishing their PhD study on time. While many of these publications were openly accessible, some were hidden behind paywalls, which supports the impression of Project Leader J, who suggested that these publications were primarily for the academic community: 'It is for a different audience (…) Scientific research are heavy papers, English, technical, scientifically sound. It is not easy for a project organisation to understand.' Furthermore, peer-reviewed publications seemed also to suffer from a success bias, which was apparent in that unsuccessful projects were less involved in publishing.

The effect of these barriers is visible in the survey results. Most organisations (93%) acknowledge the necessity to acquire knowledge about smart grids for the future of their organisations; of these organisations, only a few were planning to develop this knowledge internally. Hence, the large majority of the respondents were outward-oriented in their search for knowledge, resulting in a large potential for knowledge sharing with external organisations. However, 30% of organisations were still unaware of the existence of the subsidised projects. That said, of the respondents that knew the projects by name, 80% were aware of what was done in that project. They primarily acquired knowledge via trade magazines and existing relationships within the sector. Only one

respondent indicated having acquired knowledge through scientific publications. Although the projects are actively engaged in knowledge sharing with external organisations, the visibility of the projects by external organisations remains limited.

The project-external knowledge sharing was mainly unidirectional in the sense that the knowledge developed in the project was provided to external actors, and often not considering whether this knowledge would actually be used by the actors. In the few cases in which a consortium partner aimed to obtain knowledge from an external actor, other consortium partners enabled this interaction by introducing them to a relevant partner in their network. On another occasion of acquiring external knowledge, a multinational encountered resistance from an SME which feared that the multinational would take advantage of opening up the knowledge base. To overcome this obstacle, a smaller project partner stepped in with whom the SME felt more comfortable sharing knowledge. That this fear was not unjustified showed the case of Project N, in which a larger organisation threatened to copy products.

5. Discussion

Intra-organisational, intra-project, inter-project and project-external knowledge sharing are four distinct levels at which knowledge is shared; each level contains sub-levels at which knowledge is shared via multiple mechanisms and influenced by various barriers. Table 1 provides an overview of the main findings.

In general, there seems to be a trend that at the intra-organisational and the intra-project levels, knowledge sharing is about interactions involving specific and tacit knowledge, whereas at the inter-project and the project-external levels, it is more about the dissemination of generic and codified knowledge. Possible explanations for this include larger geographical and institutional distances and the absence of incentives at the latter two levels.

Expecting the consortia to excel at every level is unrealistic. The project leaders that are heavily involved in intra-organisational knowledge sharing are likely to have less time to focus on what is happening within other projects. However, it is not only this scarcity that creates competition between the levels; the prevalence of successful knowledge sharing at one level can also reduce the need to be involved in knowledge sharing at other levels. Furthermore, there is inevitably some interaction between the levels; knowledge sharing with overlapping consortia, which is presented as knowledge sharing at the inter-project level, often also requires intra-organisational knowledge sharing. Similar arguments can be made for knowledge sharing at the intra-project level, such as consortium participants who contact each other to address an issue and who subsequently source the required expertise within their own organisation. Interactions between intra- and inter-organizational knowledge sharing have also been discussed in the literature (e.g. Easterby-Smith et al. (2008)). In this, organisations seem to follow a transaction cost logic (Williamson, 1979) in which they aim to limit costs by sourcing knowledge at the lowest level possible, starting at the intra-organisational and, when necessary, contacting consortium partners, but seldom consulting other projects or external actors for knowledge. And this is an important finding as these levels of knowledge sharing are key objectives of the funding programmes. The fact that this not happens by default indicates the need to identify the specific the barriers.

At most levels we see personal level networks recurring as facilitators of knowledge flows. Individual employees use their connections to share knowledge at the intra-organisational level. Moreover, at the intra-project level, the employees of the consortium partners share their knowledge. Inter-project knowledge flows happen when employees form a bridge between projects. Only in the case of project-external knowledge sharing are personal networks less dominant, and this seems much more about finding the right distribution channels.

Considering that the lack of knowledge is a bottleneck to the further development of smart grids (Muench et al., 2014; Nemet et al., 2018),

Table 1
Summary results

Level	Sub-level	Mechanism	Knowledge	Prevalence	Main barriers
1. Intra-organisational	1.1 With colleagues in the same office	Requests for help from local colleagues	Specific expertise present in colleagues	All organisations	A lack of awareness of available knowledge and of relevant colleagues
	1.2 With colleagues in offices in the same country	Information requests; influencing direction of research; Jointly participating in projects	Specific information; strategic knowledge; Expertise specific to the project;	Only in larger organisations	
	1.3 With colleagues in offices abroad	Participation in matrix structures	Discussions on the development of the sector	Mainly in multinationals	
2. Intra-project	2.1 Work packages	Work package meetings and collaboration	Practical knowledge for execution work packages	Most work packages	Different interest of project partners Lack of continuity due to personnel turnover
	2.2 Project level	Project meetings; joint development	Knowledge on progress of work packages to assure alignment and project coordination	All projects	
3. Inter-project	3.1 Unconnected projects	Face-to-face interactions, possibly initiated during events organised by RVO.nl; websites	Relevant project specific experience, but very generic	Not more than superficial interaction	Wait and see attitude Lack of interest in other projects Knowledge sharing with other projects was considered not necessary
	3.2 Overlapping consortia	Shared partner transfers knowledge; joint publications; workshops	In-depth Knowledge sharing for instance on IT-solutions	Six projects	No barriers observed
	3.3 Follow-up projects	Knowledge embodied in individuals and organisation is transferred	Experiences and technologies	Eight projects	No barriers observed
4. Project-external	4.1 From project level	Deliverables via project leader, project marketing	Generic progress updates	All projects	Lack of financial and human resources Lack of interest in external knowledge sharing
	4.2 By individual partners	(Scientific) publications; marketing developed products; training graduates	Scientific knowledge; market knowledge	Most projects	Incentive structure of own organization to focus on just one specific type of knowledge being shared

with this study, we contribute insight into the different levels and sublevels of knowledge sharing along with the different mechanisms that can play a role in overcoming this bottleneck. This systematic overview was missing in the literature. Given that knowledge sharing among projects was a primary aim of the funding programmes and the fact this study shows that this knowledge sharing hardly happens between unconnected projects, show the importance of our approach and calls for policy interventions. A variety of such policy, as well as managerial, interventions will be discussed in the next section. This research thereby makes a relevant contribution to ongoing academic and policy discussions. Part of our message complements that of Naber et al. (2017) who stressed the importance of understanding the inter-project learning processes for up-scaling; we add to this perspective a more holistic approach by unfolding the levels at which the knowledge generated in pilot projects is shared and for each level the mechanisms, the knowledge as well as the barriers.

6. Conclusion and policy implications

6.1. Summary

Interviews with the project leaders of sixteen smart grid pilot projects, complemented with desk research and a survey, provided insight into how knowledge is shared in pilot projects at the intra-organisational, intra-project, inter-project and project-external levels. Not only across these levels but also across the sublevels present within these levels, the shared knowledge differs, as do the mechanisms and barriers. We opened the black box of knowledge sharing in pilot projects. The results indicate that the majority of knowledge sharing takes place at the intra-organisational and intra-project level. Knowledge sharing across projects is mainly happening when projects have overlap in consortia and when follow-up projects are initiated. Knowledge sharing at the external level is mainly unidirectional (sending) and encompasses generic knowledge about the project. This study is the first that opens the black box of knowledge sharing in pilot projects. This unravelling of the knowledge sharing dynamics at these four different levels appears to be necessary as in general the knowledge sharing is less than what policymakers aim for and less than what is required for the transition to a sustainable economy. The results of the study reveal what the challenges are and therefore lead to a set of policy and managerial recommendations, but before discussing these we need to note two limitations and recommendations for further research.

6.2. Limitations and recommendations for further research

The perspective of the project leader could bias the findings of this study. Yet, we expect this effect to be limited since there were no noticeable differences in the answers of the interviewees in duo interviews and because project leaders employed by a large variety of organisations were interviewed. Nevertheless, further research could address this concern. While this study offers in-depth insight for the smart grid sector in The Netherlands, caution must be applied to prevent an overgeneralisation of the results. The complexity of the smart grids technology makes collaboration crucial (Planko et al., 2019). In sectors with less complex technologies it might for instance be easier to find the relevant person in the organization (barrier intra-organizational knowledge sharing) and the sharing of context specific knowledge might be easier (inter-project knowledge sharing). Also the role of important actors such as electricity distribution companies in the energy sector, can be different in other countries and are not part of the actor configuration in other sectors. Probably other actors will take up a similar central role. In order to apply the framework it is important to know the specific actor configurations. We think most of our findings (e.g. the different (sub)levels, mechanisms and barriers) will still be observed in other sectors, but we highly recommend research designed to allow for quantitative analysis. A concrete suggestion is to conduct a survey of the consortium partners of a large number of projects (not necessarily smart grid projects) to gain insight into the knowledge sharing dynamics across industries and countries.

6.3. Policy and managerial recommendations

With the present study we aim to involve policymakers and the management of the consortium partners in a debate about both the desirability of knowledge sharing at the different (sub) levels and ways to facilitate this. There is likely to be a contrast in the perceived desirability of sharing knowledge at these levels between policymakers and the (private) consortium partners. As we have seen in our cases there is a stronger interest among consortium partners to share knowledge at the intra-organisational and intra-project level compared to inter-project knowledge sharing and project-external knowledge sharing, which was looked for by policymakers. This difference makes that we propose different solutions for different actors (policymakers and consortium partners) at the four levels to stimulate knowledge sharing. The coming sections briefly discuss for each level the main policy and managerial recommendations (see also Table 2).

6.3.1. Intra-organisational knowledge sharing recommendations

The main barrier consortium partners are facing relates to the lack of awareness considering the knowledge available at relevant colleagues within the organisation. To overcome this managers from the consortium partners can use tools, such as intra-organisational seminars, to disseminate the knowledge of projects within the organisation. In addition an up-to-date overview all the projects in the organisation (with offices in the same country) and an overview of themes and knowledge within the different offices also abroad will enable employees to find possible synergies and ways they can contribute with their expertise. Policy makers can facilitate this by asking applicants to summarize the smart grid knowledge and expertise available within the organisations as well as to develop a dissemination strategy for the developed knowledge in the different (international) organisations.

Organisations should also provide some flexibility with regard to the human resources to be involved in the projects; several project leaders noted that only during the project it became clear what exact expertise was required for the successful completion of the project, and indicated to have benefited from the possibility to access this additional expertise that was already available within their organisation. In certain cases these changes in the required human capital could alter the distribution of funding among the consortium partners. While this was something to be agreed on within the consortium, a few project leaders also expressed their concern that such changes could lead to a re-evaluation by the funding agency of the project and the funding, and hence were reluctant to utilize these opportunities. To resolve this, funding bodies and policy makers should be open to this and should allow for more flexibility and clarify the conditions considering potential re-evaluations.

6.3.2. Intra-project knowledge sharing recommendations

Collaborating in these pilot projects creates interdependencies; partners are likely to depend on the work of other partners for the completion of their own tasks. It is crucial that partners feel committed to the project and feel free to be open about the eventual challenges they face. In general we observed that the larger the project, the less coherence and transparency project leaders encountered. Moreover, different organisations have different interests, which can hamper knowledge sharing. Especially the presence of competitors, or consortium partners that could develop into a future competitor, could harm knowledge exchange within projects. For the project leaders it is therefore important that all partners commit to the project and that they create an environment in which all partners are and feel free to share their ideas. Commitment can potentially be arranged formally by having contracts and investing own resources. Additionally, project leaders should invest in trust-building among partners to create a beneficial environment for

Table 2
Policy and managerial recommendations.

	Sub-level	Knowledge to be shared	Policy recommendations	Managerial recommendations
1. Intra-organisational	1.1 With colleagues in the same office	Additional inside expertise	- Allow for **flexibility** in the spending and reallocating of funding in projects;	- **Organize seminars** to provide other employees insight into what they can contribute to running projects - **Flexibility** in accessing organisations' human capital
	1.2 With colleagues in offices in the same country	Specific knowledge that enables the identification of synergies	- Ask applicants to summarize their organisation's smart grid experience and **potential synergies**	- **Keep overview** of all smart grids projects in the organisation.
	1.3 With colleagues in offices abroad	Broad developments and direction of the sector	- Require multinational applicants to **describe** how knowledge will be disseminated in the organisation	- Make an **overview** of the different expertise of the different offices and develop a **dissemination strategy**
2. Intra-project	2.1 Work packages	Knowledge about project progress, and challenges.	- Restrict number of **partners** and competition in consortia - provide funds for events to get to know partners	- **Ensure commitment** of project partners by agreement and/or investments to the project invest time in trust-building
	2.2 Project level	Additional outside expertise	- Provide **flexibility** to replace or add partners and utilize networks to support this process - Encourage projects to codify knowledge	- **Find new partners** when necessary - **Codify** project knowledge to accommodate personal turnover
3. Inter-project	3.1 Unconnected projects	Common challenges	- Organize **thematic and recurring workshops** to identify shared challenges. - Stimulate **open source** initiatives	- Encourage staff to **participate** in workshops - Consider which initiatives are **worth the effort**
	3.2 Overlapping consortia	ICT and IP	- **Identify** potential **synergies** between different connected projects - Keep an eye to **prevent** a sector **lock-in** into non-optimal technology	- Appoint a **coordinator** who identifies synergies, such as ICT and IP that is applied in multiple projects, between projects
	3.3 Follow-up projects	How to take the next step	- Consider whether technologies still have **potential and require subsidies** - **Guide** project leaders to funding streams	- **Discuss the next step** for the knowledge generated - **Critically reflect** whether it still has **potential** and necessity of public support
4. Project-external	4.1 From project level	Knowledge on best and worst-practices	- Provide incentives to **budget in** this knowledge sharing (make it part of the application) - **Facilitate** sharing of best and worst-practices by offering platforms and templates	- **Explore strategies** for this knowledge sharing from the start - **Discuss value of sharing** best and worst-practices and difficulties with regard to sharing negative insights, such as the weak potential of key products of project partners
	4.2 By individual partners	Human capital	- Convince and support academic actors to **combine resources** for smart grid related degrees - **Provide m**obility grants Provide funding for industrial PhDs projects	- Develop **specialised programs** (or minors) - Give **guest lectures** - Guaranteed **employment** - **Subsidize** tuition - **Attract workforce** with smart grid experience - Get involved in industrial PhDs projects

knowledge sharing.

Funding bodies could play a facilitating role by carefully considering the size of projects and potential competing interests within the consortium. And by providing additional funds for organising events to get to know and select the partners.

Similarly to the concern regarding the attraction of additional expertise from the intra-organisational level, consortia should have the freedom to add new partners in case they are faced with challenges that are outside their area of expertise or when partners or specific persons leave the project. Project leaders should acquire new expertise, and make sure relevant knowledge is codified in guidelines or tutorials, to facilitate the replacement of partners or persons. Policy actors could play a facilitating role in this process by utilizing their network to find new partners that could deliver the missing expertise as well as by encouraging the codification of knowledge.

6.3.3. Inter-project knowledge sharing recommendations

We identified several barriers for knowledge sharing with unconnected projects. These are the wait and see attitude of project leaders, the lack of interest in other projects, and the observation that knowledge sharing with other projects was considered not necessary. This indicates that behavioural change is required to enable this kind of knowledge sharing, in which policy makers can play an important role. Policymakers should employ recurring initiatives in which consortia with relatively little effort can share their lessons with other projects, for example by means of workshops. Targeting the public funding at the development of open source solutions for common challenges might also be part of a strategy, although caution should be applied to prevent lock-in to one technology. The consortium partners should consider what benefits can be obtained from participation in these initiatives and incentivize their employees accordingly.

Sharing knowledge with other projects via shared partners is already taking place more naturally. In this way expertise and IP, for example in the form of IT knowledge, are being shared between projects. For consortium partners, this requires intra-organisational coordination of smart grid projects to identify potential synergies. Also policymakers should evaluate if there are certain synergies possible, while keeping in mind that potential technological lock-in should be avoided.

While follow-up projects could be useful to take the next step with a technology, actors and policymakers should keep re-evaluating whether the technology still has potential and need for public support. Requiring projects to formulate and reflect on potential next steps in the final report could be a useful in this regard. Based on this policymakers can make their evaluation, and could guide them through the jungle of all the different national or transnational funding opportunities.

6.3.4. Project-external knowledge sharing recommendations

We identified several barriers for project-external knowledge sharing. These are lack of financial and human resources; lack of interest in external knowledge sharing; incentive structure of own organization to focus on just one specific type of knowledge being shared.

In order to overcome the lack of financial and human resources, consortia should be encouraged to upfront budget in this knowledge sharing. If this knowledge is important for the success of the funding program policy makers should make this a stand procedure in the application. And project leaders should be aware of this and think about strategies to include this knowledge sharing from the beginning onwards.

Moreover in order to overcome the lack of interest in external knowledge sharing, consortia should be encouraged and facilitated to share all their best and worst practices with the wider community. Since this will primarily generate social returns, policymakers should take the lead in this process and make this as effortless as possible for the actors. This could be done by offering straightforward templates for reporting the successes and failures of a project and offer platforms on which these can be disseminated. However, consortia need to carefully discuss what experiences can be shared without harming the interest of one of their partners.

Even though the scientific knowledge production system is currently changing in The Netherlands with increasing attention to open access and valorisation of knowledge, the fact that the careers of researchers is still heavily depending on peer-reviewed scientific publications was experienced as a barrier to the use of other mechanisms for sharing knowledge. Being aware of this is the first step. But there are also other options to share the developed knowledge while still obtaining private returns for universities, researchers and market actors. Knowledge generated in projects is currently already used to inform teaching activities, which could be developed further into specialised educational programs. A first step could be to develop minors. Moreover, other project partners could contribute by giving guest lectures, subsidising tuition fees and guaranteeing employment for graduates. In general market actors can strengthen their smart grid knowledge by a focused hiring strategy. This can also be realised by offering industrial PhDs-projects. To realise this policy pressure as well as support could be useful.

6.4. Concluding remarks

To conclude, knowledge sharing is crucial for the transition to a smart energy system. It is however not an automatic process at the four different levels of knowledge sharing. Our approach enables a clear identification of the type of knowledge shared, the mechanisms as well as the barriers for each of the sub-levels, resulting policy and managerial recommendations. While the intra-organisational and intra-project level generate private returns, coordination related barriers need to be overcome by both individual consortium partners as jointly in the consortia. The social returns of inter-project and project-external knowledge sharing that cannot be appropriated by the private actors involved in the projects create a demand for policy intervention to realise knowledge sharing at these levels.

We call for the use of this framework from the early stages of the funding process to structure discussions on how funding tender design and evaluations could be fitted to reach the desired knowledge sharing. Part of such a strategy could be requiring applicants to specify their knowledge sharing strategies for each sublevel. Realizing these knowledge spillovers is key to the effectiveness of these projects for realizing the desired change in the energy sector.

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.

CRediT authorship contribution statement

Gerwin Evers: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Maryse M.H. Chappin:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - review & editing.

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Appendix A. Supplementary data

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