Developing Green Process Innovation Through Network Action Learning

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DOI:
10.1111/caim.12484

Publication date:
2022

Received: 30 June 2021 | Revised: 10 January 2022 | Accepted: 26 January 2022

DOI: 10.1111/caim.12484

RESEARCH ARTICLE

WILEY

Developing green process innovation through network action learning

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Funding information
Ireland Wales Operational Programme ERDF 2014-2020 Project, Grant/Award Number: 80910

Green process innovation is itself a complex process and beneficially involves inter-organizational collaboration across disciplinary, industry and university-industry boundaries with many opportunities for network action learning. We investigate how green process innovation yields actionable knowledge when co-directed, co-developed and co-deployed in a network of organizations. We undertook two case studies focused on innovation at the water-energy nexus. With the use of action learning research, we describe and reflect on the actions undertaken by the network to co-generate learning from green process innovation. We demonstrate how this inter-organizational learning is grounded in shared experiences, subjected to critical questioning and supported by (and generating) actionable knowledge. Our paper links the green process innovation process with technical and collaborative learning outcomes, achieved through network action learning. Of managerial relevance are two forms of actionable knowledge: that towards solving engineering puzzles and that addressing the problem of collaboration and learning in networks.

KEYWORDS
actionable knowledge, collaboration, green process innovation, network action learning

1 | INTRODUCTION

Faced with global climate challenges, green innovation is receiving increased attention (Gallagher et al., 2018; Juntunen et al., 2019). In December 2019, the European Commission President outlined the Green Deal that has gone to the centre of the EU growth strategy with investment in green innovation reaching across all sectors. Green innovation, where technology innovations are applied in environmental management practices and eco-friendly product designs, helps achieve sustainable development (Lisi et al., 2020; Zailani et al., 2015). Extant literature has examined the benefits of adopting green innovation for organizations, such as obtaining competitive advantage and improving eco-efficiency and reputation (Albort-Morant et al., 2016; Chen et al., 2020; Dangelico & Pontrandolfo, 2015). Further research suggests that implementing green innovation in organizations is positively related to firms' financial and operational performance (Bhatia, 2021; Xie et al., 2016, 2019). However, others suggest that adopting green innovation could also lead to uncertainty, risks and profit reduction (Dixon-Fowler et al., 2013; Tseng et al., 2012). Thus, as a potential solution to climate challenges, green innovation has its challenges and requires collective commitment across organizational networks.

Green innovation involves a complex process where organizations need to work collaboratively and across organizational boundaries with multiple stakeholders, such as engineering designers, researchers and practitioners, in order to gain access to external knowledge

(Zhang et al., 2020). Such inter-organizational collaboration aims at creating knowledge that is useful to both practitioner and academic communities—otherwise identified as actionable knowledge (Holloway et al., 2016; Shani & Coghlan, 2021). Koners and Goffin (2007) illustrate how successful innovation projects can also generate organizational learning for later projects. However, how does such actionable knowledge emerge? Stated differently, the question guiding this paper is: *How does green process innovation, when co-directed, co-developed and co-deployed in a network, yield actionable knowledge?* The relevance of this question is established in a multi-year, cross-border, EU-funded research initiative focused on water and energy. The initiative has engaged in green process innovation to recover renewable energy from the natural water flow. The complexity of the research objective was such that four disciplines collaborated: engineering, environmental science, geography and management. In addition, the research partners included water network operators, a conservation charity, a community water distribution scheme and two universities. The research scope spanned the evolution of the technology innovation through simulation, prototyping, feasibility assessment, site selection, installation and operation.

The paper begins by positioning our question within the literature on green process innovation, action learning for actionable knowledge and network action learning. We then consolidate our insights in a framework for co-developing actionable knowledge. Given the nature of the question, we undertake *action learning research* to describe and reflect on the actions undertaken by the network of stakeholders and their learning arising from collaborative green process innovation. We conclude with an outline of our proposed contributions to theory and practice.

2 | THEORETICAL CONTEXT

The starting point of this study is in a practice context illustrative of a real global environmental challenge. Three literature-based perspectives are relevant to exploring the research question: green process innovation, action learning for actionable knowledge and network action learning. We explore each, in turn, and link the emerging insights in an initial conceptual framework.

2.1 | Green process innovation

The core objective of green innovation is to reduce environmental impact during manufacturing, delivery and consumption (Huang & Li, 2017). It can be divided into green process innovation and green product innovation (Xie et al., 2019). Green product innovation is evident in product designs that use less toxic or biodegradable materials during the production process (Huang & Li, 2017). The associated innovation process includes a life cycle assessment to understand how to improve energy efficiency throughout the production and consumption process and reduce disposal impact on the environment (Lin et al., 2013).

Our focus in this article is on green process innovation. More specifically, green process innovation focuses on reducing resource consumption, improving existing production processes or introducing procedures to minimize environmental impact (Xie et al., 2016). Green process innovation opportunities can be found in measures that reduce polluted air and water emissions, improve resource preservation and efficiency and switch from fossil fuels to clean and renewable energies (Kivimaa & Kautto, 2010). Several studies have also demonstrated that green process innovation can help and promote green product innovation to achieve better firm performance (Huang & Li, 2017; Xie et al., 2019).

The scope of green process innovation can involve changes to technology, equipment or software, if not a combination of all, enabling improved production and distribution methods (Un & Asakawa, 2015). Such scope may require interaction and collaboration among multiple stakeholders and across different organizations (Kazadi et al., 2016). Such collaboration coincides with improved innovative capability (Peronard & Brix, 2019). At each stage of the innovation process, stakeholders may independently and collaboratively accumulate different learning insights from their inter-organizational collaboration (Bogers & Horst, 2014; Díaz-García et al., 2015). Inter-organizational collaboration also facilitates implementation (Coughlan & Coghlan, 2011).

2.2 | Action learning for actionable knowledge

The accumulation of learning insights from inter-organizational collaboration prompts consideration of action learning and actionable knowledge. An action learning approach means that learning from action is implemented, and in these terms, the knowledge produced is actionable (Coughlan & Coghlan, 2011). We explore now that action learning approach.

2.2.1 | Action learning

In general, the basis of learning is grounded in experience that is subjected to critical reflection and questioning and supported by existing knowledge (Kolb, 1984). Reflection provides an opportunity to step back from experience and to process what the experience means, with a view to planning new actions (Coghlan, 2012). It builds a critical capability for interpreting concrete experience, presenting one's thinking explicitly and taking new actions (Coghlan, 2012). Reflective cycles facilitate developmental learning throughout and after innovation projects, which can be applied to a subsequent project dealing with similar problems (Holloway et al., 2016). A post-project review can create transferrable (or actionable) knowledge among practitioners and maximize potential learning (Koners & Goffin, 2007).

An approach to developing actionable knowledge is through action learning (Coughlan & Coghlan, 2011). Revans (1998), the originator of action learning, had a maxim indicating that there can be no learning without action and no action without learning. He expressed the action learning process in terms of a formula, $L = P + Q$, where P stands for programed knowledge (what is available through research), which is challenged by the questioning (Q) and reflection on contemporary action, from which flows learning (L) or actionable knowledge. Action learning takes the task as the vehicle for learning. Participants work on real organizational problems that do not appear to have clear solutions (O'Neil & Marsick, 2007). To figure out solutions, participants meet on equal terms to report to one another and to discuss their problems and progress (O'Neil & Marsick, 2007). Revans' seminal work on action learning makes a distinction between puzzles and problems (Revans, 1998). *Puzzles* are difficulties for which a correct solution exists and which are amenable to specialist and expert advice. An example of a puzzle would be where best to locate an energy recovery device in a water distribution network. *Problems*, on the other hand, are difficulties where there is no single solution and which require the collaborative engagement of those owning or impacted by them. An example of a problem would be one of facilitating collaboration towards the implementations of a complex technical solution. Problems are amenable to action learning because, in response, different stakeholders can advocate alternative courses of action reflecting their values, past experience and intended outcomes (Coughlan & Coghlan, 2011).

2.2.2 | Network action learning

Inter-organizational or network learning is an established approach to sustainable improvement and innovation within a collaborative network (Holmqvist, 2003; Lavie et al., 2010; Mariotti, 2012). Seminal studies suggest that learning within an inter-organizational and collaborative network provides opportunities to address unknown and wicked problems (Brook et al., 2016). Global climate challenges are characterized by many such problems. Organizations that respond effectively through green innovation leverage alternative and complementary knowledge learned from other external actors (Albort-Morant et al., 2016; Feng et al., 2016). Further, it can be crucial to build a learning network with external actors facing the environmental challenges that allows collaboration and knowledge exchange (Song et al., 2017).

Consideration of network learning leads to a change in the action learning formula. Coughlan and Coghlan (2011) extended Revans' learning formula to accommodate the inter-organizational or network setting: $NAL = P + Q + O + IO$. In this extended formulation, NAL stands for network action learning; P and Q retain their original meanings; O relates to intra-organizational insights emerging from engaging in action; while IO relates to the inter-organizational insights emerging from the collaboration in the network. They suggest that this extended formulation has application in a setting where discrete organizations collaborate in co-directing, co-developing and co-deploying actions towards collaborative improvement and the accumulation of new actionable knowledge (Coughlan & Coghlan, 2021). Finally, adopting action learning in network settings also provides participating organizations with opportunities to collaborate in a safe and trust-based learning and questioning environment (Coughlan et al., 2021; Yström et al., 2019).

2.3 | Summary and initial framework

In summary, green innovation addresses environmental problems and can be challenging for organizations. Green process innovation may require collaboration among multiple stakeholders at various stages of the innovation process. Such collaboration may involve a learning network of organizations co-directing, co-developing and co-deploying resources for innovation leading to actionable knowledge. Figure 1 visualizes an initial conceptual framework and contends that by attending to the problem of building an inter-organizational network in parallel with resolving technical puzzles, green process innovation outcomes can be achieved.

3 | RESEARCH DESIGN

Given the nature of the research question, we undertook *action learning research* to describe and reflect on the actions undertaken by the network of stakeholders engaged in collaborative green process innovation. We describe the research context before introducing action learning research and our approach to data gathering and generation.

3.1 | Research context

Our ongoing engagement in an EU-funded transdisciplinary research project – Dŵr Uisce, has provided the opportunity to frame and to

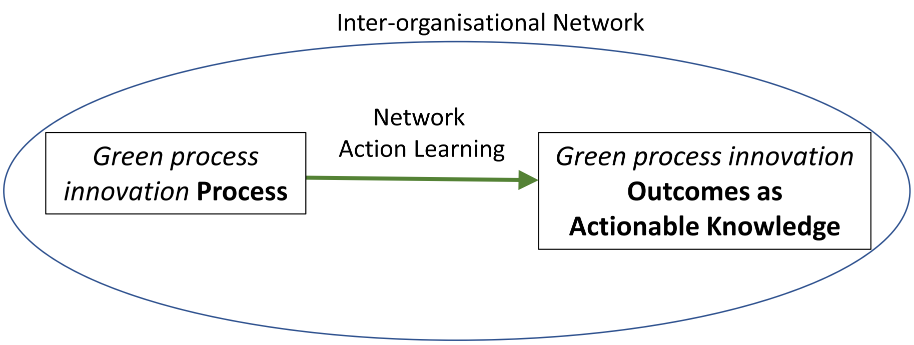

FIGURE 1 An initial conceptual framework linking green process innovation and network action learning [Colour figure can be viewed at wileyonlinelibrary.com]

explore our practice-based research question. The partners in the project, drawn from industry, civil society and academia, were committed to co-directing, co-developing and co-deploying application-oriented knowledge. In parallel with engineering and environmental science actions, there was a commitment to co-producing new learning about the underlying process of network collaboration, which would enable future diffusion of the content and process of green innovation. In this context, our research question arose and forms the basis for this article: *How does green process innovation, when co-directed, co-developed and co-deployed in a network, yield actionable knowledge?*

The research project is a collaboration between Trinity College Dublin (Ireland), Bangor University (Wales), water providers and users in Ireland and Wales. The project runs from 2017 to 2023. It is intended to develop low-carbon technologies and improve energy efficiency in water distribution networks. The project has featured technology demonstrator sites providing the opportunity for knowledge co-production and sharing within and between the sites and participating organizations. In each site, the project stakeholders have co-designed and installed a low-cost micro-hydropower energy recovery prototype based on an in-pipe pump-as-turbine (PAT) hydropower solution. By including these two demonstrators within the scope of this paper, we intend to offer an in-depth understanding of the accumulation and emergence of actionable knowledge.

The project features both a puzzle and a problem: the technical puzzle of innovating low-cost micro-hydropower energy recovery and the organizational problem faced by multiple stakeholders of creating a learning network of collaborating organizations to co-direct, co-develop and co-deploy knowledge for green process innovation.

3.2 | Action learning research

Action learning research is a related but different activity to action learning. With a focus on generating actionable knowledge as the co-directing, co-developing and co-deploying were enacted in the network, there is an opportunity to reflect on the story of the action from a theoretical perspective towards contributing to actionable knowledge (Coughlan & Coghlan, 2021). Action learning is an experiential activity oriented towards action, so action learning research is intrinsically directed towards creating actionable knowledge. The overriding value that guides the action learning approach is a pragmatic focus on learning for the sake of more effective problem solving, systems improvement and the co-generation of actionable knowledge. Action learning research offers the profile of Mode 2 knowledge production (Coughlan & Coghlan, 2011; Gibbons et al., 1994; MacLean et al., 2002). Gibbons et al.'s construct of Mode 2 as the 'new' knowledge production that is generated in the *context of application* is *trans-disciplinary*, *reflexive*, *heterogeneous* and works with *organizational diversity*. In action learning, the context of application is that of addressing the problem, which in the context of this article is that of addressing the process of green process innovation.

The active and collaborative nature of the Dŵr Uisce project enabled us to adopt an action learning research approach (Coghlan & Coughlan, 2010, 2015; Coughlan & Coghlan, 2011). Dŵr Uisce project has featured engagement with the real-world issue of green process innovation to reduce the environmental impact of water production and distribution. There was a collaborative network including managers, action learning facilitators and multidisciplinary researchers; there were iterative cycles of action and reflection; and there was a commitment to codifying workable outcomes and actionable knowledge. Through action learning research, the knowledge generated is identified as the 'L' emerging from the collaborative action learning process and a contribution to actionable knowledge (Coughlan & Coghlan, 2021).

The Dŵr Uisce project team comprised researchers drawn from engineering, environmental science, geography and management. The broader network of external stakeholders included a conservation charity, a group water distribution organization and a water plant operator. All engaged in the action learning process facilitated by the management researchers. Direct interactions and interventions took place at multiple stages of the green innovation process: (1) designing the system; (2) carrying out laboratory experiments; (3) conducting feasibility studies to identify potential sites for implementation; (4) installing the systems on site; and (5) organizing demonstrator launch events. Throughout, project participants collaborated in defining technical puzzles and associated problems; they co-directed, co-developed and co-deployed actions to address both and captured that learning for later deployment and publication. Observation and reflection notes were made throughout.

3.3 | Data generation and gathering

In the action learning research process, data were generated and gathered through engagement with others during action cycles. They were four primary sources of data: direct interactions and interventions, observations and reflection notes, project documentation and in-depth interviews with stakeholders (including researchers and practitioners). Project documentation provided additional information from regular project newsletters, website information and project reports and team meeting minutes. More specifically, data were sourced from seven editions of the project newsletter, 52 website posts, seven project reports and 13 sets of project meeting minutes.

Both informal and formal interviews were conducted at multiple stages of the innovation process. In particular, on completion of two demonstrator site installations, we undertook extensive reflective interviews with key stakeholders who were involved in the co-development and implementation of the system. The purpose of the interviews was to explore their learning and collaborative experiences in the green process innovation initiatives and to prompt further reflection. A formal interview guide was developed by the action learning facilitators and pilot-tested before formal interviews. Following the appreciative approach of action learning research, interview questions were used as prompts for reflection from which flowed new learning and actions. The interview questions covered three main themes: (1) stakeholders' views on green innovation and sustainability,

(2) challenges encountered in the green process innovation process and (3) solutions and reflective actions. Following research ethics guidelines, participants were aware of the research topic and gave their informed consent for interview recording (see the sample in Appendix A).

Informal interviews were undertaken on multiple occasions, including project meetings and meetings with stakeholders. To keep the authenticity of data collection, researchers took notes during informal interviews. All formal interviews were recorded with participant consent and transcribed in text format, resulting in 207 pages of A4 documents. Extracts from these interviews were synthesized with other data sources and feature in the discussion below.

4 | ACTION: DEVELOPING GREEN PROCESS INNOVATION THOUGH NETWORK ACTION LEARNING

Fundamentally, the Dŵr Uisce project aimed to explore the potential of new technology in water supply systems to recover renewable energy at low cost and with low environmental impact. In terms of action learning, the realization of this potential was a technical puzzle. The organizational problem faced by the stakeholders was that of creating a learning network of collaborating organizations to co-direct, co-develop and co-deploy actionable knowledge for green process innovation. We present, first, an engineering context description of the initial design work followed by a summary description of each site. We then outline the emergent factors for achieving green process innovation.

4.1 | Designing, testing and installing the system

The engineering researchers conceptualized an energy recovery system based upon adapting a pump to run in reverse as a turbine and to produce rather than consume energy. The rationale was to take advantage of the mass manufacture and, hence, lower capital costs of pumps—up to 15 times lower than conventional hydropower turbines.

In the initial laboratory and feasibility phase, the engineering researchers developed computer-based simulations of the energy recovery system. To validate the simulation data, they constructed and tested a full-scale laboratory-based prototype. The data generated during the laboratory stage confirmed the usefulness and usability of the PAT as a component of an energy recovery system.

In parallel with the construction of the laboratory-based prototype, the engineering researchers conducted feasibility studies in a water distribution network and a run-of-river setting and identified settings where a pilot system might be deployed in practice. The choice of water network was constrained by the geographical boundaries of the research area. One particular network merited particular attention, and further exploration identified the suitability of the intake to the water treatment plant. Separately, working with a conservation charity, the engineering researchers identified a run-of-river setting in a mountain location characterized by a suitable water flow and opportunity for local energy use. Arising from these feasibility studies, two demonstration sites were selected.

4.2 | The demonstration sites

4.2.1 | Blackstairs Group Water Scheme (BGWS)

The system was installed at a water treatment plant supplied from a mountain reservoir. It is owned by Blackstairs Group Water Scheme (BGWS) - a rural community water scheme affiliated to the National Federation of Group Water Schemes. An external water service company operated the water treatment plant that provided mountain-sourced drinking water to over 1000 local households. In developing the system, the Dŵr Uisce team built on the earlier feasibility study to evaluate the potential for energy recovery in the water network. So, in collaboration with the BGWS and the treatment plant operator, the Dŵr Uisce team designed, installed and commissioned a PAT-based energy recovery system on the inflow pipe to the plant. The resulting system now generates electricity for use at the treatment plant, reducing energy consumption from the national grid by 20–25% and generating carbon dioxide equivalent (CO_{2eq}) emission savings over 8.8 tonnes per year.

The BGWS and the Dŵr Uisce team hosted an open event in May 2019 to demonstrate this green process innovation to the wider community, including other GWS members and environmental consultants. The event began by introducing the system design to participants. Then, the team demonstrated the running system at the treatment plant. In a closing Q&A session, participants questioned the team and stakeholders to learn more about green process innovation, the innovation process and the potential for implementing the system in other contexts.

4.2.2 | Tŷ Mawr Wybrnant (TMW)

Tŷ Mawr Wybrnant (TMW) was owned and managed by National Trust. It featured a 16th-century historical farmhouse, which housed a rare collection of bibles. This culturally important collection of over 200 bibles in different languages was on show at the property but susceptible to damage from moisture in the air. Further, climate change with increasingly heavy and persistent rainfall, flooding and dampness had put the collection at increased risk. The core project team and stakeholders undertook a feasibility study at the site that identified the energy requirements to dehumidify the historic property and protect the rare collection. Working with the charity, the team co-designed a prototype PAT-based energy recovery system and diverted a small flow from the adjacent river through the custom-designed micro-hydropower plant to generate electricity. The system was technically similar to that at the BGWS site. However, it differed functionally, providing heat and light to the adjacent historical building. The CO_{2eq} emission savings of the installation at the mountain site are equal to 5.3 tonnes per year, with corresponding energy cost savings.

5 | DISCUSSION AND REFLECTIONS

We return to the research question: *How does green process innovation, when co-directed, co-developed, and co-deployed in a network, yield actionable knowledge?* In response, the cases provide evidence of the green process innovation process, technical-related outcomes and collaborative learning outcomes. They inform Figure 2, an update to the initial conceptual framework linking green process innovation and network action learning.

We begin our reflection with a description of the green process innovation process. The two green process innovation initiatives were characterized by both puzzles and problems and exhibited two different kinds of outcome. Technical outcomes related to *puzzles* have featured in our description of the engineering design decisions made to fit the systems to the local operating conditions. In parallel with this creditable engineering design work, there were *problems* that were anticipated and that emerged. We discuss the associated learning outcomes below, noting the inter-relationship between these puzzles and problems: They had a temporal relationship and an inter-dependency such that solving a puzzle required resolution of a problem.

5.1 | The process of green process innovation

The members of the project network collaborated at multiple stages of the green process innovation process. Co-directing, co-developing and co-deploying a technical outcome and actionable knowledge was the fundamental focus that permeated the activities at both sites. We focus on each step of the process.

5.1.1 | Co-directing a response to the problem

Much was known about the parameters of the technical puzzle, but the partners recognized that there was more to be understood. Towards that end, the project required them to develop a shared understanding of a problem and of the corresponding collaborative steps to be taken. As one partner commented:

> That is probably the biggest challenge - how to get everybody to work together. And that's around the whole understanding of the scope and scale of things, as well as simply looking practically … at how you make the supply chain work efficiently.

5.1.2 | Co-developing the response

Addressing the problem required co-development by the partners of a plan, respectful of what was known and, yet, open to what might emerge. One of the core researchers noted:

> [From previous research,] there was a case-based understanding of the implementation of energy recovery initiatives in different settings. [Sharing] that level of practical understanding [with our partners], allowed us to plan our interaction in the [Dŵr Uisce] project, to understand the steps and stages that they might have to go through, the obstacles that they might have to overcome, and the opportunity that might arise through demonstration for all to learn about implementing this kind of technology and keeping it going.

Throughout the project, a constellation of micro-problems emerged. For example, early in the BGWS initiative, the incompleteness of technical data was a puzzle that hindered the design progress. One of the core researchers noted:

In most of cases, they do not have proper [water] consumption data. Or they just have monthly consumption data [and] average data. So, when I had [only] that, I used … data for another community water scheme with similar patterns.

However, dealing with these missing data emerged as a communication problem to be addressed. The researcher continued:

> From that information, I had to build up a hydraulic model. That then was the basis [for] the feasibility

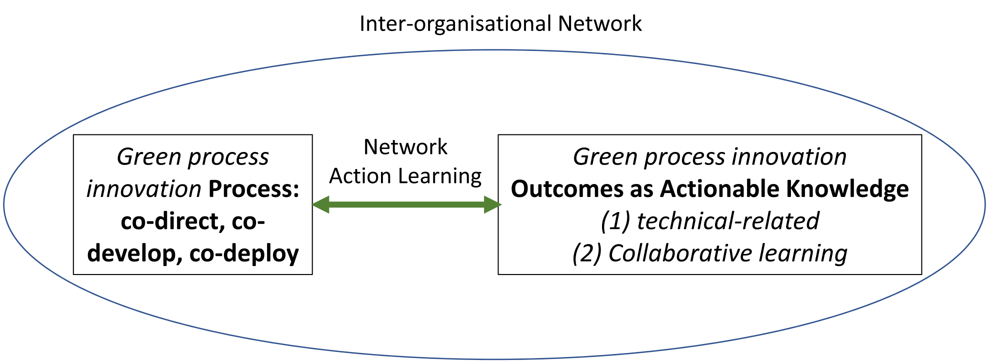

FIGURE 2 Co-directing, co-developing and co-deploying green process innovation [Colour figure can be viewed at wileyonlinelibrary.com]

assessment, as the quality of the [development] work was dependent on the raw [field] information … In general, the communication was pretty good. So [if/when] I needed more information, I could write them an email, and [the communication] was quite fluent.

5.1.3 | Co-deploying the shared understanding

As demonstration sites for green process innovation, the two installations enabled collaborative prototyping to solve puzzles—validating the designs and testing how well the designs operated in practice. One of the core researchers commented:

The [technical] lessons learned during the [implementation] process are significant. We learned how to make a better choice of the electrical equipment which controls the operation of Pump-as-Turbine. For example, the first inverter installed at [the TMW site] did not work and had to be swapped for another one of different kinds.

The demonstration sites also offered opportunities to learn about the problem of getting everybody to work together on green innovation and how best to address the puzzles. The BGWS manager noted:

[At BGWS, we] learned that to do something like this requires a good bit of time and resources from all parties involved; [it] just does not happen by accident. People have to get there and do all the work. [You] can see that problems arise, and you need to solve [those] problems to progress. [The BGWS demonstration site] shows that you need a multi-faceted team - engineers, marketing, communication, organizational skills, and the people that actually work at the plant. And I think if there was another project … you would have to understand that you need all those inputs to create something. [So] maybe some engineer might have an idea. But that does not mean to say he or she is going to be able to put that into practice without the help of all the other people.

5.2 | The outcomes of green process innovation

The outcomes of the green process innovation process were of two basic kinds: technical-related outcomes and collaborative learning outcomes. These outcomes are considered as crucial actionable knowledge for the future development of green process innovation when multiple stakeholders are involved in co-directing, co-developing and co-deploying green process innovation.

5.2.1 | Technical-related innovation outcomes

Described earlier as solutions to puzzles, the technical-related outcomes comprised a concept for an energy recovery system that had been modelled, piloted and trialed in real operating settings. As a result, a technical system design emerged that was detailed, scalable and replicable in other operating settings. In operation, these systems generated green electricity and, as such, had reduced impact on the environment. Technical-related learning was evident throughout the innovation process, and the engineering researchers co-developed in real time an understanding of the system concept. Here, the challenges and knowledge production opportunities encountered extended over the five primary process stages: designing the system; carrying out laboratory experimentation; conducting feasibility studies to identify potential sites for implementation and demonstration; installing the system on each site; and organizing demonstrator launch events.

From the outset, the engineering researchers led the development of the technical system concept. The laboratory experimentation enabled their questioning and reflection on the emerging generic design. Actionable insights were obtained from validating the system design in a controlled setting and in reality. The initial generic system design also informed the field data collection through feasibility studies. The interactions with the site operators during the feasibility studies led to a codified experience that facilitated later interactions with other stakeholders. Such codified experiences led to new actionable knowledge that offered a solid basis for developing new criteria for selecting and using demonstration sites and for prototyping in collaboration with practitioners.

Insights from the experimental model and results of feasibility studies were then used to tailor the generic system design in order to adapt to different environmental and site settings. The process of conducting feasibility studies highlighted the importance of keeping operation records and thinking ‘outside of the box’. The results of the feasibility studies informed the system designs at both sites. These new insights challenged the initial assumptions of the engineering researchers and helped to close some technology-related gaps.

Finally, the stakeholders prepared for the demonstration events as they questioned and reflected on actions undertaken during the green process innovation process. Participants at the events then asked questions related to the durability, technical maintenance, wider application in households and economic potentials of the systems. In the process, these activities and interactions generated new technical-related insights for their respective organizations and the inter-organizational networks. The environmental advisor at National Trust noted:

So, [with the launch] the first milestone has been hit - it's on and is running. I'm hoping the next milestone is when we review in a year's time. It may be a slightly different system as we optimize it. So, I'm hoping that, with the continuing … [co-]development, we will improve, improve and improve, and also try to simplify, simplify, simplify. I'm hoping that when we review the cost it will be down, the output will be increased and the efficiency will be improved.

5.2.2 | Collaborative learning outcomes

The green process innovation was built upon the involvement of multiple stakeholders at various stages of the innovation process. The learning network comprised engineering developers, site operators and owners and researchers. Together in two separate but related organizational networks— BGWS and TMW —they co-directed, co-developed and co-deployed their resources and knowledge. Facilitated by the management researchers, each network made technical innovation choices, described earlier, which progressed each innovation towards defined technical performance targets. In parallel, the collaborative learning challenge was to develop a mode of interaction through which they could generate and share technical, operational, environmental and cost data. The two sites represented live working examples of the systems in situ for potential new end users, such as water providers and landowners. This demonstration objective carried an explicit challenge to educate these potential users about the feasibility of the systems and the fit with their operating contexts. This education was reinforced through regular communication of emerging descriptions and reflections on the project work. These communications included a periodic Newsletter, social media messaging and videos on the website.

5.2.3 | Reflection—The network action learning process

The learning described was achieved through network action learning (Coughlan & Coghlan, 2011). The *problem* was one of collaboration towards the implementations of a complex technical solution. The *group* involved key stakeholders from the demonstration sites with the organizational responsibility and authority to engage and to innovate. All were *committed* to taking action in real time and also to learning from that action. System installation was a collaborative process from which the stakeholders learned from the installation experience at the BGWS site. That learning was to be deployed between sites, to potential new end users via demonstration and in future installations. The action learning process was *facilitated* by the researchers. Throughout, the participants met on equal terms, discussing the evolving innovation and progress.

The researchers collaborated actively in *questioning and reflection* throughout the project. The Dŵr Uisce team met periodically and organized those meetings as research workshops where actions planned and undertaken were questioned, reflected upon, amended and codified. The researchers in Trinity College Dublin and Bangor University met as separate groups in advance, trial running and questioning their proposed presentations. The core project team meetings typically took place over 2 days. Rather than spending time on project management details, these meetings focused on substantive content that facilitated learning in preparation, presentation and discussion was evident. The resulting discussions led to cross-disciplinary collaboration and inter-workpackage linkages, some of which had not been planned. As a core group, the researchers collaborated in the development of green process innovation, output presentation and publishing of conference papers and journal articles that spanned different boundaries.

The demonstration events involved a wider group of stakeholders. Here, the events were seen as learning opportunities for the wider community. The demonstration events enabled in-person access for stakeholders and the wider community to observe and question the green process innovation that had been co-directed, co-developed and co-deployed in practice. The result was feedforward and feedback. One of the project stakeholders commented:

> Today [the launch event at the TMW site] is obviously a key thing because they are actually [demonstrating] hydro out in the open air in [the mountains] … along with the sister project [at the BGWS site]. [So] today really feels like a big step because it's easier to engage people. You know, a lot of the visitors we have today who are less familiar with these projects … can actually see something and go ‘oh, I could do that’. So today is a big, a big milestone for the project. It's really pleasing to see it.

In summary, the network action learning approach has underpinned the learning process (Coughlan & Coghlan, 2011). The technical puzzles were addressed at both organizational and network levels, and each influenced the other. As the technology was adapted to address the puzzles at each site, the learning was taken to the other site. The co-deployment process moved from one site to the other through the network demonstrator meetings and back as the technology was implemented in each site and generalized learning by the network was framed.

6 | CONTRIBUTIONS AND IMPLICATIONS FOR RESEARCHERS AND PRACTITIONERS

The two case studies offer a timely understanding of the process, actions and challenges in green process innovation, relevant to the evident climate challenge. It is established that green process innovation can lead to energy savings and recovery (Albort-Morant et al., 2016) and that green process innovation can improve existing production processes (Xie et al., 2016). This study has identified how key stakeholders can co-generate new actionable knowledge to reduce environmental impact through a network action learning approach. We have demonstrated how the basis of inter-organizational learning is grounded in learning from the experiences of collaborative design and prototyping, subjected to critical questioning and supported by (and generating) actionable knowledge. Building on these outcomes, we focus now on the implications for researchers and on two forms of actionable knowledge to be managed: actionable knowledge towards solving engineering puzzles and that addressing the problem of collaboration and learning in networks.

6.1 | Implications for researchers

The study contributes to a transdisciplinary research agenda including green innovation and network action learning. For researchers, adopting a network action learning approach is a viable option towards knowledge co-production in green innovation. In designing such research, researchers have choices at the various stages of an initiative.

Beginning with the guiding research question, as in this study, a 'how' question fits with selecting a network action learning approach to researching in and through the collaborative actions undertaken by the various stakeholders. This framing involves making and working with the fundamental distinction between a puzzle and a problem—here, the many engineering design challenges and the building of a collaborative network. This expectation of collaboration in the network requires partners with a shared commitment to collaborative action, to learning and to research. Finally, the co-developed outcome must have both technical-related and learning components, which enable continuing growth and development of the network. As the Dŵr Uisce project progresses towards completion over the coming 2 years, such transdisciplinary insights will continue to advance thought and action towards improving the sustainable development of green process innovation. Further exploration of a possible interaction between the two types of actionable knowledge can offer new insights into supporting fruitful outcomes of green process innovation.

6.2 | Implications for practitioners

6.2.1 | Actionable knowledge for green process innovation puzzles

The study supports and extends the contention that green process innovation involves collaboration among multiple stakeholders. Consistent with existing studies (Bosch-Sijtsema & Bosch, 2015; Zimmerling et al., 2017), we found that a user-centred approach—engaging users throughout, facilitating the demonstration and diffusion of green innovation within and to a wider community—is constructive in green process innovation. In addition, however, we found that engaging users was essential not just in the early stage of the green process innovation process but throughout the later stages—through to installation. The boundary between users and design engineers was constructively porous through which the actionable engineering knowledge flowed throughout. Collaborative prototyping was critical to identifying design problems and informing the development of design and installation specifications, extending Bosch-Sijtsema and Bosch (2015).

These conclusions challenge Wicki and Hansen (2019) who considered such design problems as failures or mistakes. In this study, through network action learning, design problems were constructive prompts for stakeholders to question, reflect and generate actionable knowledge that would flow into the next innovation stage and to the other demonstration or operating sites. The progression from design specification to the experimental laboratory model formed the basis for a comprehensive, focused prototype in the first site (Ulrich & Eppinger, 2012). This demonstrator unit contributed to learning, communication and integration at that site. Although it was then a finished unit for that site, it became a comprehensive prototype for the second site. The emergent actionable engineering knowledge guided the design and installation at the second site.

6.2.2 | Actionable knowledge on the problem of network learning in green process innovation

Green process innovation is a response to complex and diverse environmental issues. It involves collaboration across disciplinary, industry and university-industry boundaries. In response to such issues, there are many opportunities for learning in action. Consistent with Brook et al. (2016), we have found that learning within an inter-organizational and collaborative network provides opportunities to co-develop a solution to environmental problems and generate actionable knowledge addressing the problem of collaboration and learning in networks. Managers have a role in building and sustaining network relationships that facilitate learning from shared experiences of collaborative development actions through critical questioning, consciously identifying new knowledge and facilitating co-directing, co-developing and co-deploying the emergent actionable knowledge. The value of that new actionable knowledge is in its potential to contribute to future collaborative green process innovation initiatives.

7 | CONCLUSION

In this study, we have offered several timely contributions to the literature and practices on green process innovation management and organization through capturing procedures, actions and challenges in practice, relevant to the evident climate challenge. We adopted an action learning research approach, undertook a study in two settings and explored inter-organizational learning and the emergence of new actionable knowledge from the co-development and co-implementation process. Adopting a Mode 2 mindset, we combined theoretical knowledge with the applied practical experience of the practitioners to produce actionable knowledge that is robust for scholars and useful for practitioners. We have demonstrated how network action learning enables green process innovation and the emergence of actionable knowledge at demonstrator sites. The basis of inter-organizational learning is grounded in network learning from the experiences of collaborative prototyping, subjected to critical questioning and supported by (and generating) actionable knowledge.

It is inevitable that this study is limited in its generalizability due to its exploratory and context-specific nature. Yet, emergent actionable knowledge of various types is relevant for other innovation projects. The guidelines for researchers and for practitioners coupled with the emerging framework are applicable to inter-organizational learning that deals with a complex and collaborative green innovation issues. Further, the Dŵr Uisce project in the study is ongoing and presents opportunities for further research on collaborative innovation and the demonstration of green innovation maturity through network action learning where stakeholders learn and accumulate actionable knowledge together.

ACKNOWLEDGMENTS

This research is part of a European research project 'Dŵr Uisce: Distributing our Water Resources: Utilising Integrated, Smart and low-Carbon Energy'. The Dŵr Uisce Project is funded by the Ireland Wales Operational Programme ERDF 2014-2020 Project number 80910.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Wu, S.-H., Coughlan, P., Coghlan, D., McNabola, A., & Novara, D. (2022). Developing green process innovation through network action learning. *Creativity and Innovation Management*, 1–12. https://doi.org/10.1111/caim.12484

APPENDIX A: SAMPLE OF INFORMED CONSENT FORM

Informed Consent Form

Participant's signature: ____________________________	Researcher's signature: ____________________________
Name in Block Capitals: ____________________________	**Name in Block Capitals:** ____________________________
Date:	**Date:**

Research Study: An action learning approach in green innovation.

Investigators:

Purpose of the study: This study aims to examine an action learning approach in a green innovation project.

The interview will last approximately 60 min. You will be asked to share your experience and opinions about your collaborative experience in a green innovation project. The interview will be audio-recorded by the investigators. All information collected will be securely stored in password protected facilities and only the investigators can get access to the data. The data will be securely disposed of 5 years after the completion of the project. Please also be advised that confidentiality of information of information provided can only be protected within the limitations of the law. Your identity or other identifiable characteristics will not be mentioned or displayed in any published project document. Each of them will be given a code during the data analysis process, and results will be presented in aggregate. If quoted, you will be given a 'pseudonym' so that you always remain anonymous. If you wish to keep the shared information in private, please contact the investigators before 31 March 2020.

I have read and understood the information provided in this form. Therefore, I consent to participate in this research project.