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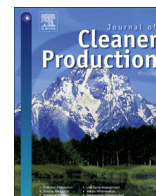
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Managerial and organizational challenges encountered in the development of sustainable technology: Analysis of Swedish biorefinery pilot and demonstration plants

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ABSTRACT

Pilot and demonstration plants (PDPs) perform critical tasks in the development of new sustainable technology by bridging basic knowledge generation and large-scale commercialization. Significant private and public funding has therefore been allocated to PDPs addressing climate change, pollution abatement technology and/or increased resource efficiency. After technology verification, PDPs typically struggle with evolving objectives, and reports of stalled or delayed development are common. Key problems may center on technical difficulties, but challenges of a non-technical nature are equally important, not least for the development of clean technology. This paper draws on a longitudinal case study of four PDPs used for advanced biorefinery technology development in Sweden and delineates the key managerial and organizational challenges that arise in and around such plants. By taking the actor networks around PDPs as the main unit of analysis, this paper gives a detailed description of various challenges, such as the division of responsibility for the operation and ownership of the PDPs, unclear roles and objectives, and the lack of specific competences and resources in the actor networks. One important conclusion is that improved knowledge about such challenges should increase the resilience of actor networks in and around PDPs, and also help shorten the formative phase of developing sustainable technology.

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1. Introduction

History shows that most technologies developed in laboratories fail to make it to market, that developing new knowledge fields may take several decades (Wilson, 2012), and that many companies engaging in such development suffocate in the so-called 'valley of death' (Nemet et al., 2018). The frequency of such outcomes may be particularly high in the case of sustainable (e.g., fossil-free, resource-efficient) technologies. One reason is private firms' underinvestment in research and development (R&D) as knowledge spillovers tend to be prevalent for sustainable technologies (Popp, 2019). Sustainable technologies must also compete with existing incumbent (e.g., fossil fuel-based) technologies, which benefit from

existing institutions and infrastructure as well as from past policy failures to fully internalize all negative environmental externalities (Huguenin and Jeannerat, 2017). This paper addresses the role of pilot and demonstration plants (PDPs) in verifying and optimizing new sustainable technology and bringing it to market, with an emphasis on the challenges associated with managing and organizing the actor networks that surround such plants.

From a technical standpoint, PDPs are experimental tools that make it possible to investigate and improve a process or process problem(s) (Reiner, 2016). A key purpose of PDPs is to perform process development and determine process economics. Providing technical services and/or demonstrating technical feasibility constitute additional purposes (Idem, 2015). PDPs thus represent bridges between basic knowledge generation on the one hand, and industrial application and commercial adoption on the other (Hellsmark et al., 2016b). Therefore, both demonstration projects (Bossink, 2015) and PDPs constitute critical intermediate steps in the technology development process (Fevolden et al., 2018),

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although the role of PDPs in innovation management and policy remains to be fully understood (Frishammar et al., 2015).

Some PDPs are owned by private firms, but due to significant long-term risks in the technological development process and the likelihood of knowledge spillovers, many plants require public funding. This especially applies to PDPs built to facilitate the development of sustainable technologies (Fevolden et al., 2018); PDPs benefitting from public funding have allowed progress to be made towards dominant designs in solar energy and wind power technology (Hendry et al., 2010). This paper focuses on publicly-funded PDPs. These are typically surrounded by broad actor networks, which operate under rather vague and complex ownership and management regimes (Hellsmark et al., 2016b).

Frishammar et al. (2015) reviewed the extant PDP research and concluded that limited attention has been devoted to the PDP-specific managerial and organizational challenges. Instead, the existing PDP-relevant literature is dominated by engineering and natural science research with its focus on the technical challenges associated with verifying and up-scaling new technology. PDPs are also described in detail in the literature on sustainability transitions (e.g., Fevolden et al., 2018) and technological innovation systems (e.g., Hellsmark et al., 2016b). These research strands highlight system-level challenges – including the roles of public policy and institutions – in developing novel socio-technical systems.

While the above research strands contribute insights into how PDPs can support various knowledge development and learning processes, and/or serve to align actor networks (Smith and Raven, 2012), existing research is silent on the immediate PDP-level challenges. For instance, the ownership and management of the research infrastructure, and the rules and codes of conduct concerning actors' access to plants, are rarely addressed. Even the technology and innovation management literature falls short in this regard (Lager et al., 2013). PDPs are important arenas for collaboration among various types of actors, i.e., industrial firms, academia, government agencies, and equipment suppliers (e.g., Bröring and Herzog, 2008). The managerial and organizational challenges are therefore often rooted in various types of heterogeneous organizations that must work together (Pisano, 1996). In a recent article, a large number of sustainability transition scholars called for new knowledge about micro-level phenomena such as how different groups and organizations interact over time to develop sustainable and clean technologies (Köhler et al., 2019).

The present paper contributes to the above literature by making the actor network around the PDP the key unit of analysis and, very importantly, by specifically investigating the managerial and organizational challenges that arise as diverse actors collaborate. Rather than just recognizing the importance of heterogeneous actor networks in the development of sustainable technologies at PDPs and other types of system-level challenges (see Section 2.3), the paper investigates the nature of the challenges that arise in these collaboration efforts.

Managerial challenges are generally process-related, whereas organizational challenges are structural in nature. This implies that managerial challenges, such as the misalignment of interests, can often be addressed directly by a single actor or group of actors, while organizational challenges are often harder to deal with directly. That said, efficient management is conducted across organizations; managerial and organizational challenges are therefore also inter-linked.

The purpose of this paper is to enhance the understanding of PDPs as arenas for collaborative innovation by highlighting the key managerial and organizational challenges that arise in and around these plants. The ambition is to provide a conceptual, generic understanding of the nature of the most prominent challenges. A particularly important contribution made by this paper is to

investigate the extent to which the nature of these challenges tends to differ across the various types of PDPs, something that in turn will influence the prospects for converting a PDP from one type to another.

The analysis does not primarily address the question of how various types of managerial and organizational challenges can – and should – be addressed. Nevertheless, even though the paper focuses on the first necessary step of increasing knowledge about what these challenges involve, the findings will carry implications for understanding how important barriers in the development of sustainable technologies can be overcome. Specifically, by extension, the paper can lead to the following benefits: actors improving their ability to coordinate actor networks; an understanding of how to improve the alignment of interests among actors; an understanding of how the structure regarding access to PDPs can be improved; and better explanations of the often unclear ownership structure. A better understanding of managerial and organizational challenges should provide scope for increasing the resilience of the technology development process and shortening the time required for the formative phase of the technology development process (Bento and Wilson, 2016).

The paper draws on both existing literature and the data from a longitudinal case study of four PDPs in the field of advanced biorefinery technology. Based on a flexible intake of forest residues and/or other lignocellulosic raw materials, such technologies permit the production of large quantities of bulk products, not least biofuels, along with other high-value products such as specialty chemicals and/or new materials (Nanda et al., 2015). The next section reviews the existing literature and elaborates on the role of PDPs as arenas for collaborative sustainable technology development. Section 3 outlines the methods, while Section 4 reports the findings from the empirical analysis. The paper ends with a conceptual discussion of key PDP-relevant managerial and organizational challenges in Section 5 and concluding remarks in Section 6.

2. Literature review

PDPs can be conceptualized in different ways. In this section, the existing literature is reviewed, and the roles of PDPs in the technology development process and as arenas for collaborative technology development are described. Particular attention is paid to the literature that has addressed the key role of well-functioning actor networks, including the barriers to the emergence of such networks.

2.1. The roles of pilot and demonstration plants in the technology development process

To the casual observer, a PDP consists of various types of hardware (e.g., pumps, pipes and instrumentation), and its overall appearance often resembles a “mini-version” of a large-scale plant, but there is more to a PDP than first meets the eye. PDPs play important roles in verifying and up-scaling new technology and in identifying dominant designs (Lefevre, 1984). They may also assist in developing broader socio-technical systems by facilitating the creation and organization of new value chains as well as bringing institutions into closer alignment. This has been highlighted in various studies, both directly and more implicitly. It is directly highlighted in the study by Hellsmark and Jacobsson (2012) that focuses on the policy challenges in moving from technology verification and PDPs to a larger-scale diffusion and that by Hellsmark et al. (2016b) analyzing the role of PDPs in technology development and innovation policy. It has also been highlighted more implicitly in earlier work by e.g. Kemp et al. (1998) looking at the role of niche formation for regime shifts and Macey and Brown (1990) looking at

demonstrations as policy by drawing on examples from the energy field.

In other words, PDPs not only address technical challenges and risks, they also contribute to a reduction in the organizational, market-related and institutional risks that surround the development of novel sustainable technologies such as solar photovoltaics and wind power (e.g., Hendry et al., 2010) as well as hydrogen systems and fuel cells (e.g., Karlström and Sandén, 2004).

It should be noted that not all PDPs are the same. Some aim at verifying and testing new technologies, products and processes, while others demonstrate the value of a process, i.e., they promote market development, diffusion and commercialization. By drawing on Hendry et al. (2010), Hellsmark et al. (2016b) propose an extended typology for PDPs. This paper follows this typology, and the four PDPs under study represent two different types of plants. The first type is the so-called *verification PDPs* whose purpose is to test, evaluate, and characterize different technological options for verifying new technology. The second type is *permanent test centers* whose purpose is either to provide a learning facility with a broad set of actors who can achieve continuous improvements over time and/or to test new technological options that facilitate both applied and basic research. Typically, these plants target a wider set of different applications than the verification PDPs (Hellsmark, 2016b).

2.2. Pilot and demonstration plants as arenas for collaborative technology development

At the core of any PDP are the engineers and scientists responsible for designing and conducting new experiments. Equally important is the operating staff, who are responsible for running and maintaining the plant. While this staff is often hired by the owner(s) of the PDP, scientists active at the plant may be employed by universities or research institutes. Another type of key actor is the private firm, e.g., in the process industries. While the fundamental motivation of scientists may be new knowledge creation and contributing to scientific publications, private firms primarily seek to develop new products and applications and improve production processes (e.g., Hutchesson et al., 1996). There may also be equipment suppliers involved, i.e., actors that supply the actual hardware and software that constitute the PDP. Finally, plant contractors and individual consultants are often involved (Pisano, 1996).

For PDPs aiming at the development of large-scale, capital-intensive sustainable technologies, the actor complexity is often particularly high. Such PDPs are often associated with major socio-technical challenges – e.g., considerable uncertainty, knowledge spillovers, and institutional path-dependence – that could motivate significant public funding (e.g., an investment subsidy). For this reason, governmental officials may also form part of the relevant PDP actor network (Fevolden et al., 2018). Apart from providing funding, government authorities could often promote an agenda expecting national, regional or local investments, job-creation and enhanced exports. Consistent with Flanagan et al. (2011), several public actors also reported that different types of governmental agencies will be involved (e.g., Hellsmark et al., 2016a). This implies that key decisions affecting PDP activities will be taken at different levels of government, i.e., local, regional, or national and at various ministries (Hendry et al., 2010).

Arenas for collaborative technology development can be perceived as physical and virtual platforms (Elmqvist et al., 2016), which facilitate for actors to connect for the purpose of knowledge sharing and collective build-up of new knowledge (Ollila and Elmqvist, 2011). This paper views PDPs as a concrete manifestation of such arenas as they offer access to technical infrastructure as

well as the opportunity for inter-organizational innovation. The organization around a PDP is typically temporary; it is non-permanent and often informal. Bakker et al. (2016) define *temporary organizing* as the activities and practices associated with collectives of interdependent individual or corporate actors who pursue *ex-ante* agreed-upon tasks and objectives within a given timeframe. The concept of temporary organizing constitutes an important lens through which the managerial and organizational challenges in and around PDPs can be studied. For example, the transformation of a PDP from a technology verification plant to a permanent test center changes the purpose, tasks and objectives. This shift in focus may jeopardize the agreed-upon finite time-span of the collaboration. Such changes will not only influence the actors and the actor networks around a PDP but also the subsequent managerial and organizational challenges of the collaboration. Brown and Hendry (2009) note that prior work on PDPs has largely ignored this important issue.

2.3. Establishing well-functioning actor networks

While the existing literature has not provided a systematic assessment of the various managerial and organizational challenges arising in and around PDPs, previous research has discussed the importance of establishing well-functioning actor networks. In many instances, though, this is not an easy task, and failures to establish such networks may often have their origins in the various managerial and organizational challenges arising in and around PDPs.

The actors around a PDP can act collectively by deploying resources towards a desired goal (Farla et al., 2012). The activities and the resources of individual actors are then combined, exploited and/or modified to advance technological development (Musioli et al., 2012). In this process, different actors contribute to technology development in different ways depending on the resources they hold (Story et al., 2011). A diverse actor network constitutes a strength since heterogeneous resources and capabilities can strengthen the social capital of the network (Burt, 2000), be pooled to reach common objectives efficiently (Gargiulo and Benassi, 2000) and provide legitimacy (Musioli et al., 2012).

Actor network diversity could, of course, give rise to *managerial challenges*, such as coordinating the actor network, aligning interests, and granting access to the plant. It could also give rise to various *organizational challenges*, including dealing with the temporary nature of work and organization, shortage of funding, and the often unclear ownership structure of the PDP. Such challenges have previously been studied for different types of actor networks, highlighting, for instance, the negative impacts following the absence of key stakeholders (Harborne and Hendry, 2009). That said, a more in-depth understanding of the actor networks surrounding the PDPs – their incentives, conflicting objectives, and sense-making – is needed, since so few studies take the PDP actor networks as the primary unit of analysis.

In theory, a diverse actor network may also amplify or reinforce weaknesses in the innovation system because of actors' varying interests and frames of reference (Frishammar et al., 2019). The multitude of different actors present could increase the likelihood that network members will perceive a given problem or situation differently, in turn leading to representational gaps (Cronin and Weingart, 2007). Previous research has shown that inter-organizational collaborations among actors are complicated to organize and manage at the company level (Hart and Milstein, 2003), in broader and more informal networks (Markard et al., 2012), as well as in regions (Sharma and Kearins, 2011) and other multi-actor arenas (Ollila and Yström, 2015). Earlier studies also highlight the importance of network management (Newell et al.,

2017). Nevertheless, the literature is silent on how these challenges play out in a PDP context.

The study by Hendry et al. (2010) highlights the importance of the alignment of actors and preferences and therefore provides important hints about where key PDP challenges may arise. The importance of actor alignment in demonstration networks is also evident in related work by e.g. Harborne et al. (2007) and the challenges involved in aligning actors' expectations and goals have been identified as influencing the success of PDP activities (Frishammar et al., 2015). Lack of alignment of expectations and goals can stem from the actors' individual preconceptions as well as from their organizational and regional affiliations, and thus contribute to weakened legitimacy and deficient social capital. A lack of alignment may also result in an absence of coherent and well-defined strategic objectives, and pose a challenge for the relevant government funding agencies (Harborne and Hendry, 2009).

Knowledge spillovers, and how to address them, constitute key challenges for PDPs. These spillovers benefit outsiders that can make use of the knowledge generated at low (or no) cost. Such positive externalities are generally a good thing for society, but can also be problematic as they undercut the incentives for private firms to invest in knowledge and technology development at PDPs (e.g., Mowery et al., 2010). In other words, since the different actors may – and most likely will – have diverging views on whether to spread knowledge broadly or to secure intellectual property rights, the knowledge spillovers dilemma is a key issue for any PDP-based actor network.

Yet another potential organizational challenge concerns possible eligibility for public funding. Here, universities and research institutes have often played important roles, not least as actual owners of PDPs (e.g. Mossberg et al., 2018) and project managers of demonstration projects (Sjö and Frishammar, 2019). If the purpose of the PDP is to be an open research and innovation infrastructure – a permanent test center – the perceived neutrality of ownership and management could become important. There are also legal restrictions, which affect how the activities and collaborations around a PDP can be carried out. Competition legislation, such as the European Union State Aid Rules, has proven to be important in this respect (e.g., Hellsmark et al., 2016b). The identification of appropriate organizational forms and strategies to enhance the performance of the actor networks will, therefore, be key (Newell et al., 2017).

Finally, the transformation of PDPs and the associated actor networks from one purpose (technology verification) to another (permanent test center) will likely imply additional complexity for management and organization. For example, as the actor network expands when a technology moves closer to the market, e.g., in a demonstration project (as illustrated by Lefevre, 1984), increasingly complex relationships among the industrial actors as well as between industry and government can be expected (Harborne et al., 2007). The nature of the managerial and organizational challenges will then probably vary over time along with the evolving technology. These organizational challenges will include the new roles that will need to be taken by existing and new actors, and the wider set of activities that must be pursued. That said, the literature is largely silent about the specific managerial and organizational challenges for actor networks in and around PDPs, what these challenges are and how they manifest themselves. The next section presents the sample used and methods for studying these challenges.

3. Methods

For the purpose of this paper, the use of case studies is

appropriate, since this allows analysis of the dynamics at play (e.g., Eisenhardt, 1989), while at the same time providing context-rich descriptions (Eisenhardt and Graebner, 2007). The analysis draws on data from a longitudinal case study of four PDPs involved in advanced biorefinery technology development in Sweden. These advanced biorefineries seek to progress technologies through the formative phase, in which the management and organization of the collaboration among actors have become particularly critical as the actor network grows. The empirical material also includes PDPs that have undergone a transition from verification PDPs to permanent test centers. Since current insights into the managerial and organizational challenges in and around PDPs are nascent, an inductive case study approach was employed (Strauss and Corbin, 1998) where the approach suggested by Gioia et al. (2013) guided the data analysis.

3.1. The pilot and demonstration plant cases

Four advanced biorefinery PDPs – with their associated actor networks – constitute the case studies. All four plants are large, partly publicly-funded research infrastructures surrounded by rather informal actor networks. These networks consist of both public and private actors who have jointly contributed to the construction and operation of the plants. The actor networks around the PDPs are also temporary, in the sense that there are no legal or formal network organizations managing the networks, and activities associated with the research infrastructure are largely project-based.

Three of the cases studied have verified and demonstrated technology successfully, while the fourth case is in the late technology verification and demonstration stage. In that sense, all cases are technologically mature and are geared towards system build-up (Hedeler et al., 2020). For all plants, the actor networks are struggling in different ways to find further uses and purposes for the plants, such as through establishing permanent test centers. This arguably provides an opportunity to analyze the key managerial and organizational challenges that arise in and around these plants, including how these challenges unfold as PDPs transition from one form to another. The following specific PDPs were studied:

First, the RISE Biorefinery Demo Plant (BDP), situated in Örnsköldsvik, Sweden. The plant was initially intended to be used for developing technology for ethanol production based on ligno-cellulosic feedstock. Over time, however, it has broadened its scope to cover additional application areas based on processing ligno-cellulosic raw materials into sugars, and then into a variety of different products. It is possible to demonstrate entire value chains by using several smaller pilot plants, which are co-located with the larger one. Since 2013, the plant has the status of an open permanent test center. Multiple key actors are engaged with this plant. The legal owner is the EPAB company which, in turn, is owned by Luleå University of Technology, Umeå University and Sekab (a minority share of 3%). Lund University also has stakes in the plant but does not own it, and additional actors include research institutes such as RISE and RISE Processum, Sekab (a technology developer), Domsjö Fabriker, More Research (a consultancy company) as well as regional actors such as the city councils of Örnsköldsvik, Umeå and Skellefteå. Over the years, the plant has received public financial support from the Swedish Energy Agency and Vinnova (two governmental agencies) as well as project funding from EU framework programs.

The second case is the LignoBoost demonstration plant, which is a permanent test center situated in Bäckhammar, Sweden. This PDP was constructed with a focus on the process of extracting lignin from chemical pulping processes; the so-called "LignoBoost process". During recent years, there have also been efforts to transform

the aim to include new process concepts for lignin valorization. Application areas are as diverse as fuel for boilers, high-value applications such as carbon fibers, and “debottlenecking” recovery boilers to enhance production capacity. The legal owner of this PDP is LignoBoost Demo AB, a subsidiary to RISE Innventia AB. Chalmers University of Technology and Karlstad University are the key university actors, and additional institutes such as RISE SICOMP also utilize the facilities. Valmet plays a key role as technology developer, and the plant has significant industrial stakeholders as well, including Nordic Paper, Stora Enso, Casco Adhesives, Södra, Fortum and several small and medium-sized companies. Public financial support has been received from the Swedish Foundation for Strategic Environmental Research (MISTRA), the Swedish Energy Agency, and Vinnova.

The third case concerns the Gobigas demonstration plant, which is an industrial-scale verification PDP that is currently mothballed. This PDP was inaugurated in early 2014 and is situated in Gothenburg, Sweden. It is owned by a municipal energy company (Göteborg Energi) and has been geared towards indirect gasification of biomass with the aim of producing a biogas of synthetic natural gas (SNG) quality that can be used for different purposes, e.g., transportation, feedstock for the chemical industry, and the production of power and heat. After successfully verifying gasification of pellets, it is presently being rebuilt to manage more complex feedstock (i.e., forest residues). Key actors in the network around this plant include the Chalmers University of Technology, the research institute RISE, technology developers such as Valmet, Repotec, and Haldor Topsøe, consultants such as Jacobs, and the Swedish Gasification Center (SFC), a networks organization. The plant has received public support from the Swedish Energy Agency and from NER 300, an EU funding program.

Finally, the fourth case is the LTU Green Fuels Demonstration Plant situated in Piteå, Sweden, which is an industry-scale verification PDP that is currently transitioning towards a permanent test center. This PDP focuses on the gasification of biomass, in particular black liquor, but also on the co-gasification of pyrolysis oil. The plant has equipment for producing DME (dimethyl ether) or methanol (both have been demonstrated). RISE ETC (a subsidiary of the research institute RISE), which is nearby, hosts several smaller pilot plants – including laboratory equipment – which act as complements. Since 2013, the plant has been owned and managed by a university, Luleå University of Technology (LTU). After a period of turmoil, the plant has now been repurposed to the area of bio-jet fuel production. LTU, the RISE research institute and Chemrec, a technology development company, all have stakes in the plant. The Swedish Energy Agency has provided public financial support historically, and industry stakeholders include Smurfit Kappa, Volvo and Domsjö Fabriker. Regional public actors have a stake as well, in this case, the Municipality of Piteå and the Norrbotten Region. Finally, lobby/network organizations such as the Swedish Gasification Center (SFC) and Piteå Science Park are also involved in the plant.

These four large and publicly-funded PDPs, and the actors around them, have previously been analyzed by Mossberg et al. (2018) with the aim of developing a typology of “actor roles” centered around PDPs.

3.2. Data collection

The primary data source consists of information drawn from in-depth interviews with actors in the actor networks surrounding the four PDPs, which were conducted in two phases with about two years between each phase. The first phase aimed at providing an overview of the actor networks around each PDP, as well as of the general challenges that actors experienced concerning joint

knowledge creation and the development of the PDPs and associated technologies. In the second phase, the organizational and managerial challenges experienced by the various network actors were directly addressed.

All in all, 25 semi-structured interviews were conducted with 21 network actors (some of these actors were interviewed in both phases). Table 1 provides a condensed description of the actors interviewed. Previously, this empirical material has been used by Mossberg et al. (2018) with the aim of shedding light on the roles that the different actors play in facilitating PDP development and diffusion, but with no focus on the associated management and organizational challenges. The interviews lasted 1–1.5 h and similar questions were asked in all cases, although somewhat adapted to the interviewed actor's roles and functions. All interviews were recorded and transcribed verbatim. Moreover, the information drawn from the interviews was augmented through several secondary sources, including company websites, press releases, and conference presentations.

3.3. Data analysis

Data were first analyzed for each PDP separately and later compared among the four cases, searching for common patterns. In doing so, the method suggested by Gioia et al. (2013) was used, and the data were analyzed in three steps. First, first-order categories and tentative second-order themes were extracted. In this step, open coding was relied upon which implies trying to stay as close as possible to the language used by the respondents. Key statements were categorized and re-categorized in several different ways. Related codes were then connected to tentative themes through axial coding. For example, statements on unclear and changing organizational structure and divergent roles and responsibilities were labeled “De facto unclear ownership.” In a second step, the coding scheme was iterated with data and literature. Here, the tentative second-order themes were further developed by drawing on insights from the data. Inspiration from the literature was sought for revising the labels of some of the themes. By doing so, the analysis subsequently revealed eleven themes, which depicted the first-order categories. These categories and the second-order themes were revised multiple times as data were revisited and reanalyzed and new literature was reviewed. In the last step, final aggregated theoretical dimensions were generated; the second-order themes were here organized into two overarching dimensions, namely managerial challenges and organizational challenges (see Fig. 2). The workflow for the empirical analysis is schematically illustrated in Fig. 1.

For the qualitative data analysis, no specific software tool was used. The interviews were transcribed and then coded manually using a combination of word and excel as tools.

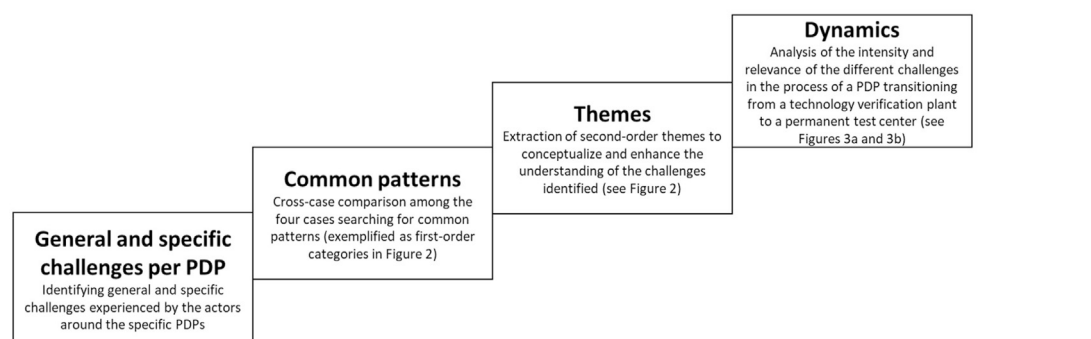
4. Findings

The data structure is visualized in Fig. 2. The *organizational challenges* center on how to organize the PDP and the associated actor networks, and these challenges tend to be closely linked to the specific characteristics of such plants. By contrast, the *managerial challenges* center on how to manage the PDPs and the associated actor networks. Specifically, the managerial challenges are largely related to issues associated with the diversity of the actor networks, such as how to coordinate and expand the networks, align interests and identify feasible business models. Here, it should be emphasized that for all the cases studied, different actors conduct management in different ways. This could partly be because no single actor holds the formal mandate of “being in charge” of the actor network. Sections 4.1 and 4.2 discuss the

Table 1
Interview Sample^a.

No.	Date	Type of Actor	Main role regarding PDP and biorefinery development	No. of words transcribed
1	13-08-19	Research institute	Manager of the business area Energy	11,748
2	13-08-23	Research institute	Director of cluster organization, investing in research and technology development	12,427
3	13-08-23	Consultant (research)	Former CTO at a technology development company, representing the early development	6139
4	13-08-23	Research institute	Senior research advisor and responsible for the PDP development	12,888
5	13-08-26	Industry	Head of innovation and development of new products	9800
6	13-08-26	Consultant (research)	CEO of a research consultancy firm	13,357
7	13-08-27	University	University professor and representative of a technology development company	11,601
8	13-08-27	Technology developer	Manager and representative of the current development of a technology development company	9508
9	13-08-28	University	Professor in chemistry and representative of the research on biochemical conversion processes	11,779
10	13-09-27	University	Principal and formal owner of PDP(s)	9368
11	15-06-11	Research institute	Director of a research institute, developing thermochemical conversion processes	8399
12	15-09-10	University	University professor and representative of the current development of indirect gasification	5088
13	15-10-08	Industry	Head of operations at large-scale demonstration plants for advanced fuels	6205
14	15-10-08	University	University professor and representative of the early development of technology	6076
15	15-10-15	Research institute	Responsible for the development of the LignoBoost technology and a large demonstration facility	7482
16	15-09-22	Research institute	Senior research advisor and responsible for the PDP development	9929
17	15-10-13	Technology developer	Manager and representative of the current development of a technology development company	8400
18	15-10-13	Consultant (research)	Former CTO at a technology development company, representing the early development	4289
19	15-10-13	Consultant (research)	CEO of a research consultancy firm	5888
20	15-12-02	Government funding agency	Administrator of research programs funding PDPs and biorefinery development	**
21	16-02-09	Government funding agency	Administrator of research programs funding PDPs and biorefinery development	5753
22	15-09-08	Industry	Project manager (consultant)	5410
23	15-09-09	Industry	(Previous) CEO	10,730
24	15-11-25	Technology developer	Manager of technology development and innovation	6687
25	15-10-02	University	Operations manager of PDP	11,952

^a This sample has in part been used in a previous publication for the development of a role-based typology for the analysis of actors and actor networks around large, publicly-funded PDPs (see Mossberg et al., 2018). ** Recording did not work; only notes and a summary of the interview are available. Some respondents had multiple affiliations but only their main affiliation is displayed in the third column.

**Fig. 1.** Schematic illustration of the workflow underlying the empirical investigation.

organizational and managerial challenges in depth.

Initially, all four PDPs were constructed to verify and demonstrate various biorefinery technologies at significant scale. For three of the plants, this initial purpose had been achieved, after which the actors involved worked to transform and rebuild the plants into permanent test facilities. The fourth plant (Gobigas) was, at the time of data gathering, at a late technology verification stage. Since the purpose of a plant aiming at technology verification differs significantly from that of a permanent test center, organizational and management challenges arise alongside the technical refurbishments. The challenges encountered vary between different types of PDP activities, and thus the dynamics over time are emphasized throughout this section, and finally summarized in Section 5.

4.1. Organizational challenges

When compared to a PDP for technology verification purposes, the actor network surrounding a permanent test center includes many more and different types of actors, in line with its larger

purpose of being an open test arena. This larger actor network naturally poses additional challenges related to the organization of the actors in the network as well as the organization of the PDP as such, e.g., in granting access to the plant. For a permanent test center to function as an attractive open infrastructure, many respondents highlighted the pivotal need for the PDP to be perceived as neutral, i.e., impartial, fair and nonpartisan. For the PDPs in this study, this posed a great challenge since these plants were initially constructed for the purpose of technology verification, in which each respective actor network tended to be dominated by a single commercial actor. Thus, a key challenge was **creating neutral space**. For example, one respondent from an industrial company explained the importance of having a “neutral party” to oversee the operations. This was believed to be particularly important when the plant represented an infrastructure that was open to a variety of different actors. In line with this, respondents also put forward the view that they felt it would be problematic if a single commercial actor controlled the plant, as this would exclude a broader set of stakeholders.

For all the PDPs studied, multiple respondents highlighted the

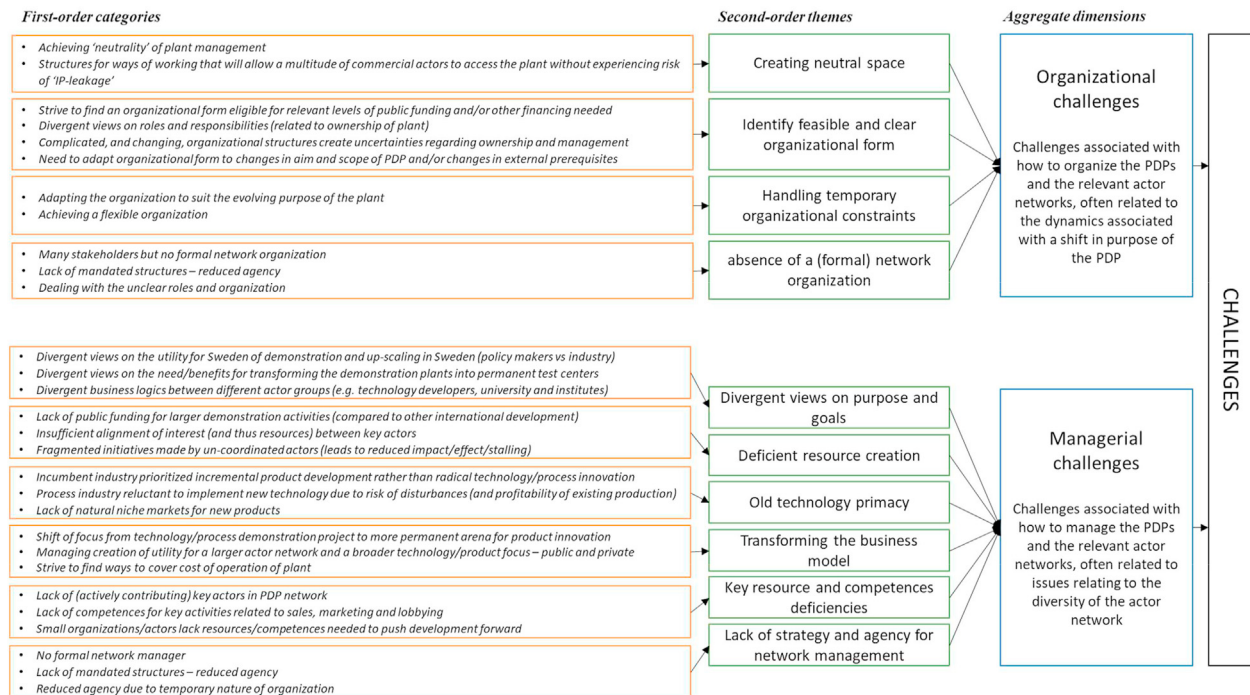


Fig. 2. A Visual Representation of the Data Structure.

ongoing efforts to **identify a feasible and clear organizational form** that suits the current purpose of the PDP, and that can facilitate the acquisition of both public and private funding. Different organizational structures, referring to different settings for ownership and management of the plants, were used to allow flexibility and to allow for public funding while at the same time protecting the intellectual property rights of the key actors involved. As an example, this was manifested in complex and changing agreements on the ownership of the plants, where some actors were formal owners of the plant whereas others were responsible for management and operations. The RISE Biorefinery Demonstration plant is a good example of this (Hellsmark et al., 2016b). This has often led to the organization of the PDP being perceived as rather disorganized, with unclear roles regarding the responsibilities of ownership, operations and work organization. As one respondent from a research institute put it:

Today it is a mishmash. The staff is the employees of (the technology developer) and (the institute) is buying the service of operation from them. The plant is owned by the (company), which in turn is owned by the university holding companies and the (technology developer) by a minority share. They are still the owners. So today, it is a huge mess.

A specific example relating to the efforts to find a feasible and clear organizational form was the experience of unclear or unsuitable roles and responsibilities of different actors (see also Mossberg et al., 2018). This was highlighted both by actors close to the physical PDP infrastructure, and by actors with less central roles in the actor network. For example, in the case of the RISE Biorefinery Demo Plant, a company having two universities as its main shareholders was made the owner, to comply with EU regulations regarding state aid. A technology development company with commercial interests in the technology to be demonstrated received a minority share, but was nevertheless the one initially responsible for day-to-day operations (and the related costs). This created a rather complicated structure, which was hard to communicate. This complex set-up was highlighted by one of the

research institute respondents who explained that there is often confusion about who really owns the facility in practice. In fact, some persons believed that the plant “belonged to industry” whereas others sustained a narrative of that same facility belonging to “the research institute”. A key reason for this ambiguity was that the plant was intended to be open and public, which is a condition for being eligible for public funding from authorities.

A similar arrangement, in terms of ownership structure, was made in the case of the LTU Green Fuels Demonstration Plant, again in order to comply with rules and regulations regarding public funding (not least the EU state aid rules). As this and other PDPs have evolved towards becoming more permanent test centers, this model of ownership has been questioned, especially by university officials who had doubts about their role in owning and taking responsibility for such research infrastructure:

Should we have such a business it must be able to live and thrive in the same conditions as the other activities we have at the university. Our task is to do research, not to do ancillary (demonstration) business.

In the case of the Gobigas Demonstration Plant, where a municipal energy company was the owner and manager of the plant, the structure for ownership and management has also been questioned, but for different reasons. Multiple actors expressed doubts about whether it is the role of a municipal actor to own a plant intended for technology demonstration. Consequently, the present owner (Göteborg Energi) has been looking to sell the plant and withdraw from the demonstration project before the project's expected end in 2020.

Compared to the other three cases, the LignoBoost demonstration plant had the clearest and least disputed organizational form. The plant is owned and managed by a research institute, which initially also owned the technology to be demonstrated. After initial demonstration activities, the technology was sold to a technology development company (STFI Packforsk) in 2008. Although the costs of owning and managing the plant have also been questioned in this case, the purpose of running the plant as a permanent test

center is within the scope of the research institute, namely, marketing its resources of strategic research infrastructure and its role as a “science partner” for industry in innovation. The transformation of the plant into a permanent test center has also contributed to strengthening the institute's role in the region where it is located, and facilitated new collaborations with regional, national and international actors.

The role of governmental actors and funding agencies may vary as a PDP develops. In the early stages of PDP development, governmental funding agencies are key. Government funding involves difficult trade-offs, not least in terms of striking a balance between the societal goals of public funding (e.g., carbon mitigation) and the commercial interests of private actors to verify and demonstrate new technologies for specific purposes. As a new technology is verified, and the objectives of the PDP activities evolve, it also becomes increasingly important to ensure that the knowledge that has been developed is utilized in new projects aiming at further up-scaling and commercialization. All the PDPs studied were, as already highlighted above, constructed for the aim of technology verification (i.e., having an implicitly temporary nature). When the purpose of the PDP evolves towards that of a more permanent test center, the temporary (initial “project”) nature of the plant, and the associated organization, become more noticeable.

Another key challenge is to **handle temporary organizational constraints**. This challenge applies to human resources/competences (i.e., to have access to the right people at the right time and not lose them if/when organizations in the actor network around the PDP change their priorities), as well as to comply with funding schemes (i.e., to have an organization that is stable but still flexible enough to continuously attract the funding needed). One strategy put forward by some of the respondents to handle temporal organizational constraints is to work towards an associated research program supporting the activities at the PDP. As one respondent at a research institute puts it:

I think these linked research programs are important for these facilities, because the plants in themselves cost so much money to keep up and running. It is not just that you have the staff there, stuff breaks down after a while and you want to do something in the plant, and this costs money. So, it requires financing, of course, from business but also from society to ... make it work. So that is a good part of the project too, look at how this [the funding] could be generated.

For the cases studied, the type of funding available for related technology research and development activities evolved from the Swedish Energy Agency funding large, technology-specific research programs to a more diverse set of funding agencies supporting more specific and product-oriented programs. Many of the latter initiatives specifically target the interests of expanding actor networks and create collaboration among actors along the different prospective value chains. The actor networks around the PDPs tend to be diverse, consisting of a significant number of actors, all with different resources, aims and interests.

At the same time, there is an **absence of a (formal) network organization**, in the sense that all the actor networks lack a formally constituted organization. Instead, the actors are held together within the boundaries of the different agreements and projects, which together constitute the formal activities around the PDPs. This is a considerable challenge, because no one holds a mandated responsibility for the strategic development of the actor network. It also complicates the coordination of activities associated with the PDP and actor networks, and weakens the alignment of goals and resources.

The above examples illustrate that the organizational challenges differ, depending on the PDP's purpose, and that the organization of

these plants needs to be adjusted once a plant has transitioned from one type to another. The challenges associated with such a transition are therefore addressed, and then also briefly summarized in Section 4.3.

4.2. Managerial challenges

As noted above, the actors in the networks surrounding the PDPs are diverse with diverging aims and purposes for participating. An upside of this is access to a varied set of competences and resources but it also brings about challenges. One key challenge identified is the fact that the different actors have **divergent views on the purpose and goals** of the PDP, including different and sometimes conflicting perceptions of key roles and responsibilities. This poses a significant challenge for the efficient management of joint efforts to support the PDP development activities; it weakens the alignment of monetary as well as human resources and capital. Divergent views and interests need to be understood and managed to avoid misunderstandings that would otherwise hamper the collaborative work and even stall overall PDP development. In the words of one of the university respondents:

The problem is whether this kind of organization [university] believes that they should be technology suppliers or that they should make money on that you enter a sphere of products. The problem always arises when you are not clear on your role. Many interpret the task of public outreach as meaning they should start their own new companies and create products, and if you have that mindset when you participate in this type of project, that creates incredible problems and lockups.

In the case of sustainable technologies, divergent views on the goals of the PDP can be particularly challenging. The development of these technologies will be associated with a mix of societal goals (e.g., decarbonization, regional development) and commercial goals (e.g., the establishment of new competitive industries). These varied goals may increase the risk of conflicting views emerging on the relevant priorities in terms of resources and activities. Multiple respondents articulated concerns in this sense.

The empirical analysis indicates that the challenges of divergent views and interests among the actors in the networks become even more pronounced as a PDP transforms from a technology verification plant to a permanent test center. This is in part due to the expanding actor network, but also because the plant, as a permanent test center, can accommodate a more multifaceted portfolio of “sub-purposes.” Therefore, the challenge of aligning the stakeholders' goals, purposes and resource deployment priorities tends to become more important over time.

Also, related to the issue of divergent views on purpose and goals, another key managerial challenge that has emerged from the data analysis is that of aligning the actors in the network to create joint sense-making, and fostering a sense of community to facilitate collective knowledge creation. When this was achieved, the actors' resources could be efficiently combined to create new resources on both the firm/actor level and the network level. Examples include technology acceptance/legitimacy, trust and guidance. Such resources are parts of what fills the “spaces in-between” and could be viewed as a way of mobilizing a strategic collective body (Yström, 2013). However, this generally does not happen, resulting in **deficient resource creation**. As one respondent from a university put it:

Thus, cooperation and networks ... without cooperation and without networks and without committed actors, it is very difficult to get financing, and financing is after all the alpha and omega.

The cases studied had managed to generate resources on the network- and system-level to differing extents, but it was only in the case of the LignoBoost demonstration plant that a unified strategic collective body could be discerned. This was manifested

by a more pronounced alignment of the network actor's perception of the aims and purposes of the PDP (shared goals), as well as a broad legitimacy for both the PDP as such and its technology. All the PDP cases studied had the potential to improve in this area. The RISE research institute, by owning and managing the LignoBoost demonstration plant, is the actor that most clearly performs a set of roles related to both the strategic and the operational aspects of PDP development.

Regarding actor presence and activity in the networks, the fact that incumbent actors sometimes tend to be reluctant to participate actively in the development and progression of new technology has constituted a key managerial challenge. The analysis suggests that this may be due to incumbents prioritizing either incremental product development or the development of premium products in already established markets, rather than putting advanced biorefinery development at the forefront. This key challenge can therefore be referred to as **old technology primacy**. In the advanced biorefinery case, these incumbent actors, typically those representing the pulp and paper industry and the district heating sector, are key, since they control large flows of biomass and own strategic infrastructure that could be used to integrate new technologies at a significantly lower cost than constructing new plants and creating new biomass routes. The quotes below illustrate this issue and originate from two respondents, both representing the research institute sector.

I think the big (incumbent) industry has been a little cautious. You could imagine that the oil companies, who are selling the product, should have been more active. And even those who sit on the commodity side, the paper and pulp companies, I perceive them as a bit conservative. I do not really know what could trigger them. But ... I may find it a little strange that none of them have been [pushing] harder for this and more seriously, before. Many people look at it and look at it, but it's like nobody's doing business.

There has also been a slight deficiency in the system, the conventional industry organizations have not been able to push the issues [development of new technologies/products related to the PDP] because their companies have not awakened yet, and then they cannot lobby.

Another key challenge is that operating a PDP as a permanent test center requires a business model that is completely different from the one followed when the plant was first built, if it is to cover the plant's operating costs. **Transforming the business model** is a key managerial challenge. For example, for the PDP to function as an economically viable permanent test center, paying customers are needed to secure continuous revenue streams. Consequently, the plant needs to be marketed. The case studies emphasize that transforming a PDP's business model from focusing on technology verification to also including commercial marketing activities, has been a major challenge. This is highlighted by a respondent from a research institute and another representing a technology developer:

Previously, we have run projects that have used the entire facility. Now we get assignments where they want to borrow parts of the facility. So, we have a challenge to refine the business model. Because we have rented it out every day, the whole installation. Now we must find another business model where we rent the parts in a different way.

Now we must try to package (this). It is always the big job when you develop, when you scale-up from lab, pilot and so on. All the time (you must ask yourself) – why are we doing this? What are we really going to sell? What is our business concept? Our concept is not to sell machines, but to sell a bunch of documents that tell (someone) how to design, run, and make money from it (the plant). Then someone else delivers the machines and builds the factory. This [building the plant] is done by somebody else. It is not easy. It is

both the mindset (and) ... Most people are researchers here and hardly know what a tender is and have never been in negotiations or anything. It is a pretty big change. Some cannot handle the change ... Or they never enter that change.

The case studies also reveal divergent interpretations regarding the desired scope of collaborative development. The earlier stages of technology verification and demonstration are generally perceived as easier to collaborate around, compared to when the PDPs are to function as permanent test centers and the focus shifts towards the development of new products. In the interviews, this was highlighted by one of the respondents from a technology development company:

We saw that our bit [of that], when we discussed with [two industry companies] about this and we said that we would like to continue to develop this [process] together with you, they were very open to it, since it brings [the area] forward. While when it then comes to what to make out of the [produced material], whether to make new fuels or materials, or so ... I especially remember that a guy from [one industry company], a senior manager in a (product) area we could develop together, he said, "Keep your hands out of our pockets," so they did not really want to collaborate on that.

This quote is interesting from a network management perspective since the transition from technology verification to a permanent test center requires the involvement of new actors and an expansion of the actor network. Consequently, there is a need for active management to deal with the challenge of activating and engaging actors that can provide the resources needed. Meeting this challenge includes engaging incumbent industries, end-users of the technology and R&D actors and technical consultants that can develop, test and evaluate complementary technologies and address wider system issues.

If the actor network fails to attract new actors and pursue the necessary expansion, there is a clear risk that it will lack **key resources and competences**. For the cases in this paper, access to actors who can contribute to the development of new business models, marketing and public relations has been missing. The above-mentioned reluctance of the incumbent industry to participate actively in development has also been put forward by the respondents as causing key resource and competence deficiencies. The representative quote below is from a respondent at a technology development company:

If looking at the members in [the cluster around the PDP], there is nothing missing from a technical perspective, but maybe what's missing are public relations, marketing and lobbying and the push to promote the political decisions necessary to enhance the development.

Finally, the empirical analysis indicates that an additional managerial challenge is the **lack of strategy and agency for network management**. This can be illustrated by the lack of clear agency for both the strategic and operational management of the actor networks around the PDPs, especially when the purposes of the PDP evolve. Individual projects associated with – and carried out at – the PDPs will typically have clear and mandated management. In several of the cases, a subset of ongoing projects associated with the PDP can be viewed as sub-networks managed by lead organizations. For all four PDPs studied, the larger actor networks around the PDPs are informal in character, and they lack a formally mandated management. The analysis suggests that this shared (non-mandated) network management constitutes a reactive approach to the managerial challenges encountered – such as trying to adopt the organization to fit current funding possibilities – rather than designing an organization fit for a jointly defined, long-term strategic purpose.

5. Discussion

The empirical findings support the notion that the organizational and managerial challenges tend to vary across the various types of PDPs, and this in turn is highly relevant in cases where a PDP is transitioning from one type to another. Figs. 3a and b summarize how these challenges evolve in terms of intensity and relevance in the process of a PDP transitioning from a technology verification plant to a permanent test center. The coloring illustrates the significance of the different challenges. It should be noted that these figures only provide rough assessments. This process should not be viewed as linear and stable over time, nor should all the different challenges be viewed as evaluated on a similar scale, due to their inherent characteristics.

As illustrated in Fig. 3a and b, some challenges change over time and become more, or less, important – while others are more constant and need to be addressed equally regardless of the PDP type. For example, in the case of a technology verification PDP, creating a neutral space, e.g., in terms of plant ownership, is typically not important since the tests and demonstrations are performed as projects with already well-defined and committed actors. There is therefore little need to attract additional actors at this stage. In contrast, when the technology has been verified and there are ambitions to transform the PDP into a permanent test center, neutrality becomes increasingly important (see Fig. 3a). It then becomes essential to attract a wider set of customers/partners, to cover the costs of continuous operations.

Similarly, the managerial challenge related to the lack of strategy and agency for network management is generally less urgent when the PDP is in the early technology verification stage (see Fig. 3b). At this stage, the actor network is relatively limited and homogenous, and the tasks at hand (i.e., build the plant and verify

the technology) are straightforward. As the purposes of the PDP evolve and increasingly start to resemble those of permanent test centers, the actor networks expand. This means that the activities at the plant need to be renegotiated among the actors, and strategic network management becomes increasingly more important (Söderholm et al., 2019).

A final example concerns the managerial challenge of deficient resource creation. In the early stages, resource creation challenges will often be critical, not least due to the need to secure the funding required to start the construction of a technology verification plant. During the operation of such a plant, this type of challenge is less urgent since the tests and experiments can typically be funded on a project basis. If the aim shifts and there are ambitions to transform the PDP into a permanent test center, the issue of resource mobilization and creation again becomes more important. Specifically, there is a need to secure future revenues through new business models. It also becomes increasingly important to maintain high legitimacy for the plant operation among a wider set of actors.

In some regards, PDPs can be viewed as arenas for open and collaborative development (Yström, 2013). PDPs have similarities to some of the projects commonly analyzed from an open innovation and temporary organization perspective, but there are also significant differences, such as the fact that PDP actor networks tend to be more informal in character and lack clear structures for management and organization. Previous research in open and collaborative innovation has identified the activities of enabling peer collaboration and mobilizing a strategic collective body as key features for enabling joint knowledge creation. From the case studies, the PDPs in question have the potential to perform such activities. Nevertheless, pursuing them involves encountering various types of managerial and organizational challenges, not least the lack of a mandated network manager. This is especially true in

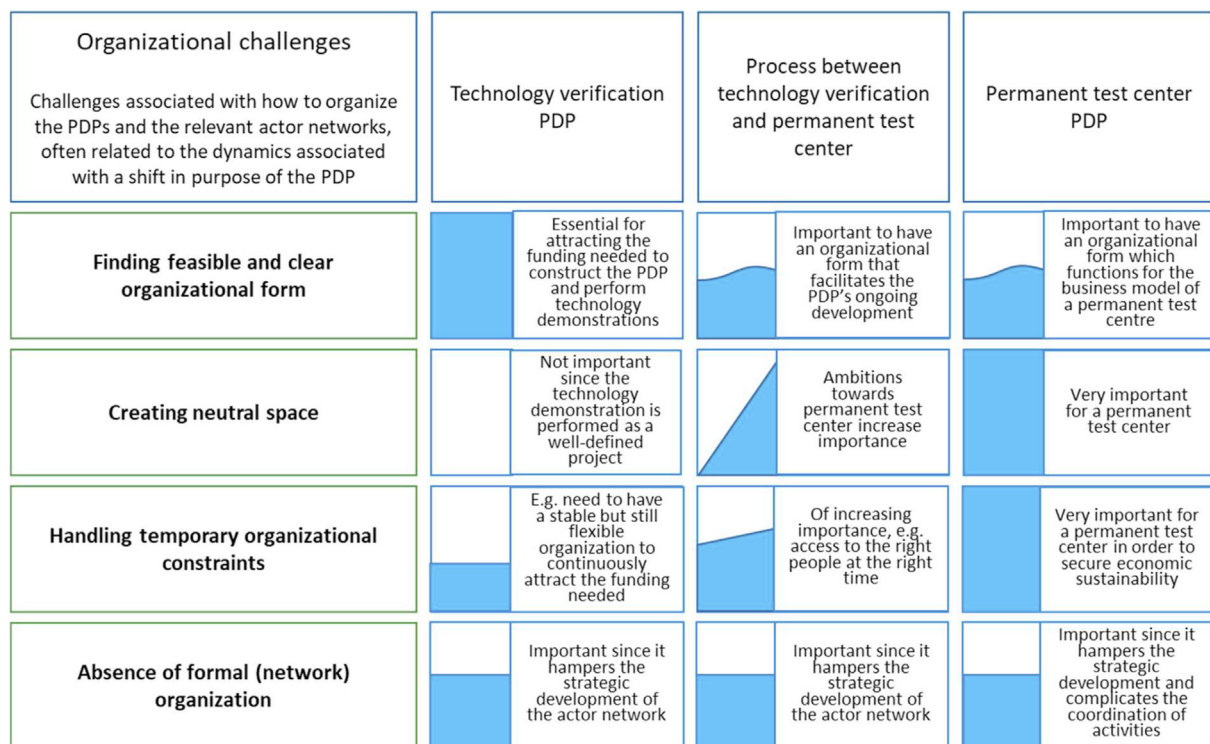


Fig. 3a. Transition from a Technology Verification Plant to a Permanent Test Center: Organizational Challenges. The blue shapes in the figure illustrate how the organizational challenges encountered changes in intensity and relevance in the process when a PDP transitions from a technology verification plant to a permanent test center, the shape and amount of blue space indicate the intensity and relevance of the challenge and how it evolves. It should be noted that this process is not necessarily linear. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

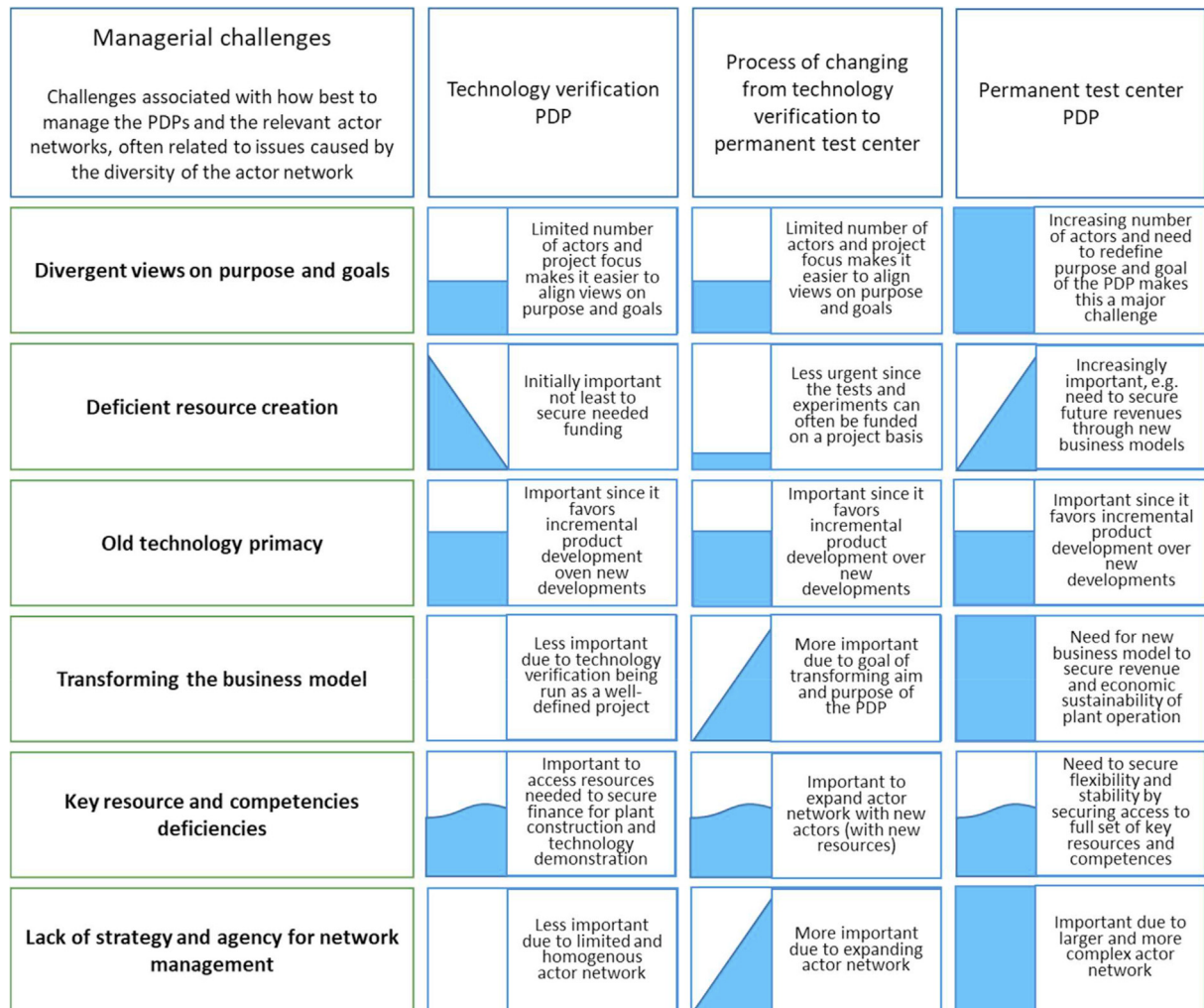


Fig. 3b. Transition from a Technology Verification Plant to a Permanent Test Center: Managerial Challenges. The blue shapes in the figure illustrate how the managerial challenges encountered changes in intensity and relevance in the process when a PDP transitions from a technology verification plant to a permanent test center, the shape and amount of blue space indicate the intensity and relevance of the challenge and how it evolves. It should be noted that this process is not necessarily linear. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

the case of sustainable and clean technology development; public actors such as government agencies and local governments are normally present in the networks surrounding PDPs with a sustainability focus, but rarely assume the roles of network managers (Söderholm et al., 2019).

That said, PDPs can be regarded as arenas for collaborative technology development, providing both the chance to create and strengthen connections between actors in the associated networks as well as the physical spaces that enable joint knowledge creation. In light of this, the key objective of a PDP manager will be to create and manage the space “in-between” the diverse actors in the network and the physical infrastructure, with the purposes of strengthening the interactions within the actor network and facilitating the generation of resources at the “arena” level. This is no easy task since there is often no single actor who holds the mandate and the resources to take on the challenges identified in this paper. The different actors have different resources and pre-requisites for managing the challenges in different ways, and to different extents. The collaboration processes and the facilitation of “shared” network management will be key.

PDPs are essential for the development of sustainable technology (Bossink, 2015), including biofuels, bio-based materials

(Fevolden et al., 2018), wind power (Harborne and Hendry, 2009) and solar PV (Brown and Hendry, 2009), not least during the so-called formative phase during which the conditions for new technologies to emerge are set up. If the organizational and managerial challenges are not adequately addressed, there is a risk that the associated sustainable technologies are viewed as failures even though the demonstration activities have shown that they perform as expected (from a technical standpoint). This should, in turn, increase the likelihood of the technology surviving the formative phase and achieving large-scale adoption over the long term. While technical verification and up-scaling represent the engines of the PDP activities, addressing managerial and organizational challenges properly will help that engine run more efficiently. Thus, improved knowledge about the organizational and managerial challenges that characterize the activities in and around the PDPs can increase the prospects for better goal fulfillment, e.g., by aligning the interests of various actors. Such knowledge can also assist in making the development process more efficient, e.g., through reduced costs of negotiation and contracts. Improved knowledge could also help increase the resilience of the technological development process and make it more robust over time.

Previous research has shown that the formative phase can be a

very lengthy process and may typically extend over more than two decades for energy technologies (Bento and Wilson, 2016). This is unfortunate given the urgent need to combat global climate change and environmental pollution. Devoting explicit attention to the organizational and managerial challenges surrounding the development activities in and around PDPs could contribute to shortening the duration of the formative phases for new sustainable technologies. In other words, the duration of the formative phase may be determined by factors other than the characteristics of the underlying technology, e.g., substitutability or unit scale (Bento and Wilson, 2016). It will, this paper illustrates, also be influenced by the effectiveness of the often heterogeneous actor networks that collaborate at and around PDPs, and their collective attempts to deal with various organizational and managerial challenges. Addressing organizational and managerial challenges also contributes to strengthening the innovation system in and around the PDPs. This generates an important degree of robustness in the system, which ideally provides stability that can facilitate increased stamina and “muddling through” the formative phase and assist in crossing the “valley of death.”

6. Conclusions

This paper explored the role of PDPs as arenas for collaborative technology development, in particular in the context of sustainable technology. The development of clean technologies and resource-efficient production processes relies heavily on verification, optimization and efficient up-scaling in PDPs, and such activities require the involvement of heterogeneous actor networks. This paper contributes to the literature by making these actor networks surrounding PDPs the key unit of analysis, and by investigating the managerial and organizational challenges that arise as these actors collaborate. A number of generic organizational and managerial challenges were identified. These included: the division of responsibility for the operation and formal ownership of PDPs; the sometimes unclear role and purpose of PDP activities; the dynamics of purpose and the associated effects on the actor network structure; and the lack of specific competences and resources in the actor network.

The results have practical implications for organizing and managing the actor networks around PDPs. Highlighting the importance of organizing and managing PDP development activities should lead to a higher level of preparedness for critical non-technical challenges when a PDP begins to transition from one type to another. The difficulties encountered when managing a more diverse actor network as technologies develop could be planned for at an earlier stage. The need for a transparent, yet flexible, strategy for the planned activities while providing agency for actor network management, should be cornerstones of such preparatory work. The above is likely to be particularly important in the context of sustainable technology development, which is typically surrounded by a wider set of network actors and stakeholders. Finally, a more comprehensive understanding of the managerial and organizational challenges should provide scope for improving the conditions for widespread commercialization of sustainable technologies, not least by increasing the resilience of the technology development process and by shortening the length of the formative phase of this process.

The analysis in this paper has important limitations, which should be addressed in future research. The case investigations in this paper only address the challenges associated with the development of biorefinery technology. Even though the ambition of the paper is to highlight and address generic challenges that are likely to be encountered in several types of technologies, it would be useful to test the validity of this hypothesis by investigating also

other PDPs (e.g., in wind power, solar PV, etc.).

One reason why a broadening of the empirical scope could reveal interesting results is that different technologies may experience different life-cycle patterns. For instance, for some technologies, large – even global – markets are needed to enable mass-production, economies-of-scale and learning-by-doing in production. Other technologies, however, rely more heavily on experimentation and close user-producer interactions (learning-by-using), and they therefore tend to be more dependent on a strong home market. For these reasons, the characteristics of the actor networks surrounding PDP development will likely differ, as could also the nature of the organizational and managerial challenges encountered at the plant.

These challenges could also materialize differently depending on the local context of the PDP, e.g., due to interactions with local government bodies and nearby universities, institutes and technology developers. The importance of such geographical aspects of PDP development could also provide a fruitful avenue for future research.

CRediT authorship contribution statement

Johanna Mossberg: Conceptualization, Writing - original draft, Writing - review & editing, Visualization. **Johan Frishammar:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Funding acquisition. **Patrik Söderholm:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition. **Hans Hellsmark:** Conceptualization, Funding acquisition.

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.

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