

Article

The Role of Trials and Demonstration Projects in the Development of a Sustainable Bioeconomy

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Abstract: This article provides an overview of the literature on demonstration projects and trials, and accounts for how insights drawn from this literature can contribute to the development of a sustainable bioeconomy. The article reviews the literature on demonstration projects and trials, covering both more broad-based studies on demonstration projects mainly carried out in the US and more specific studies on demonstration projects for energy technologies carried out in Europe, the US, and Japan. The aim of the article is to account for how demonstration projects and trials can contribute to the development of a sustainable bioeconomy.

Keywords: bioeconomy; demonstration projects and trials; organizational solutions; learning outcomes

1. Introduction

Creating a sustainable bioeconomy—which takes advantage of unused or underexploited bio-resources, turns them into replacements for fossil-based fuel, energy, and products and contributes to the reduction of greenhouse gas emissions and the protection of local environments—is a truly monumental task. It depends on companies entering into an uncertain field where they do not know if their production technologies will work, how high their production costs will be, or if their products will meet a receptive market. In such an uncertain environment, companies usually invest and proceed cautiously in a stepwise manner, starting with laboratory experimentation, moving on to pilot plants, and then full scale demonstrations before engaging in full-fledged commercial activities (see for instance, [1]). Demonstration projects and trials are consequently a crucial tool for companies to facilitate learning and reduce risk associated with bio-based innovations and a vital instrument for policy makers to direct and encourage the development of a sustainable bioeconomy.

Although demonstration projects and trials play a critical role in development and deployment of new technologies, the literature on the subject is fairly fragmented and disjointed. The aim of this article is provide a comprehensive overview of this literature and highlight important findings of relevance for the development of a sustainable bioeconomy. Studies have shown that demonstration projects and trials play an important role in developing new bio-based fuels, energy and products [1] and insights gained about demonstration projects and trials are therefore highly relevant for both companies and policy makers engaged in the bioeconomy.

The article reviews two important strands of literature. The first strand of literature includes broad-based studies on demonstration projects that have mainly been carried out in the US and the second strand of literature covers more specific studies on demonstration projects for energy technologies that have been carried out in Europe, the US, and Japan. The early US studies distinguish between experimental and exemplary demonstration projects and analyse why some demonstration projects succeed while others fail. The literature on energy demonstration projects emphasizes that demonstration projects do not only address technological challenges, but also a range of economic and environmental issues. These two strands of literature study demonstration and trial projects that have been carried out in different locations, at different times and for different reasons, and it is therefore difficult to compare outcomes across these studies. However, this article does not aim to compare projects directly but rather seeks to carry out a qualitative review to arrive at a synthesized assessment about the goals, organisational solutions, and learning outcomes of demonstration and trial projects. We therefore believe that these two stands of literature can provide important lessons for both companies and policy makers on how demonstration projects and trials can contribute to the development of a sustainable bioeconomy.

Beside demonstration and trial projects, there are many other approaches and methodologies that have the goal to explore and assess the adequacy of emerging technologies and their market possibilities, such as agent-based modelling, patent studies, cost-benefit analysis, Delphi studies, road mapping, and back casting (for an overview see e.g., [1]). These approaches are primarily desk-top analyses and simulations, whereas demonstration and trial projects specifically comprise “real-world” testing. In addition, life cycle assessments (LCAs) can address complete production chain, from raw materials to final end products, and related inputs of energy and resources and outputs of emissions, focusing on carbon footprint, energy and resource efficiency and other relevant environmental issues. Examples are studies that have performed LCAs of biogas, biorefineries, and bio-based chemistry [2–5]. However, this paper focuses just on demonstration and trial projects. More specifically, this article aims to address three questions that are of particular importance to companies and policy makers:

- (i) What can companies accomplish by engaging in demonstration projects and trials?
- (ii) What determines the success and failure of demonstration projects and trials?
- (iii) How can policy makers affect the outcome of demonstration projects and trials?

The article is organized around the two strands of literature. This enables the reader to see how studies of trial and demonstration projects have emerged as separate strands of research and how these studies have been influenced by context and changed over time. Hence, the article is organized in the following way: Section 2 reviews the first strand of literature on demonstration projects and trials in the US, Section 3 reviews the second strand of literature on demonstration and trial projects for energy technologies, and Section 4 concludes with insights about the role that demonstration projects and trials can play in the development of a sustainable bioeconomy.

2. US Demonstration Projects and Programmes in the 1970s, 1980s, and 1990s

The US experiences with demonstration projects and programmes refer to federal activities for a broad range of technologies, including agriculture, education, housing, environmental protection, health, transportation, and energy [2,3]. According to Magill and Rogers [4], the US Department of Agriculture supported for over 70 years “demonstrations in diffusing agricultural innovations” [4] (p. 24). Both Magill and Rogers [4] and Macey & Brown [2] give reference to work of Baer et al. [3] and Myers’ report on the role of demonstration projects for accelerating the application of new technology [5].

Baer et al. analyse 24 demonstration projects funded by 11 different federal agencies and they state that “a demonstration focuses on market demand, institutional impact, and other non-technological factors, the goal being to provide the basis for well-informed decisions on whether to adopt the technology” [3] (p. 950). Baer et al. distinguish between field trials to

prove a technology and demonstrations, and they reduce demonstrations to a test for the market. They emphasize market failure as the main rationale for government support of demonstration projects. Baer et al. [3] emphasize the following attributes for diffusion success: a strong industrial system for commercialisation, low technological uncertainty, and no tight time constraints.

Myers [5], however, argues that it is necessary to distinguish between two types of demonstration projects: (1) *experimental projects* for “testing the workability of an innovation under operational conditions”, and (2) *exemplary projects* “to demonstrate the utility of the innovation to potential adopters (that is, to diffuse the innovation)” (summarised by [4] (p. 27)). Magill & Rogers emphasize that by mixing these two types of demonstration projects in prior research it was difficult to determine whether a demonstration project can be assessed as successful or not. Projects that are more experimental can by definition not contribute to the diffusion of the technology, but they can contribute quite successfully to the testing of the technology under operational conditions. According to Magill and Rogers [4], Myers [5] highlighted that these two types of projects differ regarding to audience, design and attitudes of demonstration managers.

Clark and Guy [6] understand demonstration projects as examples “where public funding is used to sponsor preparation of a facility showing the capabilities of a technology, and its subsequent demonstration to potential users” [6] (p. 387). They refer as well to the study of Baer et al. [3] and they too do not distinguish between experimental demonstrations and exemplary demonstrations.

Boyd, Borrison and Morris [7] analyse determinants for success of demonstration projects. They distinguish between three dimensions of success: (i) application success; (ii) information success, and (iii) diffusion success, and single out different conditions relevant for the success. The conditions which lead to these dimensions of success are summarised in the following Table 1. Boyd et al. point out that a new technology has different market values in the early high-value market and in the mature market which include lower-value applications. However, they do not mention the importance of market niches at early stages. For them it is essential to assess how the new technology fits into the existing mix of technologies, that means the existing socio-technical regime.

Table 1. Determinants of successful demonstration projects (adapted from [2,7]).

Attribute of Demonstration Project	Application Success	Information Success	Diffusion Success
Technology “tried and tested”	X	X	X
Well-designed experiment focussed on precise objectives	X	X	X
Significant initiative for demonstration from potential users	X	X	X
Significant cost sharing by participants	X	X	X
Significant risk sharing by participants	X	X	X
Demonstration applicable to variety of sites		X	X
All key parties are involved		X	X
Well-defined high potential initial market			X
Conclusive to decision making on economic basis, minimal impediments			X
Supply and support industry in place			X

Macey and Brown [2] keep the distinction between the two types of demonstration projects—experimental and exemplary projects, but they distinguish also between two phases of exemplary demonstration projects. In the phase 1 projects, the main goal is “to communicate information and promote the technology primary to opinion leaders and early adopters”, while the main goal in *phase 2 projects* is “to reach the broader range of adopters . . . : it may be periodically adjusted or adapted to meet differing local demands as its application environment extends” [2] (p. 230). Macey and Brown underline that the success of an exemplary demonstration should not necessarily be measured by the adoption of the technology, but by analysing if the project influenced planning and implementation decisions [2] (p. 229). The three different types of demonstration projects have different roles in the innovation process and their success or failure has to be assessed differently. Macey and Brown highlight following reasons for success or failure of demonstration projects: (1) user

involvement is crucial at all stages of demonstration projects to facilitate information and learning; (2) project design should not be rigid to allow user input and modifications to improve effectiveness; (3) careful planning to take account of market readiness and user participation; (4) dissemination of results and evaluation information should be included in the project design [2] (p. 234).

Government support for demonstration projects can “influence the diffusion of innovations indirectly by indicating to potential adopters the direction of federal policies and priorities” [2] (p. 231). In terms of functions of technological innovation systems this can be captured with the concept “guidance of the search,” one of the main functions of technological innovation systems (i.e., [8,9]).

3. Demonstration Projects for Energy Technologies

Lefevre defines demonstration programmes as attempts “to shorten the time within which a specific technology makes its way from development and prototype to widespread availability and adoption by industrial and commercial users” [10] (p. 483). Lefevre shows that the complexity of demonstration projects is caused by two reasons. First, demonstration projects have to serve different objectives beside technological issues: a “variety of economic and environmental considerations” [10] (p. 484) have to be addressed. He lists stimulation of new industries, further training of installers and maintenance personnel, public acceptance, and involvement of existent industrial manufacturers as non-technical objectives of demonstration projects [10] (p. 485); Second, demonstration projects have to develop a division of administrative responsibilities between governmental or other public agencies and private participants, and conflicting interests have to be addressed and settled. Conflicting interests may occur regarding the dissemination of the results of the demonstration because the private partners have an interest to treat the results as proprietary. Lefevre points out that it is necessary to discuss when it is proper to select demonstration projects as a proper policy tool to accomplish political and technological goals. He highlights following issues as relevant:

1. Allowance for failure: demonstration projects are experiments and should include the possibility to shift back to technical verification in the case of evidence for technical prematurity;
2. Cost and risk acceptance: if the private sector is willing to accept costs and risks this is an indication for near-term or medium-term commercialisation;
3. Trialability: prospective adopters can sample the innovation; in the case of modular innovations this may be easier;
4. Audience identification: should distinguish between technical (engineers, architects, planners etc.) and non-technical audience (residents, general public);
5. Audience predisposition toward innovation: is the intended audience favourable of the innovation or do they have to change their behaviour;
6. Need for inducements beyond demonstration: the future commercial success of a demonstrated innovation may depend on other public policy instruments, such as “purchase commitments, tax exemptions and credits, and other incentives for manufacturers and buyers” [10] (p. 489).

Sagar and Gallagher [11] give an account of primarily US activities in energy technology demonstration and deployment. Regarding demonstration projects, they highlight three roles of such projects helping the demonstrated technologies closer to the market: (1) test a new technology in real-world conditions and gathering technical and economic performance data that can help refine the technology; (2) help in scaling up a technology, which is important for technologies that require much larger scale for testing than usual laboratory tests; and (3) demonstrate the feasibility of the technology for the market and therefore enhance their confidence [11] (p. 3). Sagar and Gallagher provide also a review of prominent energy technology demonstration and deployment programmes. However, regarding the assessment of demonstration programmes, they concentrate on the government budgets for such programmes. In 2006, Gallagher et al. repeat the same argument that demonstration projects “bring technologies closer to the market” in three ways: (1) testing new technologies under almost real-world conditions, including the collection of technical and economic performance data to refine the

technology; (2) scaling-up technologies from the laboratory test stage; and (3) demonstrate feasibility under real-world conditions to manufacturers and potential buyers [12] (p. 203).

3.1. Aims of Demonstration Projects and Trials

Harborne and Hendry define demonstrations and trials as:

“a government-funded programme or project that has specific technological, operational, and social objectives; with an overall budget and duration; which invites bids with a clear specification of goals; evaluates projects against these, requires a formal management structure; and provides ongoing customer/user support from the manufacturer or operator” [13] (p. 3586).

The group around Harborne, Hendry, and Brown [13,14] has explicitly focused on and theorized about the aims of demonstration projects. This group investigates especially the role of demonstration projects for transitions to a low-carbon energy sector, and here especially for complex large-system innovations. They also highlight combatting “market failure” as the main rationale of public demonstration interventions, covering “national security, economic opportunities and societal benefits,” including mitigating climate change [15] (p. 4507). They understand demonstration projects as an “extension of the prototyping process” to overcome uncertainties. These uncertainties, however, include not just technological or market uncertainties.

The group around Harborne, Hendry and Brown has developed a taxonomy for demonstration and trial projects and programmes according to their aims [13] (p. 3588) and [15]:

1. Prove technical feasibility;
2. Reduce building, materials, components, operating and maintenance costs;
3. Prove feasibility in commercial applications;
4. Hybrid projects.

We suggest adding two further categories:

5. Develop public awareness and acceptance;
6. Introduce institutional embedding of the technology and related practices for societal change.

Here we are drawing on insights from studies on technological innovation systems that highlight the need for public acceptance [16] and on insights from the literature on sustainability transitions that underline the importance of institutional embedding. Hoogma et al. identify three aspects of institutional embedding in niche development: (1) embedding includes the development of complementary technologies and the necessary infrastructure; (2) institutional embedding produces widely shared, specific, and credible expectations that are supported by facts and demonstration successes; and (3) embedding ensures the inclusion of a broad array of actors aligned in support of the new technology (networks of producers, users, third parties, esp. government agencies, etc.) [17] (p. 29). Coenen et al. emphasize the need for analysing institutional embedding in the geographical context for explaining “the extent to which and in what ways geographically uneven transition processes are shaped and mediated by institutional structures” [18] (p. 973). In practice, most of the projects and programmes have multiple aims. Therefore, the category “hybrid” will probably dominate.

Hellsmark [16] applies in his thesis the technological innovation system approach with the focus on the different functions of such systems [8,9,19] in his analysis of the role of system builders in realising the potential of second-generation transportation fuels from biomass. Following Karlström and Sandén [20], he identifies demonstration projects as “a particular type of materialisation that is important in the industrialisation of new knowledge fields” [16] (p. 34). The function of materialisation has not been so much explored in analyses of technological innovation systems, but this concept captures “the process of strengthening the development and investment in artefacts such as products,

production plants and physical infrastructure” [16] (p. 33) and in this respect this concept builds on large technical systems of Hughes [21,22].

Hellsmark identifies the following roles of demonstration projects related to the different functions of technological innovation systems: (1) they contribute to the formation of knowledge networks; (2) they reduce technical uncertainties; (3) they facilitate learning that can be instrumental for decisions on technology choice; (4) “they may also raise public awareness of the technology, strengthen its legitimacy and expose system weaknesses such as various institutional barriers” [16] (p. 34), and (5) they may form a starting point for advocacy coalitions. Karlström and Sandén list three types of results of demonstration projects: (1) learning which will be fed back into technical development; (2) open up a market by improved public awareness and scrutinizing institutional barriers, and (3) developing a network of actors [20] (p. 288).

Frishammar et al. review insights on pilot and demonstration projects from three strands of literature: engineering and natural sciences, technology and innovation management, and innovation systems [23]. Building on these insights, Hellsmark et al. address the role of pilot and demonstration plants in technology development, focusing on the processing industry, renewable energy generation in general, and biorefinery technologies in particular [24] (p. 1744). They highlight risk reduction and learning outcomes as the most important outcomes of pilot and demonstration activities [24] (p. 1746).

3.2. Organizational Solutions

The group around Harborne analyses different solutions for organising demonstration and trial projects and programmes [15] (p. 4508f). They identify the following organisational solutions:

1. One-off high profile “demonstrations” and competitions to create public awareness about the potentials of a new technology at an early stage;
2. Coordinated “programmatic demonstrations” to systematically measure, test, evaluate, and characterise technology for a particular application, often comparing different models and technologies;
3. Programmatic “field trials” and tests to improve the performance and reduce costs, in the immediate run-up to commercial roll-out backed by subsidies and incentives, contributing to the development of installation know-how and the establishment of standards; and
4. Permanent testing and demonstration facilities (“test centres”), providing a learning facility and knowledge resource, and supporting manufacturers in many ways, including product certification.

Hellsmark et al. distinguish for the third type of projects between deployment projects, which improve performance and reduce costs, and projects for market introduction of down- and upstream auxiliary technology [24] (p. 1755).

While demonstration projects are considered crucial on a system level for the emergence and diffusion of radical new technology, it remains less clear why and how individual organisations engage with such form of experimentation. On the one hand, they provide valuable stimuli to reduce the inherent uncertainty and risk associated with radical new technologies, while on the other they may help incumbents to innovate and/or imitate to help new technology to commercial breakthrough [14]. The group around Harborne has a focus on manufacturers of renewable energy technology because the manufacturers have experience with technological innovation and participate in a large number of such projects.

This focus “neglects the wider social process of getting ‘buy in’, on which successful innovation depends. While DTs (Demonstration and Trial projects) have at times encouraged collaboration to overcome barriers, policy makers have not systematically built socio-political considerations into programmes. Equally, they were rarely mentioned by companies, although apparent to observers. It remains a neglected issue in designing and managing DTs” [15] (p. 4511). That means that a study of demonstration and trial projects should address also the wider social process, not just the technical aims of the projects and programmes.

Regarding organisational solutions, several themes have been discussed more thoroughly by Hendry et al. [15]: (1) the coordination between technical development and demonstrations and trials; (2) structured steps from technical development via demonstrations and trials to market development; (3) market development before technology advance; (4) learning effects and unintended benefits, and finally (5) capturing and spreading learning. The first two themes address two issues: first, problems related to firms' attempts to use government subsidies for demonstration projects and trial for own R&D activities, which should be finance by them and not be government means. Second, the process from R&D via demonstrations and trials towards commercialisation is not a linear one. This means that demonstration projects and trials will naturally lead to loops back to R&D activities. These processes have to be considered and coordinated. The third theme addresses the maturity of the technology deployed—it is also evolving: we can distinguish between different generations of technology—while the first generation can already be commercialised on the market, a second or third generation undergoes refinements in R&D and demonstration and trial projects. And subsidies for demonstration projects and trials of new generations of technology should not be used for the older generation of technology. In the next section we cover mainly theme (4) and (5) related to learning.

Regarding the second theme, Karlström and Sandén distinguish between demonstration projects in different phases of the formative period of a technology's life-cycle. In the experimental phase, demonstration projects should "be designed to maximise learning and novelty" and a variety of projects should be selected. In the take-off phase, where market growth is the aim, consumer awareness and network formation become important and therefore demonstration projects should support the prove of technological and financial feasibility, outreach activities and institutional embedding [20] (p. 288). This distinction is important when the timing of certain types of demonstration projects is to be considered. Another important feature to be considered is the size of a project (ibid). Some issues cannot be demonstrated on a small scale and require therefore large projects, especially demonstrations of system innovations fall in this category and require often full-scale demonstrations.

3.3. Learning Processes and Outcomes of Demonstration Projects and Trials

The group around Harborne has developed a database of "demonstration projects and field trials in the development of wind power, solar photovoltaics and fuel cells from the 1970s to the present day", interviewed key experts and performed case studies on a number of organisations [15,25] (p. 779). For wind power, there are 148 programmes and projects at 577 sites in Europe, Japan, and the US (ibid) and nine case studies listed, and for solar PV, 92 programmes and projects and 15 case are studies listed [15,26]. The database allows them to analyse (1) the "impact of government strategies" on demonstration and trial programmes and their objectives; (2) "stakeholder involvement and location"; (3) "evolution in design and technology supported by successive programmes", and (4) "stakeholder learning and the effects on manufacturing capability and competitiveness" [13] (p. 3587). Brown and Hendry [26] apply also the concept "dominant design" when analysing the application of solar photovoltaic technology, distinguishing between a fluid phase with a number of competing solutions and the emergence of a dominant design for grid-connected PV and off-grid PV installations. The emergence of new generations of PV technologies will however contribute to a new "S-curve" [26] (p. 2570).

Harborne and Hendry stress the importance of understanding the contribution of demonstration projects for learning processes and the coordination of policy measures in support for the development and deployment of new energy technologies [13] (p. 3581). Tax credits and other demand-pull instruments are not to be categorised as trials or demonstrations, but projects supported by such instruments can also include relevant learning and feedback possibilities. Hendry et al. [15] highlight that demonstration and trial projects should ensure in their budgets performance monitoring, maintenance and trouble-shooting, which are all essential for learning. The group highlights the non-linearity of innovation trajectories and apply a "socio-technical systems approach" [13] (p. 3580) stressing the importance of different modes of learning in different phases of these systems [25].

We can distinguish between learning by searching (mainly R&D to acquire know-why in the form of formalised knowledge), learning by doing (mainly “rules of thumb” and know-how acquired during manufacturing as tacit knowledge), learning by using (mainly know-how acquired in the utilisation of technology and especially important for complex, interdependent systems of products and acquired by the users of a technology), and learning by interacting (mainly necessary for complex innovations direct interaction between users and producers are necessary) [27].

Elaborating further on these types of learning Dannemand Andersen [28] distinguishes between different types of knowledge: concept knowledge, process knowledge, and utilisation knowledge (the term embodied refers to knowledge that is part of an artefact, while disembodied refers to knowledge about how the artefact is manufactured or used). However, Dannemand Andersen defines learning through R&D as learning by doing (see Figure 1), while Kiss and Neij [29] apply the above introduced distinction between learning by searching and learning by doing as Kamp et al. [27]. Kiss and Neij highlight that learning by searching and interactive learning have been facilitated through governmental RD&D [29] (p. 6521). However, they point out that testing and technology certification has supported learning by doing and learning by interacting and they do not address demonstration projects or programmes. “Learning-by-interacting is based on actors’ involvement, interaction and networking, as well as enhanced by mutual interest and change agents” [29] (p. 6522). The concept of experiential learning has been discussed [28,30] in relation to the type of learning taking place while project participants are collaborating on building new technological solutions and refining them as they are used and the importance of communication across functional boundaries for example between designers and producers [31].

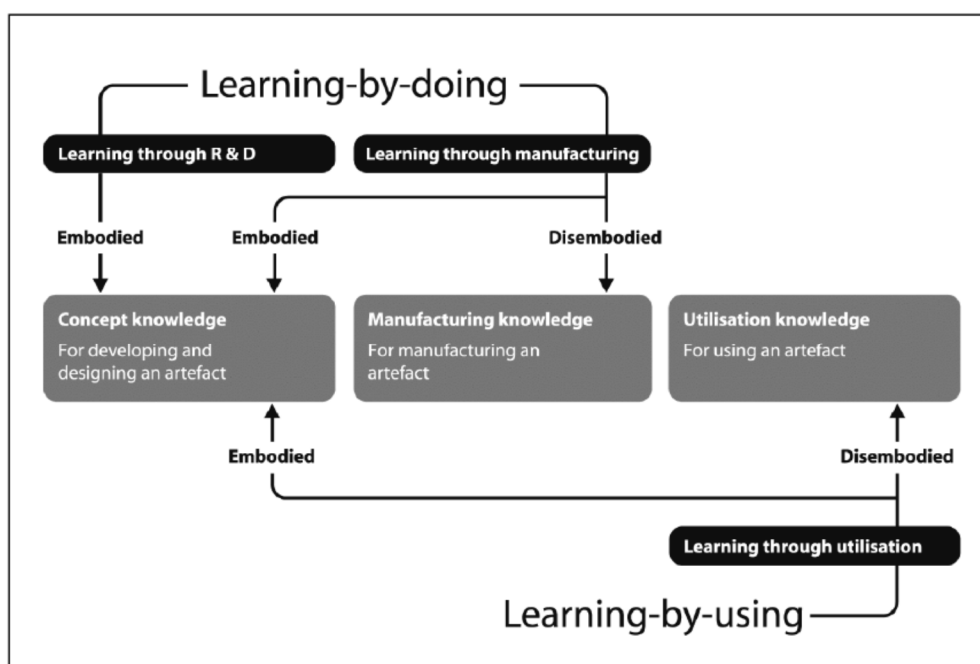


Figure 1. A model for knowledge and learning [28] (p. 41).

The concepts developed by Lundvall and Johnson [32] on the learning economy draw upon on Ryle’s [33] concepts of know-how, know-what etc. These concepts have been developed into a theory of interactive learning which is relevant for all stages of the demonstration project. The further development of these concepts into the STI/DUI (Science, technology and innovation/Doing, using and interacting) model [34] is particularly relevant for understanding the combination of scientific knowledge and practical experience necessary for success in a demonstration project. Some other concepts of learning have been developed by Lorenz and Lundvall [35], which include certain aspects

such as the freedom individuals have to take decisions and solve problems. This might be particularly relevant for understanding the particular learning processes taking place in a demonstration project. However, we cannot find evidence for the science, technology, and innovation (STI) mode dominating totally in demonstration projects and trials in comparison to the doing, using and interacting (DUI) mode [34]. We assume that demonstrations and trials have elements of both modes of innovation: in such projects, new technology has to be used to demonstrate their functioning both for the firms, potential customers, and concerned citizens. And we have interactive processes, since such projects mostly are practiced in an interactive setting, especially if they are institutionally embedded. The STI mode is also prevalent, since the assumptions of the demonstrated technology will be verified or modified due to the exposure to real-world-conditions in the experiments. Such results have to be codified in reports and manuals, standards have to be developed and eventually harmonised in cooperation.

In connection to knowledge and learning, the concept of the “knowledge base” might contribute to a better understanding also of demonstration activities. Asheim and Coenen distinguish between two types of knowledge bases, a synthetic and an analytical knowledge base [36] (p. 1176). A synthetic knowledge base conceptualises innovation processes dominated by “the application of existing knowledge or through new combinations of knowledge” (ibid), while an analytical knowledge base “refers to industrial settings, where scientific knowledge is highly important, and where knowledge creation is often based on cognitive and rational processes, or on formal models” (ibid). Put differently, synthetic knowledge is about designing and constructing something, while analytical knowledge is about understanding and explaining something. Drawing on the concept of knowledge bases, [37] further refine the distinction for the analysis of innovation biographies. Here innovation is conceptualized as a learning process that involves “analysis” and “synthesis”. Analysis refers to the understanding and explanation of features of the (natural) world. “Synthesis” refers to the designing or construction of something in order to attain functional goals [38]. Analysis typically belongs to the realm of natural science, whereas synthesis typically belongs to engineering. However, these concepts are more or less ideal types. In demonstration projects, both knowledge bases often come together since demonstration projects tend to involve not just research collaboration between firms and research organisations, but also interactive learning with customers and suppliers [39]. The integration of both synthetic and analytical knowledge bases become even more evident when adding a spatial dimension to the analysis of demonstration projects [36] (p. 1179f). Harborne, Hendry and Brown [13,14] follow Karlström and Andersson in their distinction of different results of demonstration projects supported by the government: “(i) learning; (ii) opening a market through increasing customer awareness and clarifying institutional barriers; and (iii) forming a network of actors to drive technology and policy change” [14] (p. 169). They highlight that government policy has to take into account the impact of a range of competing technologies and therefore to consider multiple demonstration projects, not just to pick one winner. Their analysis of demonstration projects for fuel cell technology in public busses reveals that (1) these demonstration projects are purely framed as technological and not as social experiments, which explains some of the limited results, and (2) alternative technologies complicate a picking winner strategy and therefore they suggest building socio-technical scenarios to establish a social vision (2007).

Hendry et al. [15] addressed an issue related to who has ownership of the learning outcomes of the demonstration projects and trials. How far the learning has been captured only by a single firm or has been disseminated to others remains a question. Different stakeholders have different interests and can act differently in the diffusion of the results of the projects. An issue is also how larger companies and SMEs (small- and medium-sized enterprises) collaborate in such projects and how the companies retain control of significant intellectual property. Hendry et al. [15] (p. 4517) concluded that it may be easier to enable learning “down the supply chain than in promoting technology exchange between partners.”

Finally, Asveld [40] has emphasized that experimental approaches can also facilitate other types of learning, such as learning about moral and institutions. Moral learning involves gaining an understanding of “values motivating support for technological developments, understandings of those values and consequently the norms by which we evaluate technologies.” Institutional learning involves gaining an understanding of social processes and vested interests that might promote or hamper the development and deployment of a technology.

4. Discussion and Conclusions

In this article, we have reviewed the literature on demonstration projects and trials, which provides us with important insights into how demonstration projects and trials can contribute to the development of a sustainable bioeconomy. In this section, we use these insights to answer the three questions posed in the introduction: (i) What can companies accomplish by engaging in trials and demonstration projects? (ii) What determines the success and failure of trials and demonstration projects? (iii) How can policy makers affect the outcome of trials and demonstration projects? We address these questions by discussing the insights from the literature on the background of the emerging bioeconomy. We believe that these insights are important not only for bioenergy, which has so far been a prominent part of the bioeconomy, but also for biofuels and bio-products, which is expected to become an increasingly important part of the bioeconomy in coming years [41].

4.1. What Can Companies Accomplish by Engaging in Trials and Demonstration Projects?

We have seen that trial and demonstration projects act as “market engagement programmes” that support field tests of new technologies and provide data on their performance in target applications [2,3,11,13–16,20,42]. They are, in this sense, an important instrument for firms to reduce uncertainty and facilitate learning. Nevertheless, we have seen that trial and demonstration projects can vary widely in terms of their objectives. Some trial and demonstration projects focus on reducing technological uncertainty, while others focus on facilitating learning about market acceptance. This is an important issue related to the development of a sustainable bioeconomy. Even though further technological improvements are needed for biorefineries to reach commercial viability [43], there is an even stronger need to support market-creation for the fuels, chemicals, and materials that can be produced [44]. In a case study of the strengths and weaknesses of the innovation system for Swedish biorefinery development, Hellsmark et al. [45] conclude that appropriate policies that explicitly facilitate market adoption and commercialization are weak or altogether lacking. Similarly, Hansen and Coenen [46] suggest that the hesitation of incumbent firms (in paper and pulp) to invest in biorefineries is severely hampered by a lack of knowledge on new bioproducts markets and users. Based on our review, we distinguish between the following aims of demonstration projects and trials, while keeping in mind that most of the projects will have several aims (see Table 2).

Table 2. Goals of demonstration and trial projects.

Goals of Demonstration and Trial Projects
Prove technical feasibility
Contribute to the formation of knowledge networks
Facilitate learning that can be instrumental for decisions on technology choice and can form a starting point for advocacy coalitions
Reduce building, materials, components, operating and maintenance costs
Prove feasibility in commercial applications
Prove environmental feasibility (e.g., through LCA analysis)
Develop public acceptance and awareness
Expose system weaknesses such as various institutional barriers, and
Introduce institutional embedding for societal change

Providing proof for technical and commercial feasibility and establishing knowledge networks have been shown to be important objectives in the biorefinery sector (which exploits different types of biomass such as lignocellulosic feedstock from forestry and agricultural residues, micro-algae, organic household waste etc.) [47]. Understanding public perceptions has been shown to be critical for managing costs of emerging biorefineries [48]. For reducing costs of biorefineries, closed-loop production networks in bioenergy-based industrial symbiosis have been suggested as an appropriate strategy [49]. This requires comprehensive demonstration projects which include coordination of several and interlinked projects, where the side-streams of some actors can be exploited as feedstock by others.

The review shows trial and demonstration projects can reduce risk and facilitate learning in a wide range of areas that should be useful for companies that want to introduce new bio-based fuels, energy, or products. Even though individual pilot and demonstration plants may primarily be geared to specific aims, Hellsmark et al. [50] found that biorefinery technology deployment would require comprehensive activities that cut across all the listed purposes. This poses a challenge to policy-makers with regards to how they should design support for pilot and demonstration plants to ensure systematic progress from technology to market. Still, development activities in pilot and demonstration plants provide key elements to address challenges related to deployment exactly because they focus not only on “pure” technical challenges but also help reduce the organisational-, market-, and institutional risks and uncertainties that actors face in advancing biorefineries.

Finally, it is important to note that non-firm stakeholders may emphasize social and environmental goals related to trial- and demonstration-projects. Policy makers and NGOs might expect a demonstration or trial project to lead to more environmentally sustainable production of specific classes of products and local residents might expect a trial or demonstration project to generate new jobs in their region. These goals might or might not overlap with the goals of the company carrying out the demonstration or trial project and can serve as a basis for cooperation but also as a source of conflict.

4.2. What Determines the Success and Failure of Trials and Demonstration Projects?

We have seen that success can be measured by comparing the objectives of the trial and demonstration projects and the achieved outcomes of these projects. However, intangible learning outcomes [27]—such as strengthened networks between firms, technology providers, authorities, user groups, and other stakeholders [17]—can be as important as successful demonstrations. Moreover, failures can sometimes be the first step towards better solutions [20]. Nevertheless, the literature review revealed following suggestions for managers regarding management of demonstration projects and programmes:

- User involvement is crucial at all stages of demonstration projects to facilitate information and learning. This is particularly challenging in a bioeconomy context as markets are often still to be formed, which makes it difficult to identify relevant users a-priori;
- Project design should not be rigid in order to allow user input and modifications to improve effectiveness and market readiness. As they are dependent on the development of a particular biorefinery technology and its associated products, processes, and services, the aims and activities of a demonstration project may need to co-evolve with changing markets, industries and institutions;
- Considering the required size of the projects, a key barrier for the deployment of biorefineries is the large investments needed to fully test the viability and feasibility of different biorefinery concepts and designs [43];
- Dissemination of results, performance monitoring, trouble shooting, and evaluation information should be included in the project design. Demonstration projects and programmes in an uncertain

and immature field such as biorefineries need to be permissive of failure to improve learning, and they need to acknowledge the high-risks involved in its development and deployment;

- The programme should be clear about the maturity of the technology to be demonstrated, and subsidies for demonstration projects and trials of new generations of technology should not be used for the older generation of technology. Protection to market selection should only be provided to immature technologies: for example, support for further development of first-generation biofuels should not be provided.

Although we do not know if all of these suggestions will be equally important for companies in the bioeconomy, it is reasonable to assume that actors in the bio sectors could avoid some pitfalls if they observe these suggestions.

4.3. How Can Policy Makers Affect the Outcome of Trials and Demonstration Projects?

We have seen especially in the second strand of literature that demonstration and trial projects facilitate the alignment of promising new technologies with societal conditions [15,17]. Such alignment is necessary for the successful development, diffusion and deployment of emerging technologies and hence a transition towards more sustainable societies. Demonstration and trial projects are therefore important not only for companies, but also for policy makers.

Hellsmark and Söderholm [50] emphasize that innovation policies for biorefinery development should be attentive to synergies between concurrent production of biofuels, bio-based chemicals and bio-energy. Moreover, there is a strong need to support (niche) market-creation for fuels, chemicals and materials produced in biorefineries through for example public procurement and various types of price guarantees. Currently, policy support for innovation in the bioeconomy do often not include such demand-side instruments, which are nevertheless of central importance for the commercialisation of new bio-based products [51]. This highlights the importance of alignment between policy support for bioeconomy-related demonstration projects and further downstream activities to support more bio-based products in reaching the market.

To some extent, policy makers have a common interest with companies in the sense that both want the companies' trial and demonstration projects to be successful. Nevertheless, policy makers often have a broader mandate and want learning outcomes gained from one company's trial or demonstration project to be disseminated to other companies throughout the industry. This goal might be in conflict with the goals of the companies that are involved in the trial and demonstration projects and might affect their willingness to participate in such projects. This is an issue that should be addressed systematically in future research. Another issue that that should be addressed in future research is the different types of knowledge that are created and disseminated through trial and demonstration projects. Currently, there is not one theory or concept of learning that covers all the potential learning processes in a demonstration or trial project. More work needs to be done in this area in order to understand how the complex and extensive learning processes occurring in trial and demonstration projects become visible and accessible to participants, stakeholders and competitors.

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