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Toward prospective voluntary agreements: reflections from a hydrogen foresight project

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Abstract

There is substantial interest in promoting the emergence of a hydrogen-based energy economy. If successful, this would represent a policy-led, discontinuous transition away from existing fossil fuel-based systems. Such a move has few precedents and few policy tools exist to manage such a complex and uncertain endeavour. Furthermore, existing hydrocarbon energy systems can be considered Techno-Institutional Complexes (TIC), which have developed through the path dependent co-evolution of physical technologies and social institutions. These complexes have numerous structures that ensure their perpetuation and create important barriers to the implementation of alternatives like hydrogen-based systems. The authors explore the application of prospective voluntary agreements (PVA) as a policy tool/process that can help facilitate a move towards a hydrogen-based economy through foresight and negotiation. From this perspective, we look at the recent case of the Nordic Hydrogen Energy Foresight project for evidence.

Keywords: Carbon lock-in; Environmental voluntary agreement; Foresight; Hydrogen economy; Increasing returns; Path dependence

1. Introduction

The Hydrogen Economy is increasingly seen as a viable alternative to the fossil fuel-based system that currently predominates. It is also hailed as a solution to many environmental problems, especially global climate change. The emergence of a hydrogen-based energy system, however, faces enormous barriers and inertia from the technological lock-in of pre-existing energy systems. This rigid condition can be understood from the perspective of the Techno-Institutional Complex framework, which sees the inertia in large technological systems arising from co-evolutionary interactions among physical infrastructures and the social institutions that build and perpetuate them [1].

Overcoming these barriers will require coordinated actions by both the public and private sectors and will most likely require the creation of a new techno-institutional complex based on hydrogen as the economy's energy carrier. Facilitating such a transition will be highly complex and full of uncertainties and with few policy tools that exist for decision makers wishing to initiate such a complex transition process. We propose an integrative policy tool, the *prospective voluntary agreement* (PVA), as a vehicle that can assist in initiating the transition toward a hydrogen economy.

The PVA [2] combines the virtues of two existing policy approaches: *foresight activities* and *environmental voluntary agreements*. Foresight initiatives create improved understanding of entire innovation systems and common vision for future actions (e.g. [3,4]). Environmental voluntary agreements utilise multi-stakeholder negotiation techniques to arrive at mutually acceptable goals that may generate more efficient results than regulatory actions for the environment [5,6]. PVA

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combines these two approaches to commit key-stakeholders into action to create desirable and even radically different futures [2]. In this paper we apply and elaborate this approach in the context of the Nordic Hydrogen Energy Foresight project (Nordic Foresight) [7]. We posit that PVA can assist decision makers in facilitating the emergence of the H_2 economy through a process that ultimately commits the key-stakeholders to future actions.

2. Initiating techno-institutional change

Policy interest in moving towards a hydrogen-based economy is rising, largely because converting hydrogen into useable energy can be more efficient than fossil fuels and has the virtue of only producing water (H_2O) as the by-product of the process [8]. Hydrogen, however, is not itself a source of energy. Hydrogen must be created from another energy source such as fossil fuels, nuclear or renewables. Several policy-making organisations are actively exploring or investing in the facilitating technologies and networks needed to create hydrogen based infrastructures. One such effort is the Nordic H_2 Energy Foresight undertaken by five Northern European countries.

The introduction of hydrogen technologies, however, faces significant barriers, not the least of which is the existence of a well developed and ubiquitous energy system that already produce services comparable to those offered by the proposed hydrogen infrastructures. These pre-existing energy systems, including electricity generation and distribution as well as liquid fuel systems for transportation have been termed Techno-Institutional Complexes (TIC) [1]. The TIC examples include the large physical technologies and systems as well as the institutional and managerial networks that build and perpetuate them. The social and technological components of the system co-evolve into a highly interdependent complex that resists change. The social actors that are the members of TIC create rules and practices to foster their perpetuation and thus play an important role in creating system stability and barriers to alternatives [1,9,10].

The emergence of large technological systems has been elaborated by several authors [1,9,11] and tested empirically (e.g. [12,13]). The evolutionary process begins when entrepreneurs produce variations of a given technology, which compete in a market place characterised by increasing returns to scale [14,15]. Ultimately a specific variant gains a temporal and performance advantage and emerges from the competition as the dominant design, locking-in key technological architectures [16]. The emergence of a dominant design subsequently leads to an industry shakeout that dramatically reduces the number of producing firms and consolidates the market. The surviving manufacturers organisationally lock-in core technological competencies, distribution networks and customer-supplier relationships, conditioning their future investments in non-dominant design technologies [17,18]. This leads to localised organisational learning and a shift from radical product innovation to incremental process innovation and product refinement [16]. This process has been documented in the emergence of numerous technologies including the automobile, electricity and the personal computer.

Ultimately, if the system becomes socially and economically pervasive, or if there are other justifications such as national security, government may intervene and encourage system expansion through a variety of mechanisms including subsidies, incentives or out right ownership [1]. The impact of government intervention is to override market forces as government policies lead system extension. Frequently legal regimes and governmental ministries are established around the system to facilitate the expansion and governance of the TIC. The ongoing role of these institutions is to create needed stability and predictability in system operation. They also dramatically intensify the barriers to change because of the created interests, which are dependent upon continuation of the present system.

A shift from the current fossil fuel-based energy system to one based on hydrogen will likely follow a similar evolutionary or transitional patterns, but at a more rapid rate [19]. The shift to a hydrogen-based economy would represent a discontinuity with the current fossil fuel-based TIC. This is important because discontinuity changes tend to create greater resistance than continuity-type changes [20]. Continuity changes to technological systems tend to leave the overall system architecture in place and alter only select components or subsystems [10]. Discontinuity changes, on the other hand, seek the replacement of an existing system with an entirely new infrastructure that provides similar services [21]. Continuity change tends to be easier to accomplish because it maintains the primary system attributes and minimises disruption [20]. In contrast, a discontinuous change creates winners and losers, especially among the created interests, and engenders numerous barriers and significant inertia.

Techno-institutional lock-in, therefore, implies that there are systematic forces that make it difficult to change the development path of existing techno-institutional systems. Historically, policy-makers have rarely attempted to make discontinuous changes to existing technological infrastructures. More traditional policy has been of the continuity type, focusing on corrective optimisation of existing systems [22,23]. These corrective policies that seek to minimise pollution from existing technologies can even reinforce lock-in conditions by escalating the commitment to existing systems. Transitions to new systems, on the other hand, are rare and require different actions on the part of policy makers. Instead of corrective optimisation, they need evolutionary policies that foster technological change and the restructuring of industries [13,24]. Promoting this kind of change requires an emphasis on mutual learning among the various actors involved and coordination, presumably through the combined use of regulatory, economic and voluntary policy tools.

Furthermore, authorities can take an active role and facilitate the emergence of new markets for Hydrogen technologies, as in the case of California [25]. New markets can be protected spaces for learning and development of the technology and at the same time influence preferences of potential customers [26]. The literature of innovation systems [27], transition management [28] and strategic niche management [29] emphasise the active facilitative role of government in early market development of new technologies. With similar premises, Könnölä et al. [2] have identified three general policy objectives that can facilitate an escape from conditions of technological lock-in. These include fostering: (i) the diversity of technological options, (ii) common vision for the implementation of technological alternatives, and (iii) changes in the physical and social networks. In the following sections, we elaborate on these objectives within the context of the emerging hydrogen economy.

2.1. Diversity of technological options

As discussed above, *diversity of technological options* is one of the first stages in the evolutionary emergence of a new technology or system. It includes both physical technologies, in the form of technological artefacts and infrastructures, and social technologies in the form of organisational designs and institutions [30]. The development and diffusion of these new options, however, are often hampered by the presence of pre-existing dominant designs that can lock out innovation and investment in alternatives [1]. Given this condition, authorities wishing to change the status quo can use regulatory, economic and voluntary policy tools to encourage stakeholder actions to expand the diversity of technological options. An important goal of this process is to engage in mutual learning about the merits of differing options [24,29]. Due to limitations of bounded rationality and imperfect information, it is impossible to identify ex ante which technologies and organisational responses will be most desirable for society [23]. Thus rapid learning and diffusion of knowledge are important at the early stages.

Hydrogen energy systems must be currently seen as conceptual, and thus, in the predominant design phase. At present there is substantial diversity of options at the artefact scale. For example, there are currently six major competing approaches for fuel cell design (e.g. phosphoric acid, molten carbonate, solid oxide, direct methanol, alkaline and proton exchange membrane) and over 400 organisations sponsoring the different variants of fuel cells globally [31]. The 2004 Worldwide Fuel Cell Industry Survey describes the dynamics of a growing industry; between 2002 and 2003 worldwide sales increased 41% to $338 million and R&D expenditure increased 13% to $859 million [31]. However, for components like fuel cells to be useful they will have to be integrated into a larger energy system that includes hydrogen production, transportation, storage, transformation, generation and end uses. Hence, a mediated evolutionary process will ultimately select a dominant system design [32] and it is possible that governments may choose the technological standards, as in the historic case of nuclear power generation [33].

There is a danger in any government's prematurely selecting a technological winner given the uncertainties. Thus, while enhancing the diversity of technological options is fundamental for adaptive flexibility and evolutionary potential of technological systems [34], the challenge for decision makers is to balance between the exploration of diverse options and ultimately signalling which dominant design will be supported by policy. Along these lines, Adamson [35] has argued the need for a long term binding commitment at the level of the EU Parliament to ensure that the emerging pathway of the hydrogen generation from natural gas does not become locked into a dominant production route. Developing transition roadmaps, or visions for the implementation of the diverse options, is a way to organise the complexity of the evolutionary process.

2.2. Visions for implementation

Many technologies become commercially established without government intervention. The personal computer, for example, was commercialised almost entirely by private companies.[1] It is therefore possible that hydrogen energy technologies can be commercialised without government interventions. If the only element of the dominant design were the fuel cell, and not the large associated infrastructure and systems, then the competitive forces, however imperfect, would play the decisive role in the outcome. However, a hydrogen economy is composed of conjoint technological complements, which are public–private collaborations that require coordination on a very large scale. The financial estimates for building the infrastructure vary, but are in the trillions of dollar, which is well beyond the capacity of most private companies. The apparent scale and cost of the undertaking will require multiple producers of complimentary assets that will have to be coordinated through a wide array of standards [36].

Given this situation, a likely scenario is that governments will play a key role if hydrogen systems are to become a reality. Governments can make numerous justifications for this intervention (Table 1). Just as governments played a catalytic role in the creation of the Internet, automobile transportation, telecommunications, electricity and other systems, public officials and authorities will likely play an essential part in building a hydrogen economy [37]. It is clear, however, that governments cannot do it alone and will need the special knowledge and resources of the private sector. This has become known as "civic markets" whereby public and private sectors act together to solve mutual problems with collaborative solutions [38].

In addition, financial institutions—both private and public—will also need to be engaged to supply the capital needed to finance the development and construction of viable systems. Ultimately end users will have to be drawn in as well and convinced to adopt the new technologies. Coordinating the participation of these various actors is extremely difficult and unlikely to be successful using only command and control approaches [23]. An alternative is the creation of a common vision, or series of visions, that participants can identify with.

[1] The computer itself, however, was developed dominantly through governmental initiatives.

Table 1
Government justifications for intervention in the emergence of hydrogen systems (Authors' own elaboration)

National and economic security. Energy infrastructure is vital to economic function. Energy is fundamental to national security.
Environmental concerns. Climate change and other environmental issues obviously play a constraining role. These are external to most private, profit maximising decisions.
Infrastructure cost and risk spreading. The cost estimates are varying, but the general perception is that the cost will be high. No matter what, corporations and banks have said they can't do it alone. Most past systems of this scale have required some government intervention.
Public safety. Hydrogen has a chequered past. Public safety issues will bring government into management. For example, regulating safety played a key role in legitimising the automobile in the US.
Natural monopoly/resource coordination. No reason to build multiple parallel systems. Natural monopoly arguments that worked in the past for other systems will apply. Codes and Standards setting processes are the probable way that governments and municipalities will interact in the hydrogen economy system.
Lock-in of pre-existing energy systems. The existing energy TIC can be seen as locking out investment and innovation in hydrogen technologies. Governments can make public, good arguments to engage in hydrogen system development.

While shared visions can coordinate actions of autonomous but interdependent actors, then emergence of such implementation plans can be impeded by the inertia of the pre-existing dominant TIC. In fact, giving preference to the existing actors in today's energy systems may hinder progress towards shared implementation visions for a hydrogen economy [10]. New, discontinuous technologies are rarely commercialised by manufactures of existing dominant designs. These manufacturers are more likely to engage in rent seeking and lobbying to protect their existing franchises and business networks than foster change that makes their current systems obsolete [1,9]. While they should not be ignored, the limitations of engaging the producers of current dominant designs in productive vision creation need to be recognised and considered.

By initiating processes for creating the shared systemic understanding of techno-institutional co-evolution, authorities and stakeholders can begin to formulate pathways to alternative technology arrangements. Clark and Morris [39] document such a process in California for creating the tariffs applied to intermittent power (wind and solar) when public and private stakeholders collaborated for over 10 months to create a new shared policy and mechanism. In turn, Eames and McDowall [40] discuss the development of six alternative visions about H_2 energy systems building on the multi-criteria evaluations of different stakeholder groups with relation to the UK Sustainable Hydrogen Energy Consortium [41].

A vision building process entails the creation of future oriented scenarios that clarify the new technologies and their new systemic interconnections as well as the new institutional arrangements needed to facilitate their implementation [9,27]. These visions can then guide the physical and organisational changes needed to escape a lock-in condition and facilitate any discontinuous change. Here the policy tools that have been successful include *foresight activities*, which have been employed to improve the understanding of an entire innovation system and create common vision for future actions (e.g. [3,4]).

2.3. Changes in physical and social networks

Ultimately, the move toward the H_2 economy will require the restructuring of industrial boundaries and the creation of new technological infrastructures [42]. Only through change in existing physical and social networks can the vision of a hydrogen economy be attained. Therefore, converting visions of alternative pathways into policy for implementation requires a redefinition of stakeholder roles and institutional structures, as well as actual changes in the physical systems. Such changes can be induced by many actors, including policy-makers and other non-profit or non-government organisations along with profit making stakeholders who shape institutional context through their strategic actions of creating and claiming value [43]. Authorities may initiate and facilitate processes that encourage corporate initiatives that break traditional industry boundaries, engage actors from outside the TIC that provide new alternatives and motivations, which form new coalitions with different value networks to develop and implement different H_2 infrastructures. Within high uncertainty of future technological solutions and markets, viable pilot demonstrations can concretise different technological H_2 visions [44].

In this context, authorities may initiate policy actions to facilitate change to existing networks. Again, given historical precedent, it is risky for governments to "pick technological winners". Instead, governments are often more successful when they foster competition among differing coalitions and learn from the outcomes of the competition [45]. Also for the hydrogen economy, it makes sense for public officials to encourage coalitions with different visions on H_2 technologies to compete for market share. Policy actions such as regulations, construction or acquisition specs, procurement requirements etc. may spur the emergence of such competing viable coalitions by supporting simultaneously the development of their widely different architectures, configurations, features and standards [46]. A policy approach that can foster these type of actions are *environmental voluntary agreements*, which have been successful in committing industry to desired action by building on incentives and collaboration, without ruling out regulatory actions in case of non-compliance [5,6,47].

Obviously, implementation of change towards the hydrogen economy systems will not occur within a vacuum, but will be subject to the inertial forces of existing fossil fuel based energy systems. As previously discussed, collaborative action can also be used to enforce the TIC on existing energy systems [48] and inhibiting change. Inertia within the TIC creates lock-in to present institutions that hinder the development and diffusion of alternative technological solutions. Swedish tax legislation, for example, has been biased against the production of electricity in combined heat and power generation plants, largely because of the lobbying of nuclear and hydropower companies [9]. In parallel, the diffusion of wind turbines both in Sweden and in The Netherlands faces institutional obstacles in the application of permits for location for wind turbines [9]. Such institutional obstacles create further challenges in the early phases of the H_2 concept development and must be considered ex ante by decision makers.

3. Prospective voluntary agreements and a H_2 foresight

Policy makers wishing to foster a transition to hydrogen-based energy systems face unusually high uncertainties in addition to the barriers created by the lock-in or well-entrenched pre-existing energy system. As mentioned, there are few demonstrated policy tools that deal with this level of complexity and challenge. However, it has been noted elsewhere that environmental voluntary agreements and foresight activities are promising tools that may help advance the hydrogen related policy in such circumstances [19].

Furthermore, we have argued [2] that combining these two approaches can prove valuable in achieving the needed coordinated action. Such integration allows authorities to use the threat of potential regulatory actions as well as innovation-oriented economic incentives to connect stakeholders in a mutually beneficial learning and ultimately commitment to action. Such a combined policy tool enables the creation of an open forum for stakeholder learning and the fostering of systemic understanding of present and future options. It can also provide a common platform for key stakeholders to negotiate an agreement leading to action for escaping lock-in. Thus, we call this integrated new policy tool a *prospective voluntary agreement* (PVA), which can be defined as follows [2]:

> *''When confronted by high complexity and uncertainty on the technological and institutional advances related to desired discontinuity changes, authorities may broadly engage stakeholders in systematic, future-oriented intelligence gathering and a medium-to-long-term vision-building process. This process is aimed at creating an agreement between contracting parties, in particular between authorities and industry, to facilitate collaborative action towards the creation of (i) a diversity of technological options, and (ii) a vision for the implementation of technological alternatives, that facilitates (iii) desired changes in the physical and social networks. The outcome will ultimately define long-term targets, responsibilities, monitoring, rules and possible sanctions in case of non-compliance.''*

PVA is an ideal public-private mechanism that could be useful in the case of a hydrogen energy transition, where high complexity and uncertainty on the technological and institutional advances necessitate learning and enhanced stakeholder coordination for implementation. Environmental voluntary agreements have already proved useful in similarly uncertain and complex situations, especially to anticipate the enforcement of European Union directives or national regulations [5]. Environmental voluntary agreements, however, can be limited and often facilitate the optimisation of environmental and economic performance within present production systems. In contrast, a PVA process focuses on the implementation of alternative technology arrangements, which cover a broader and more encompassing range of technologies.

Elsewhere [2], we discuss the different dimensions of PVA in light of the experiences from the negotiated agreement on the French end-of-life vehicles. Here we suggest the use of the PVA approach in the context of the Nordic H_2 Energy Foresight efforts conducted between the years 2003 and 2005 [7]. From the viewpoint of PVA, this project is particularly interesting, as it deals with the facilitation of the systemic transformation from present energy systems toward the H_2 energy economy. The exercise was a collaborative effort between the Ministries of five Nordic countries including Denmark, Finland, Iceland, Norway and Sweden along with extensive and numerous research, industry and government stakeholders. It was a pilot foresight exercise at Nordic level with a total budget of 730,000 euros, co-funded by the Nordic Innovation Centre, Nordic Energy Research programme and 16 Nordic partner organisations [49]. Fundamentally, it was designed to provide decision support for defining Nordic R&D priorities and making effective framework policies for the introduction of H_2 energy in Nordic countries. The main steps of the project included a series of pre-structured interactive scenario, vision, roadmap and action workshops (in more detail, see Table 2), which were supported by extensive preparatory work including systems analysis and modelling of alternative H_2 systems [7].

This process shared much with the archetypal PVA process. The effort was anticipative and was designed to create future markets and new institutional arrangements in a national or regional level. The process built on stakeholder learning and facilitation methods used in foresight activities [4] in order to avoid the premature definition of issues typical to negotiated agreements. Nordic foresight was also an iterative process building on cycles of learning between project partners and external experts. Thus, in this context, Nordic foresight could be seen as a partial PVA process providing also a basis for initiating negotiations and obtaining agreement among Nordic ministries and other key stakeholders.

In PVA, the iterative process cycles that focus on mutual learning through PVA prepares contracting parties for agreement negotiations. The goal is to initiate an institutional transition process that leads to new institutional and technological arrangements. Such changes often require active mediation between stakeholders and authorities. In the negotiations of an agreement, the coordinators move from facilitation to mediation, helping key stakeholders to identify and compare decision alternatives in order to work out an agreement. Correspondingly, Nordic foresight was managed and facilitated by a team of specialists in energy systems and technology foresight. Thus, the different phases of Nordic foresight probably contributed to the strategic intelligence [27] of knowledge in the Nordic region by providing support for companies, research institutes and governments to define their R&D strategies and policies.

Ultimately, the Nordic foresight process lacked an important element of the PVA, which is a final negotiated voluntary agreement. While the PVA process includes the participation of a diverse set of interested public and private stakeholders, the ultimate agreement is only contracted between authorities and specific stakeholders crucial for the implementation and

Table 2
Main phases of the Nordic Hydrogen Energy Foresight, the series of pre-structured workshops [7]

The Scenario Workshop. Experts considered the hydrogen society and its external conditions that cannot be affected by a hydrogen technology policy but are likely to affect introduction of H_2 Energy in the Nordic energy system. The scenario workshop produced three scenario sketches for Nordic H_2 energy introduction.
The Vision Workshop. Experts discussed hydrogen technology visions in the Nordic context focusing on the issues that can be affected by Nordic actors. The views were collected with the help of a questionnaire on the vision list developed in a brainstorming session.
The Roadmap Workshop. Experts outlined the sequence of implementation and mutual interdependence of the hydrogen technology visions from today and until 2030 including barriers, needs and drivers for realising the visions in relation to the implications on science and education and government policies.
The Action Workshop. Experts discussed the actions needed to overcome barriers and to realise the Nordic hydrogen energy visions and roadmaps focusing on three important areas of development: (i) hydrogen production and distribution, (ii) hydrogen use in transport, and (iii) stationary use of hydrogen. In addition, generic cross-cutting issues and conditions and possibilities of utilising new business opportunities were discussed.

diffusion of new technology(s) such as hydrogen. Only after creative formulation of various alternative technological pathways can the process be directed towards focused negotiations for an agreement between key stakeholders.

The Nordic foresight efforts might have provided sufficient basis for negotiations and final agreement among key partners to support the development of H_2 energy systems. Indeed, in line with the triple-helix framework [50,51], the coordinators invited participants equally from industry, research organisations and the public sector in the project consortium and the organised workshops. The project workshops resulted in preliminary recommendations, which were further elaborated by the small expert group. Among different issues on H_2 R&D activities, the recommendations stressed the importance of cooperation and coordination between ministries and other stakeholders to build up the conditions of an adequate institutional and physical infrastructure for the emergence of the H_2 economy [7].

Hence, such recommendations could be further used for initiating negotiations on a possible PVA between Nordic ministries and key stakeholders. Based upon this, there were some important issues in the Nordic foresight process that could have inhibited the creation of a final PVA. Despite continuous efforts to engage policy makers, it proved difficult to ensure their full engagement in the process [49]. Furthermore, most of the participants were known advocates of the H_2 economy [49], which may have caused a lack of relevant diversity among the participants in view of initiating negotiations for a public-private agreement.

4. Discussion

In this paper, we looked for policy tools to support the emergence of hydrogen economy. In this context, we elaborated on evolutionary policy objectives and looked at the recent Nordic Hydrogen Energy Foresight exercise from the viewpoint of prospective voluntary agreements (PVA). This foresight exercise may have contributed to the policy objective of fostering the diversity of technological options especially through the development of alternative H_2 technology roadmaps that supported participants to align their R&D activities. Common vision-building for the implementation of technological alternatives, in turn, emerged through the action workshop and quantitative modelling that reduced uncertainties such as the impacts of discount rates, technology efficiencies, fuel prices and energy policies.

Changes in the physical and social networks were aimed at particularly in the elaboration of policy recommendations. These efforts were, however, limited by the low participation level of policy-makers. Despite these conditions, the initiation of PVA negotiations building on the foresight process and compiled common policy recommendations is worth further efforts. In such a process, the coordinators would have a key role to engage in active communication in particular with the Nordic ministries to initiate the processes in which they would actively pursue negotiations on long-term targets, responsibilities, monitoring, rules and possible sanctions. Such an agreement would then contribute to the overarching institutional framework for the implementation of the recommendations envisioned in the Nordic foresight exercise, something similar to that which was achieved through the German policy packages in the support of wind turbine technologies [9] and California's tariff rules for intermittent power [39].

In view of fostering participation of policy-makers in similar kinds of future activities, the general framework of TIC may help policy-makers identify their role(s) in terms of coordination of technological change and facilitation of mutual learning among stakeholders. This contrasts with the traditional emphasis on forecasting and correction of market failures with the optimisation oriented policy actions [22,23]. In this context, PVA can be considered a systemic instrument [27] that improves understanding of the co-evolution of techno-institutional systems and, thereby, also helps synchronise environmental and innovation policy fields. Encouraged by the above reflections on Nordic foresight, we recommend the creation of further research on PVA with application to other technology fields.

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