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Is cluster policy useful for the energy sector? Assessing self-declared hydrogen clusters in the Netherlands

Pieter Mans, Floortje Alkemade, Tessa van der Valk*, Marko P. Hekkert

Department of Innovation and Environmental Sciences, Copernicus Institute for Sustainable Development and Innovation, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, The Netherlands

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Abstract

Research on science-based industries has shown that it is important for organisations to be active in interorganisational networks. Cluster policy has been developed as a means to stimulate the development of these networks and thereby the success rate of these industries. Cluster policy is however not a common policy instrument in the energy sector. In this paper, we focus on three self-declared clusters active in hydrogen-related R&D in the Netherlands and address several characteristics of these clusters. We conclude that cluster policy is a useful addition to existing energy R&D policies but that monitoring whether self-declared clusters actually function as clusters and what their contribution is to the overall system is pivotal in reaping the benefits of cluster policy.

Keywords: Cluster policy; Hydrogen R&D system; Self-declared clusters

1. Introduction

The R&D stage of innovative energy technologies that differ radically from today's incumbent technologies can be characterised by high uncertainties. Uncertainties are related to the technology itself, e.g. uncertainties about future performance, the future market size and the political support for the new technology (Meijer et al., 2007). One way to deal with these uncertainties is to be well embedded in an R&D network or cluster. Clusters can be defined as hybrid institutions at the border between public and private realms, based on voluntary associations (Raines, 2002).

The specific attention for the establishment of clusters of activity is inherently driven by the characteristics of science-based industries. Owing to the speed of technological change, it is impossible for individual organisations operating in a science-based industry to possess all capabilities and resources required for research and development activities in-house. This results in a certain distribution of competences and resources across actors that are active in an industry (Meyer-Krahmer and Schmoch, 1998; Pyka and Saviotti, 2001). This distribution of competences and resources makes it imperative for organisations to search for partners, in order to make use of those assets of these partners that are complementary to their own (Pfeffer and Salancik, 1978; Miotti and Sachwald, 2003). In view of this, the formation of networks of collaborative activities in new science-based industries is considered to be pivotal in the survival and growth of these industries (Powell et al., 1996).

Based on the arguments given above, organising R&D activities by means of cluster formation is expected to generate performance advantages. Cluster policy is not yet a common energy policy instrument, but is a well-known instrument in innovation policy. In recent years, network or cluster formation has been propagated in the Netherlands as a policy tool to improve the performance of complex R&D systems (Roelandt and Den Hertog, 1999; Den Hertog et al., 2001). Cluster policies focus on facilitating the emergence of networks and creating the institutional settings that provide incentives for market-induced cluster formation (Smits and Kuhlmann, 2004).

*Corresponding author. Tel.: +31 302531625.
E-mail address: t.vandervalk@geo.uu.nl (T. van der Valk).

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Hydrogen is seen by many as the fuel of the future. However, transformation to a hydrogen-based energy system requires major changes in the energy system. Major technological breakthroughs are necessary before the hydrogen economy becomes a reality (Dixon, 2005; Hisschemöller et al., 2006; Lattin and Utgikar, 2007; McDowall and Eames, 2006; Murray et al., 2007). Therefore, many nations and also the European Union spend substantial resources on hydrogen technology development. The hydrogen R&D system is complex, consisting of many organisations each with their specific competences concerning complex technologies such as fuel cells, hydrogen storage and alternative hydrogen production technologies. The performance of the R&D system depends on the functioning and interactions of each of these organisations. Therefore, this R&D system has the right characteristics for which network or cluster formation and therefore cluster policy may be beneficial, thereby stimulating the technological innovation necessary to reach the hydrogen economy.

The popularity of the cluster concept in innovation policy may make groups of organisations inclined to declare themselves to be clusters. In the Dutch hydrogen R&D system, this thought is confirmed by the fact that three groups of companies and institutes have declared themselves to be hydrogen clusters. However, the performance benefits ascribed to operating within a cluster are based on certain characteristics of clusters described in literature, which enable knowledge sharing and exchange among the members of a cluster. In order to reap the performance benefits ascribed to clusters, such 'self-declared clusters' must therefore also actually exhibit these characteristics of clusters. Furthermore, as multiple clusters and other individual actors jointly constitute the hydrogen-based energy system, the specific contribution of each of these clusters or actors is of importance to the performance of the overall system. These two issues are pivotal in formulating effective cluster policy, and in assessing whether the clusters actually advance the transition towards a hydrogen economy.

In this article, three self-declared clusters active in hydrogen R&D are examined. The aim of this article is twofold. First of all, we determine whether self-declared clusters active in the hydrogen R&D in the Netherlands actually function as clusters according to properties ascribed to clusters in literature, focussing on properties deriving from geographical concentration and network structure definitions. Subsequently, a further characterisation of the activities conducted in these clusters is made to gain insight into the contribution of these clusters to the overall hydrogen innovation system. Our central research questions are therefore: *Are self-declared clusters focussing on hydrogen R&D actually clusters according to properties generally ascribed to clusters?* And: *What do these self-declared clusters contribute to the hydrogen R&D system?* By answering this question, this paper aims to contribute to the development of effective cluster policy in the energy sector. Our empirical data consist of all publicly announced hydrogen cooperation projects in the period 2000–2005 in the Netherlands.

In the next section, we will describe the cluster notions and possible properties of clusters that are used in this paper and give an outline of the methodology used for the analysis of the self-declared clusters. An overview of the data used and a short description of the Dutch hydrogen innovation system is given in Section 4. Network analysis data and results are then presented in Section 5 and finally the conclusions and discussion are given in Section 6.

2. Determining whether self-declared clusters are actually clusters

Within the Dutch hydrogen R&D system three self-declared clusters exist. In order to assess the potential effectiveness of cluster policy in improving the performance of the R&D system, we first study whether these self-declared clusters actually exhibit cluster properties. In doing so, we focus on two properties that are often used in the literature: (1) geographical concentration (regional cluster identification) and (2) the density of links within the cluster as compared with the entire hydrogen R&D system. Regional cluster identification starts from geographically concentrated actors with shared unique institutional properties (Marshall's (1890/1920) interpretation), who form a sort of 'idiographic' combination (Dirven et al., 1993). Porter's 'diamond of national advantage' (Porter, 1990) is also based on this principle, although Porter places more emphasis on industrial organisation rather than institutional properties (Feser and Bergman, 2000). The method used to analyse such regional clusters within the hydrogen R&D system is described below.

2.1. Analysis of self-declared clusters: location quotient analysis

A frequently used identification method for regional clusters is the calculation of concentration ratios or location quotients (LQs) (Miller et al., 1991; OECD, 1999; Morgan, 2004; Holland et al., 2004). The LQ is calculated using the following formula:

$$LQ_a = \frac{N_a A}{N_{total}}, \quad (1)$$

where LQ_a is the LQ in region a, N_a is the number of actors in region a, A is the number of regions present in the nation and N_{total} is the total number of actors present in the nation. A $LQ > 1$ indicates an over-representation of actors in that region relative to the nation's average.

In order to define the active loci in hydrogen technology development, the regions must be predefined. In this paper, we apply the so-called COROP division to define the borders of the regional clusters. The Netherlands is divided in 40 COROP areas. Each area is economically bound and has specific institutional properties often unique for that area. The COROP classification is based on the principle that every COROP region contains a central core (e.g. a city) and is surrounded by a supported area. This supported area has economic ties with the centre core. A COROP region does not cross the borders of a province (CBS, 2005). These properties make this division suitable for regional cluster calculations. For every COROP region, we calculate the LQ for hydrogen R&D actors. Although various values can be found in the literature, a $LQ > 1.25$ is frequently used as evidence for 'regional specialisation' (Bergman and Feser, 1999). Following this convention, we use a $LQ > 1.25$ to indicate regional clusters or 'hydrogen hot spots'. This method allows us to assess whether the self-declared clusters are actual hydrogen hot spots.

2.2. Analysis of self-declared clusters: graph structure analysis

The second method we apply to examine the cluster properties of the three self-declared hydrogen clusters stems from graph theory and allows for the assessment of social cohesiveness of the clusters independent from their physical proximity. For high-tech sectors, it is assumed that sometimes physical proximity is of less importance. The growth of international cooperation signals a decrease in the importance of geographical proximity in interorganisational collaboration, especially in high-technology sectors (Hagedoorn, 2002). This tendency may indicate the emergence of so-called 'global technological systems' (Bartholomew, 1997), in which especially regional proximity may have become less relevant.

Social network analyses enable us to determine subgroups based on interaction (interorganisational collaboration in our case) between actors. Subgroups within these connected networks can be calculated in different ways. One of the calculations that fits the idea of clusters is the calculation of so-called lambda sets (Borgatti et al., 1990). A group of actors is a lambda set if each member of the group has a higher *connectivity* with all other members of that group than with actors outside the group. *Connectivity* is defined here as the extent to which two actors stay connected when linkages are removed from the network. The lambda value represents the number of paths, i.e. direct and indirect connections, between two actors and is therefore a measure for the cohesiveness of them. Because more cohesion means more possible knowledge transfer, the value is also used as an indication for the knowledge transferred between two actors. As lambda sets are about paths connecting actors in a network, these actors do not necessarily need to be adjacent in this network to be part of the same lambda set. Theoretically, there is no maximum length of this path (Wasserman and Faust, 1994).

Within a lambda set, connections between actors must be valued binary. In our case, interaction is based on cooperation of actors in projects. Here, we assume that a connection between two actors is present when these actors cooperate in at least two projects. Consequently, actors cooperating in only one or no projects at all are considered to be unconnected. This allows us to separate groups formed by stable network relations (more than 1 relation) from groups formed around just one project (1 relation). A core of stable relations is seen as a precondition for a cluster.

The two methods described above allow us to assess the extent to which the self-declared clusters actually function as clusters based on geographical proximity and joint projects. In the next section, we describe the methodology used to determine the specific contribution of these clusters to the hydrogen R&D system, by addressing properties of these clusters that are of importance to the functioning of the system.

3. Analysing the contribution of self-declared clusters to the system

Measuring the performance of R&D systems that are still in the early stages of development such as the Dutch hydrogen R&D system is very difficult. The length and size of the hydrogen transition makes the (preferred) outcomes of the R&D phase unpredictable. The value of R&D outcomes not only depends on the hard-to-predict usability of the separate technologies; it is also subjected to the architecture of the complete system and the unpredictable needs of future generations. In addition, this entire transition to a hydrogen-based energy system takes place in a global environment in which large economic and political powers are involved. Therefore, strategic decision-making should not be directed at specific technologies, but should consider two basic conditions: creation of technological variety and progress to market (Rotmans et al., 2000). Variety is needed within the system as a flexibility strategy to deal with the many technological and market uncertainties (Frenken et al., 2004). Progress to market represents the process in which technological knowledge is transformed into usable products. This may initially be in the form of prototypes and later in commercial products. Progress to market is a good indicator for measuring the applicability of basic research. Where basic R&D primarily leads to learning by searching, the introduction of prototypes to niche markets makes feedback from potential users possible and therefore leads to learning by doing. Both forms of learning are necessary in an R&D system (Sagar and Van der Zwaan, 2006). Therefore, in this paper the outcomes of the R&D system will be valued by the variety of technologies and the distance to market (DTM).

As one can imagine, spreading the research capacity over more technological options will slow down the overall progress. Focussing on only one or a few technological options would accelerate the technological development, but the chance of a wrong bet on the technology of the future would increase. The point is that the two conditions for the predevelopment phase in the transition (variation and DTM) are potentially conflicting. This problem is also known as the exploration versus exploitation paradox (Nooteboom, 2000).

Overall, within the hydrogen innovation system sufficient variety and decrease of the DTM are necessary to improve its future performance. The extent to which this is the case depends on the focus of the activities conducted by different organisations belonging to this system, as well as by groups of these organisations claiming to be a cluster. Where variety is concerned, an actual cluster is more likely to be specialised in one technological option, rather than exhibiting large variety in its own activities. In this way, individual clusters make a clearly definable contribution to the overall R&D system. The accumulation of activities of clusters and individual organisations that are part of the system determine its eventual variety. To further characterise the contribution of the clusters to the overall hydrogen R&D system we also determine the DTM of their projects.

Below a description of the methodology used to measure variety and DTM is given.

3.1. Contributions made by self-declared clusters: variety and DTM

The variety and progress of the technology is calculated from the activities conducted in the projects. The variety is measured by entropy calculations with the following formula (Theil, 1967; Frenken et al., 1999, 2004):

$$H = -\sum_{i=1}^{m} p_i \ln p_i, \qquad (2)$$

where the entropy H, is an indication for the variety of technological options, p_i is the share of activities of technological option i. The entropy has a minimum value of $H=0$, when only 1 technological option is developed. The maximum entropy is valued $\ln m$. Calculations are performed for the overall hydrogen R&D system of the Netherlands and for the technology developed within the clusters. These 'cluster technologies' are defined by technological developments within projects where all or at least two actors are a member of the cluster.

The progress made by the clusters and the R&D system as a whole, is defined in terms of DTM. This distance is measured by calculating the average progress made within the individual projects. The activities within the projects are classified into five categories: Basic research, applied research, strategy/feasibility, demonstration and commercialisation. The activities are valued 4–0, respectively. This means a 4 is given for basic research because the activity is far from being commercialised. An activity is valued 0 when it is labelled as a commercial activity. A project can contain more than one of these activities. Finally, all the categorical activities are added and divided by the total number of activities resulting in a measure for the average DTM. When this value is measured over time, a trend in terms of progress becomes clear.

4. An overview of the Dutch hydrogen innovation system: the data

The three self-declared clusters that are the subject of this research are Biohydrogen (BioH2), Energy Valley (EV) and Hydrogen Network Enterprise (H2NE). These clusters are very different with respect to shape and content, but their self-declaration as 'cluster', 'platform' or 'network' qualifies them as a self-declared cluster. BioH2 has an international programme that came into existence in 2002. It is directed at hydrogen production from biomass and waste streams. EV is a public–private-based cooperation in the North Netherlands directed at the stimulation of energy activities in that area. EV does thus not specifically aim at hydrogen technology; nevertheless, it is active in several hydrogen projects. Formally, EV was founded in February 2004, but it has been operational since the beginning of 2003 (Energy Valley, 2004). H2NE is an industrial cluster located in Arnhem directed at the commercialisation of knowledge related to hydrogen technology. H2NE was founded recently in the second half of 2005. Each of the clusters consists of a variety of members, an overview of which is given in Table 1.

Table 1 illustrates that the clusters differ greatly with respect to the characteristics of the cluster members. EV is dominated by local and national governmental actors, the H2NE cluster consist of members from industry, and universities and other research institutes are the main actors within the BioH2 network.

The database constructed for this research contains all hydrogen-related projects on which information was publicly available and in which at least one Dutch actor was involved. The projects were carried out (partly) between 2000 and 2005. The so-called 'snowball' method was used to collect the projects. As a starting point for our data collection we used the database of the Dutch national government and the different framework programme databases of the European Union.[1] Additionally, a scan of Dutch newspaper articles related to hydrogen was used to verify and complete the database. Confidential projects are thus not present in our database.

The database contains 250 Dutch actors who participated in 166 projects that were (partly) conducted between 2000 and 2005. Fig. 1 shows the cumulative number of projects that were performed in the Netherlands per quarter of a year between 2000 and 2005. The graph was compiled by adding all the projects that are carried out in each quarter. If a project ran from January to December 2001, the project is divided over four quarters in which 25% of the project is performed.

[1]The national databases are solely based on subsides provided by the Dutch Organisation for Scientific Research (NWO) and Senternovem. The popular national WBSO subsidy has not been used because of confidentiality rules. The projects subsidised by the EU are all part of the 5th and 6th Framework Program (FP5 and FP 6).

Table 1
Overview of members of self-declared clusters

	Energy Valley	H2NE	BioH2
Universities	Groningen University (RuG)		University of Amsterdam (UvA) Delft University of Technology (TUDelft) Groningen University (RuG) Wageningen Univeristy (WuR) Radboud University (RUN)
Research institutes			TNO ATO ECN
Industry		Adjuvant Hexion Nedstack	LeAf
Energy companies	NAM Gasunie		
Government local	Assen Emmen Groningen Leeuwarden		
Government provincial	Drenthe Friesland Groningen		
Government national	Ministry of Economic Affairs		Novem
Government European			
Other	N.V. NOM	NWV (Dutch hydrogen society)	

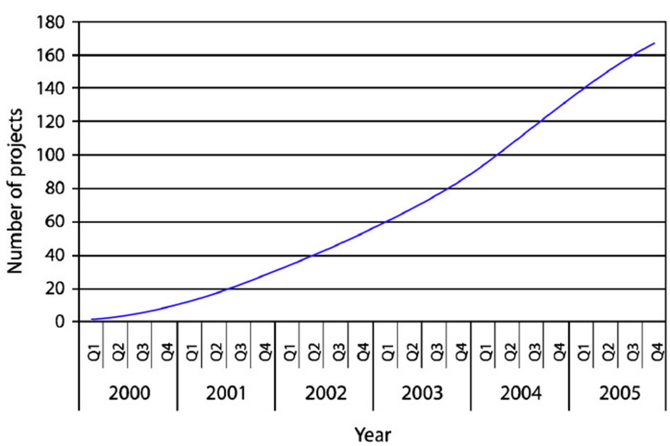

Fig. 1. Cumulative number of projects performed in the Netherlands between 2000 and 2005.

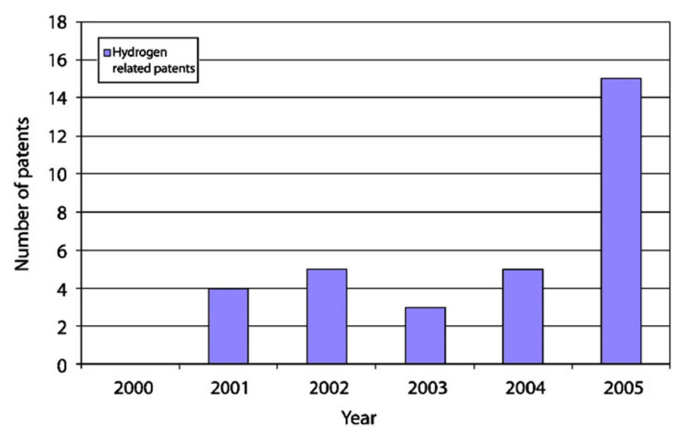

Fig. 2. Number of hydrogen technology-related patents granted in the period 2000–2005.

In Fig. 1, it can be seen that the number of projects carried out increased during the period under investigation. This increase continues until the end of 2004, after which the line flattens off.

When we consider the actors that are involved in hydrogen research, the Energy Research Centre of the Netherlands (ECN) is by far the most prominent player in the Netherlands. ECN participates in 36 projects, compared with 22 projects for the second most prominent player, TNO MEP[2] (Dutch Organisation for Applied-Scientific Research; unit focusing on environment and energy issues). Other actors involved in R&D mainly consist of universities, (semi)public research institutes as well as a few large companies. Besides technological research, a large part of the actors involved are facilitating or consultancy companies dealing with business strategy and project management.

Fig. 2 shows the number of hydrogen-related patents that were granted during the period 2000–2005. Note that the number of patents is much smaller than the number of

[2]Since January 2005, TNO has a new organisational shape. Five areas in different fields of expertise replaced the 15 existing institutes. TNO MEP is now divided among several of these new areas. Because this change occurred in the final year of our evaluation and agreements made that earlier contracts were not affected, we kept the former organisational shape intact for our analysis.

projects, a clear indication that the hydrogen innovation system is still in a very early development stage. The increase in patents in 2005 might be an indication that the system is moving towards a more market-oriented stage, which is also consistent with the flattening off of the number of publicly announced projects.

Another important aspect of the R&D field is the participation of Dutch actors in international projects. In total, 18 projects of our database are financed by the European Union. Although this is a minority of the 166 projects, these 18 projects are all quite large in terms of budget. Contact with foreign actors is also thought to have a large influence on the variety and quality of the technological developments in the Netherlands. This is not only because of the large budgets available, but also because of knowledge transfer. In our social network analysis, only participants located in the Netherlands are accounted for and relations with foreign actors will not be taken into account, as these actors are not members of the self-declared clusters studied here.

5. Results: cluster properties

In this section, we present the results of our analyses. We start with showing the results on the geographical concentration of cluster members, followed by an assessment of their extent of social cohesiveness. Subsequently, the results on the specific contributions made by the different self-declared clusters to the overall system of hydrogen-based energy development are given.

5.1. Cluster properties: LQ

The LQs for the different COROP regions are given in Fig. 3. Remember that the LQ is a measure for regional proximity within the self-declared clusters.

Of the 40 COROP regions in the Netherlands 31 include actors who were involved in one of the 166 hydrogen projects. Two-third of all actors are situated in only seven out of 40 COROP regions. 11 COROP regions have a LQ higher than 1.25. These 11 regional clusters are marked as 'hydrogen hot spots'. Fig. 4 shows these 'hydrogen hot spots' in the Netherlands.

Generally, the 'hydrogen hot spots' have an obvious motivation for being involved in hydrogen research. Rotterdam for example has a large chemical industry located at its port, which produces hydrogen as a by-product (COROP 29; LQ = 3.35). Furthermore, the headquarters of several large players are located in Amsterdam (COROP 23 with a LQ of 4.53) and universities and

Fig. 4. COROP regions with LQ > 1.25 in the Netherlands. (*Note*: Derived from CBS map 'Indeling van Nederland in 40 COROP-gebieden' (CBS, 2005)).

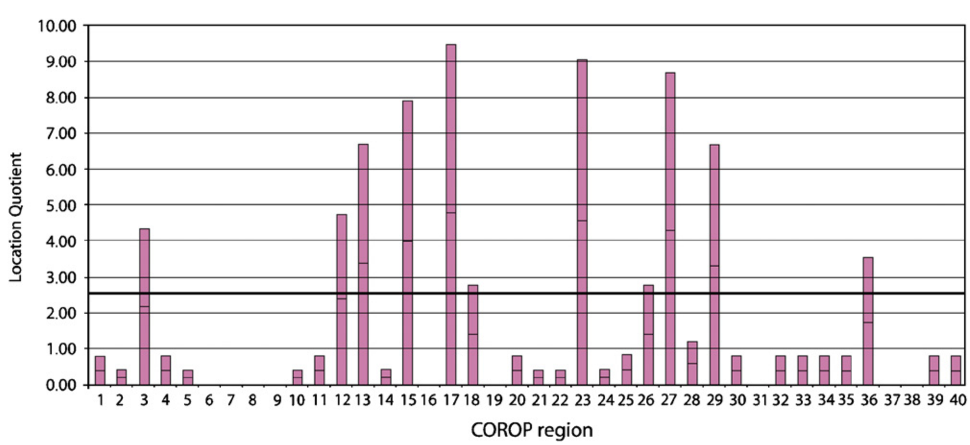

Fig. 3. Location quotient for each COROP area.

research institutes in other areas (COROP regions 12, 17,18, 27 and 36) are reasons for clustering of hydrogen-related activities. One exception is the Arnhem/Nijmegen area (COROP 15 with a LQ of 3.96) where there seems to be no specific institutional reason for the development of a 'hydrogen hot spot'. The region is home to the members of the H2NE complex, one of the self-declared clusters. Looking at the other two self-declared clusters, EV is concentrated in regions 1–7, where most members are situated in region 3 (LQ = 2.18). Biohydrogen is mostly concentrated in COROP region 13 (LQ = 3.37), where three out of 10 members are situated. However, the other members of this cluster are spread throughout the country in such way that no real region can be appointed.

The first observation we can make from the LQ calculations is the large number of 'hydrogen hot spots' compared with the number self-declared clusters. Most of the active regions apparently do not have an officially organised network or platform although they are geographically grouped together. The structure of the R&D field already showed that most actors are existing institutes that were established in a certain region before they started developing hydrogen technology. This means that actors did not choose this location on grounds specifically related to hydrogen development.

The second observation is that the three COROP regions with the highest concentration of business are not connected to any of the self-declared clusters. Although the clusters are to some extent connected to a 'hydrogen hot spot', the related hot spots do not have the highest LQ scores.

Finally, only two of the self-declared clusters are clearly connected to a certain region. The industrial cluster H2NE is concentrated in only one COROP region and the public–private-based EV covers six adjacent COROP regions with a concentration in region 3, Groningen. The science-based BioH2 is the least regionally bound, with only a relatively small core in region 13 (Wageningen) and the other members spread across the country.

To summarise we thus observe that the self-declared clusters cannot be defined by geographical proximity alone. Although two of the clusters coincide with hydrogen hot spots, these hot spots do not have exceptionally high LQ scores. This observation could be an illustration of the high-tech nature of the self-declared clusters, which decreases the influence of geographical proximity effects. We now continue to test whether the self-declared clusters exhibit other cluster properties.

5.2. Cluster properties: graph structure analysis

In this section, we present the results of the lambda calculations for the hydrogen network. As discussed in Section 2, the lambda value represents the number of (indirect) connections between two actors and is therefore a measure for their cohesiveness. Because more cohesion means more possible knowledge transfer, the value is also used as an indication for the knowledge transferred between two actors. Our aim is to analyse whether the actors that participate in the self-declared clusters participate in more joint projects than non-cluster actors, where increasing lambda values illustrate increasing cooperation between actors.

First of all, Fig. 5 shows the entire network in which several members of the self-declared clusters, especially of BioH2, are visible. In this figure, we can already see the central position that ECN has in the field and also TNO MEP, and ATO are well connected. These research institutes thus seem to fulfil hub-like functions within the network of cooperation. Furthermore, we observe that

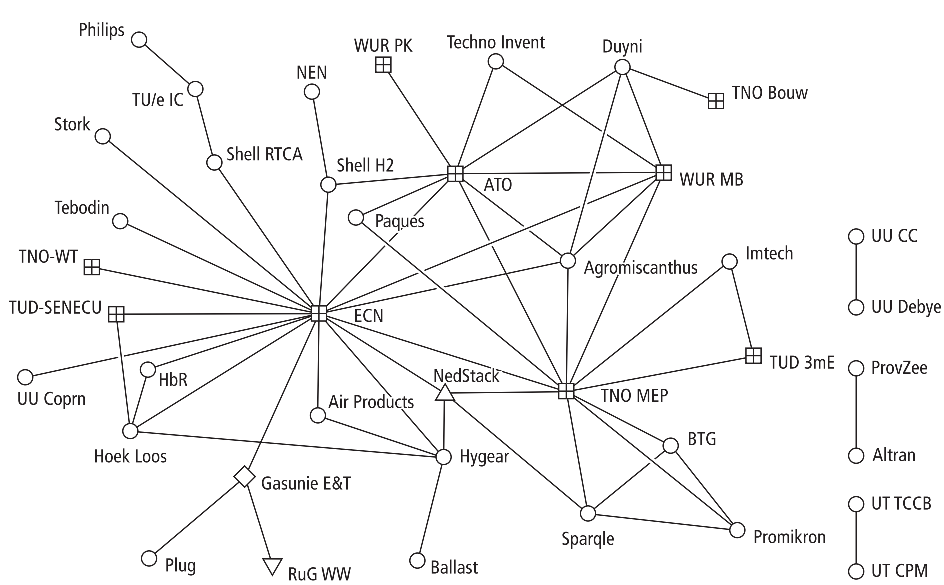

Fig. 5. Network of hydrogen collaboration projects. Diamond = member Energy Valley; up triangle = member H2NE; box = member BioH2; down triangle: member Energy Valley and BioH2; circle: not a cluster member.

these hubs are mostly BioH2 actors and that few actors of the other self-declared clusters are part of the network of stable relations (i.e. participate in two or more projects).

Fig. 6 shows the network of interorganisational co-operation that remains when employing a lambda value of three. This graph thus only includes organisations that have a minimum of three paths connecting them. As can be seen in Fig. 6, the remaining lambda set consists of one member of H2NE, several members of BioH2 and several other organisations that are not members of the self-declared clusters.

Once the lambda value is raised to five, and thus only organisations connected by at least five paths are included in the network, only four BioH2 and one organisation that is not a cluster member remain (see Fig. 7). As is shown in Fig. 8, at a Lambda value of 6, the network consists solely of four members of the BioH2 cluster.

Overall, when we consider the network for higher lambda values (Figs. 6–8) we see that the BioH2 cluster is the only self-declared cluster that is confirmed as a cluster when analysed with respect to social cohesiveness. Interesting to note is that collaboration is not necessarily restricted to cluster members as signified by the presence of non-cluster member Agromiscanthus at lambda value 5.

To summarise, the analyses above demonstrate that the self-declared cluster members do not distinguish themselves from other actors within the hydrogen network with respect to regional proximity. Furthermore, only the BioH2 cluster exhibits the property that there is more cooperation with cluster members than with non-cluster members, thus being established as a cluster in that sense. In the next section, we will analyse the contribution made by these self-declared clusters to the overall system.

5.3. *The contribution of clusters to the overall system: variety and DTM*

The variety of the R&D within each cluster is measured by entropy calculations as explained in Section 3. Fig. 9 shows these entropy calculations for each of the clusters as well as for the overall R&D system.

The entropy calculations are based on the distribution of projects between the four subsystems (production, distribution, storage and conversion). The maximum entropy is therefore $\ln(4) \approx 1.39$. The overall R&D system and eventually also EV have a variety close to this theoretical maximum. This means that within the EV cluster projects with respect to each of the four subsystems are conducted. Biohydrogen, on the other hand, is specialised in one part of the energy chain, production. Hence, it has low variety values in terms the overall energy-chain development. H2NE has overall entropy values of zero. This means that in none of the periods between 2000 and 2005 development in two or more different subsystems was conducted.

To further specify the contribution of a cluster the average DTM of the R&D projects performed within the cluster is determined. Fig. 10 presents this average DTM results for the overall system as well as for the activities

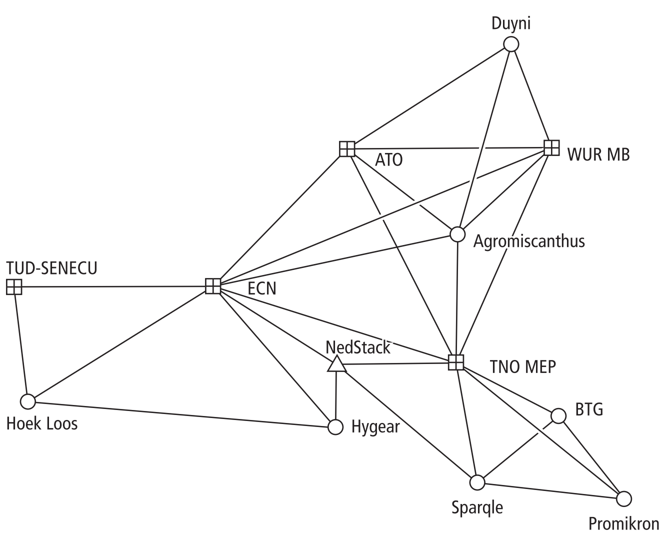

Fig. 6. Network of lambda value = 3. Square = member Energy Valley; up triangle = member H2NE; box = member BioH2; circle: not a member of a self-declared cluster.

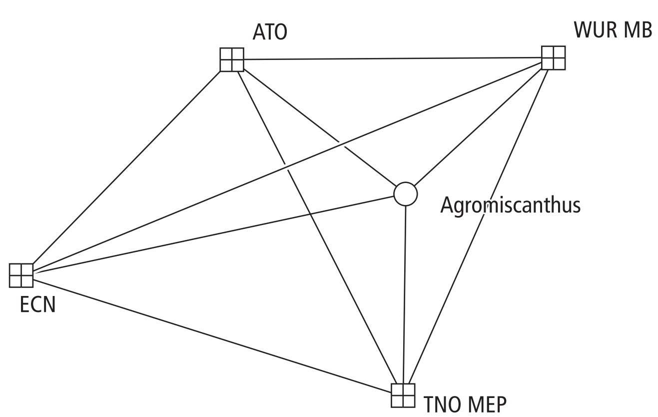

Fig. 7. Network of lambda value = 5. Square = member Energy Valley; up triangle = member H2NE; box = member BioH2; circle: not a cluster member.

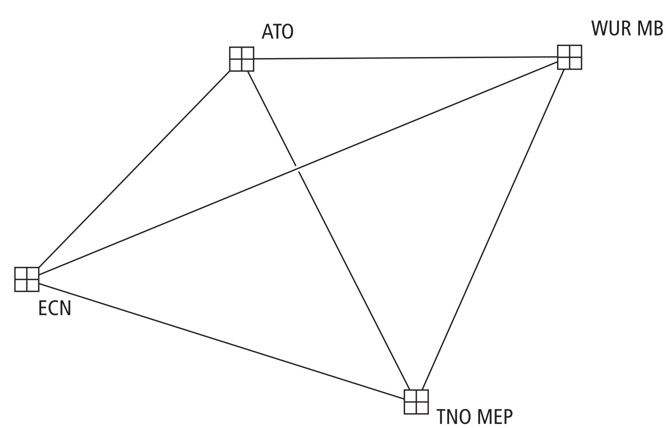

Fig. 8. Network of lambda value = 6. Square = member Energy Valley; up triangle = member H2NE; box = member BioH2; circle: not a cluster member.

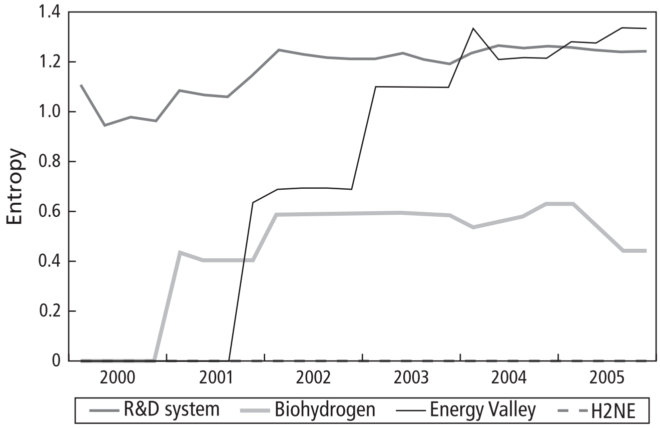

Fig. 9. Entropy dynamics for the overall R&D system, Energy Valley, biohydrogen and H2NE.

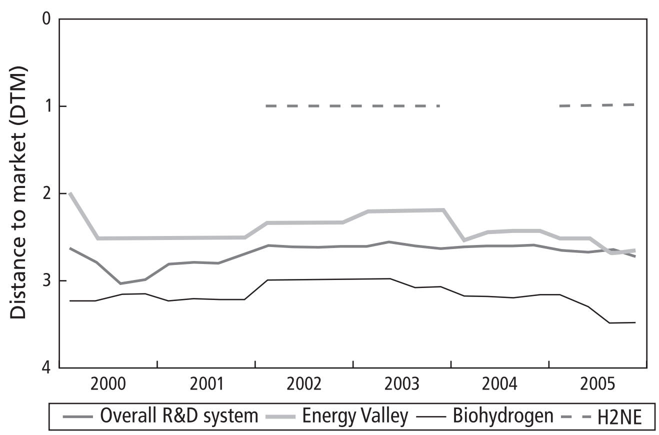

Fig. 10. Average DTM for the overall R&D system and of cluster BioH2, Energy Valley and H2NE.

that took place in each of the clusters. As described in Section 3, DTM is measured on a five-point scale (basic research, applied research, strategy/feasibility, demonstration and commercialisation). An average distance to market of 0 indicates that all project concern commercially available products whereas an average distance to market of 4 indicates that the projects consist of basic research only.

When we consider Fig. 10, we note that the EV cluster projects have relatively small DTM values compared to the overall R&D system, hence a shorter DTM. Cluster BioH2 has a slightly larger DTM than the overall system. Finally, although there were only two projects performed within H2NE they show a very short DTM.

Based on these two measures we can say that H2NE is a typical, specialised cluster, exhibiting low variety and short-DTM. This specialisation is consistent with the low variety in cluster partners (all industry). The other two clusters have more variety and a larger DTM. EV has the highest variety while BioH2 has the largest DTM.

6. Discussion and conclusions

Returning to the research questions addressed in this paper, namely: Are self-declared clusters focussing on hydrogen R&D actually clusters according to properties generally ascribed to clusters? And: What do these self-declared clusters contribute to the hydrogen R&D system? Table 2 provides an overview of the results obtained on the various measures applied here.

First of all, the extent to which the different self-declared clusters actually exhibit cluster properties is of importance. While H2NE and EV are indeed somewhat regionally bounded, they do not stand out from other hydrogen hot spots. Also, the members of these two clusters were not found to cooperate more within the cluster than with organisations that are not cluster members. The third self-declared cluster studied here, BioH2, was found to be not regionally bounded, but it is the only self-declared cluster that is confirmed when looking at the level of cooperation among cluster members. A possible explanation for these findings may be that the high-technology character of the hydrogen field precludes geographic proximity effects from occurring (see also Miotti and Sachwald, 2003). Location does not seem to matter much for cooperation. In evaluating cluster policies, this geographical concentration should thus play a minor role, and social cohesiveness should be focussed on, especially in high-technology sectors. Overall, when taking formal cluster properties as a benchmark, only the BioH2 cluster stands out as an R&D cluster. The other two call themselves a cluster but do not exhibit formal cluster properties. With regard to their social cohesiveness, these two self-declared clusters seem to suffer from 'weak network failure' (Klein Wolthuis et al., 2005, p. 612) i.e. a lack of inter-organisational relationships potentially reducing the performance of the self-declared cluster.

Now, how can the contribution of these clusters to the overall hydrogen-based energy system be characterised? The relatively low entropy value of BioH2 indicates a high level of specialisation of research and development efforts within this cluster. Its high DTM-value is likely to be related to the characteristics of the members of this cluster: most members are either universities or research institutes,

Table 2
Overview of the properties of the self-declared clusters

Cluster property	BioH2	Energy Valley	H2NE
Geographical concentration	None	Some	Some
Social cohesiveness	Substantial	None	None
Contribution to the system			
Variety (entropy)	Some	Substantial	None
DTM	Father than average	Closer than average	Much closer than average

which are types of organisations that generally focus on conducting basic research. BioH2 is thus a relatively specialised cluster consisting mainly of universities and research institutes, focussed on conducting basic research.

In the case of EV, there is a large variety in activities conducted. The DTM of these activities is somewhat shorter than average. As was already discussed above, the level of geographic concentration and social cohesiveness of the EV cluster does not justify its declaration of being a cluster. Also, from the results obtained on our entropy measure, this group of organisations does not have a clear focus and therefore does not make a clearly definable contribution to the overall system. The usefulness of directing cluster policies at such a group of organisations is therefore highly questionable.

With regard to H2NE, it needs to be noted that this cluster was only established in the second-half of 2005, and therefore has exhibited only little activity so far. Over time, it will be able to assess how this cluster has developed.

In this study, we have shown that two of the self-declared clusters have a specific focus within the hydrogen R&D field. BioH2 focuses on fundamental research on a number of technological alternatives while H2NE focuses on the development of products that are almost ready to be marketed. This clear division of labour makes it easier for policy makers to gain insight into who conducts which R&D activities and to create a process of change when necessary. Instead of dealing with a large number of individual organisations, the attention can be directed to a smaller number of clusters.

So from this study, we draw the preliminary conclusion that cluster policy might be a very interesting add on to existing energy policy practices. But in this study, it was shown that not all self-declared clusters actually exhibited cluster properties and make a clearly discernable contribution to the overall system of innovation. Just labelling a cluster is not expected to be enough to reap the benefits ascribed to clusters. For policymakers, this suggests that cluster policies as such might not be sufficient to reach policy goals. The policy needs to include incentives for the cluster partners to actually function as a cluster. A first step would be for the government to monitor whether the cluster actually functions as a cluster and create incentives for the cluster members to do so. In this respect, the extent of collaboration between cluster members should be focussed on in high-technology sectors. A lack of inter-organisational relationships reduces the level of coordination among these organisations and thereby hampers innovation (Klein Woolthuis et al., 2005). Stimulating cooperation can be done by anticipating on initiatives arising in the market, and subsequently facilitating these initiatives by assuming the role of broker in the exchange of knowledge (Larosse et al., 2000). This leads to the recommendation that self-declared clusters should invest in their functioning as a cluster in terms of joint projects. This recommendation might be particularly valuable for the newly established H2NE cluster.

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