Innovative regions and industrial clusters within hydrogen and fuel cell technologies

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Abstract
Regional governments in Europe seem to play an increasing role in the hydrogen and fuel cell (H2FC) development. A number of regions support demonstration projects and build networks among regional stakeholders in order to strengthen the region’s engagement in H2FC technologies. In this article we analyse regions that are highly engaged in H2FC activities based on three indicators: existing hydrogen infrastructure and production sites, general innovativeness, and the presence of industrial clusters with relevance for H2FC. We find that regions with a high activity in H2FC also are generally innovative regions. Moreover, the article points out certain industrial clusters that favours some regions’ conditions for taking part in the H2FC development. However, existing hydrogen infrastructure seems to play a minor role for region’s engagement. The article concludes that an overall well-functioning regional innovation system is important in the formative phase of an H2FC innovation system, but that further research is needed before qualified policy implications can be drawn.

Keywords: Clusters, Regions, Hydrogen,
1 Introduction

Innovation in energy technologies is high on the political agenda in Europe not only for reasons of energy and climate policy, but also to help increase the EU’s overall competitiveness (the “Lisbon Agenda”) through initiatives such as the Competitiveness and Innovation Framework Programme (CIP). In this connection competitiveness not only refers to minimizing firms’ expenditures to energy but also (and maybe in particular) to industry’s ability to innovate and stay competitive within new and sustainable energy technologies.

The regional level seems to have an increasing importance in providing good political and socio-economic framework conditions for innovation. Asheim and Gertler (2005) have emphasized that a regional level of governance of economic processes, between the national level and the level of clusters and firms, is important in supporting the institutional settings that can promote innovation. In a study of a global economy’s impact on innovation policy Lundvall and Borrás (1999) find that ‘The region is increasingly the level at which innovation is produced through regional networks of innovators, local clusters and the cross-fertilising effects of research institutions’. This trend seems to be confirmed by studies and actions at the hydrogen and fuel cell (H2FC) area in Europe, where the regional level has been recognised as a significant driver on the pathway to a hydrogen economy. Examples on this are the work done in recent years to get the local and regional authorities represented in the Joint Technology Initiative and the Hydrogen and Fuel Cell Platform which has culminated in the constitution of the Regions and Municipalities Partnership on Hydrogen and Fuel Cells (HyRaMP) in April 2008.

The Internet provides numerous examples of regions (remote islands, cities, municipalities, federal states, etc.) that declare themselves as hydrogen communities (Mans et al., 2008). Furthermore, regional authorities have in many cases developed fully fletched strategy plans.
and allocated significant public financing in achieving the goals of such strategies. Just two examples representing both small and large communities are:

- The Western Isles Hydrogen Community Plans: Creating a Pathway to the Hydrogen Economy (concerning the Outer Hebrides, a part of the UK)
- Fuel Cell and Hydrogen Network in North Rhine-Westphalia (Concerning a federal state in Germany)

The European project Roads2Hycom has analysed 96 potential hydrogen communities based on a call for Registration of Interest (Shaw and Mazzucchelli 2007). Their analysis shows that government or regional/local authorities are involved in nearly 80% of the registrated projects. This makes regional authorities the most important actor ahead of SMEs and large corporations. Regional authorities’ engagement is typically guided by energy and environmental policy concerns but also by industrial or political-economical policy concerns - especially stimulating new industrial clusters based on these new technologies. As regional authorities actively are involved in stimulating H2FC technologies and related industrial clusters a range of questions arise. Hence, the research questions for this article are:

- Do geography and cluster aspects matter in establishing a European hydrogen energy technology innovation system?
- Are there any geographical relationship between regions with a high level of H2FC activities and
  - existing hydrogen infrastructure and hydrogen production sites?
  - generally innovative regions in Europe? And
  - existing industrial clusters in Europe?

2 Innovation systems and industrial clusters

The process of innovation is often complex and uncertain and technological innovation is not solely a matter of technology, manufacturers and markets. Policy makers, analysts and inno-
vators also have to address the wider framework or environment in which companies operate, and in which new innovations and technologies emerge. The concept of innovation systems takes this broad view of the process of innovation. An innovation system can be defined as the “elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge” (Lundvall, 1992). The elements are various types of actors forming the system: Manufactures, suppliers, consultancy companies, public authorities, policy makers, universities, research institutes, trade associations, consumers etc. Relationships take shape as informal or formal networks such as project activities or buyer-supplier relationships. These relationships link actors in interactive learning processes. For instance, the relationship between actors involved in a demonstration project builds on exchange of knowledge and know-how. The interaction is influenced by the institutional set-up in which it takes place. The institutional set-up is laws and rules shaped by policies that regulate the interaction between actors. It also includes norms and codes of practice, which typically depends on cultural differences.

When analysing regional policy measures for promoting hydrogen communities two theoretical branches of innovation system studies are available. First, the analytical focus can be set on the technology or the emerging industrial sector and innovation theorists then talk about technology-specific innovation systems – TIS (Jacobsson & Bergek 2004, Hekkert et al. 2006, Carlson & Stankiewicz 1991) or sectoral innovation systems – SIS (Breschi & Malerba 1997, Malerba 2002). Second the analytical focus can be set on the geographical entity of the community and innovation theorists then talk about regional innovation systems - RIS (Cooke, 2001; Asheim & Gertler, 2004; Asheim & Gertler, 2005). These two theoretical approaches are parallel to two distinguished but often related policy fields, respectively Research and Development policy and Regional Development policy. The technology specific approach is more concerned about directing R&D initiatives at an overall level. Its focus is on analysing barriers and possibilities in the technological development.
The regional innovation system approach is to a larger extent interested in directing regional innovation policy. This approach takes a more holistic view on a region’s production structure. In the regional approach the administrative borders of a region defines what to include in the analysis depending on which industries are located in the region. The focus is partly on strengthening the regional innovation system’s ability to innovate and partly on improving the ability to benefit from external links. The two approaches TIS and RIS can therefore be seen as relevant for two different political levels, respectively national (or supra-national) and regional level.

2.1 Regional innovation systems and clusters

Focus in analyses of regional innovation systems (RIS) is on the “institutional infrastructure supporting innovation within the production structure of a region” (Asheim & Gertler, 2005). RIS emphasizes the importance of a regional level of governance of economic processes between the national level and the level of clusters and firms.

The RIS approach focuses particularly on localised learning and intra- and interregional knowledge flows. As in the other branches of innovation system studies, learning is viewed as a social interactive process building on trust (Lundvall 1992, Cooke 2002). But in the RIS, geographical proximity is often seen as a vital facilitator of innovation processes, because of the tacit character of knowledge. In RIS studies geographical proximity is thought of as one out of more factors influencing innovation processes positively. Other factors are 1) specialised suppliers with a specific technology or knowledge-base, 2) regional culture such as norms, values, routines and expectations (Asheim and Gertler 2005), and 3) a certain degree of social cohesion to avoid polarisation in a region (Lundvall and Borras 1999).

The approach of RIS is tightly affiliated with the concept of industrial clusters but the two concepts should not be conflated. Clusters should be seen as more sector specific than RIS (Asheim and Coenen 2004). The latter can in principle stretch across several sectors because
it includes the entire production structure within a region. In consequence regional innovation systems may consist of several clusters with relevance for H2FC development.

Porter (2000) defines a cluster as a “Geographic concentration of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (for example universities, standard agencies, and trade associations) in particular fields that compete but also co-operate”.

Two matters are important to notice in Porter’s definition of a cluster. The first is the notion of geographical concentration. Physical proximity is seen as extremely important for the innovation process because it eases the sharing of tacit knowledge. Another important matter in the definition of a cluster is how companies are interconnected. In a cluster, companies, suppliers and service providers compete and cooperate both horizontally and vertically in the value chain. In fact the interaction between companies and the physical proximity is two sides of the same coin. They are mutually related and that is what creates the spill-over in form of a specialized workforce, specialized regional suppliers, information, and training facilities. And that is considered to increase the productivity with which companies can compete, nationally and globally.

Although, some studies find that for high-tech sectors physical proximity is of less importance (Mans et al. 2008). In some high-tech sectors external relationships to companies located worldwide can be of just as great importance – or maybe greater – as relationships to companies located in their own region. In relation to H2FC technology this should not be neglected and it might suggest that regions in formulating their policy strategies pay a special attention to how these ties can be strengthened as well.

From a regional policy perspective the most commonly used policy instrument in promoting clusters has been to support network activities (Sölvell et al.2003). Within the H2FC area
this has often been in form of Public Private Partnerships (PPP). Other policy objectives have been to promote innovation through RD&D (research, development and demonstration) funding, create a special brand for the region, attract new firms and talent to the region, provide assistance to businesses, diffuse technology within the cluster, study and analyse the cluster and its needs, etc.

In the H2FC area industrial clusters in Porter’s version do not exist yet. And it seems uncertain if it is an appropriate strategy to start creating H2FC clusters from scratch. Instead the most reasonable way for regions to promote the creation of H2FC clusters seem to be support of other (relevant) clusters in the direction of a stronger uptake of H2FC technologies. In this way a region will be able to build their H2FC engagement upon competences and strengths already present in the region.

However, in order to create the right conditions to fulfil the vision of a hydrogen economy the cluster approach seems to be too partial to stand alone. Its focus on segregated single clusters seems to be inadequate to address the system character of a future hydrogen based energy system. Furthermore, directing policy towards a single cluster is in jeopardy of favouring certain technology options (“picking the winner”). Hence, regional innovation policy needs to create framework conditions for H2FC innovation that are broader based than the single cluster focus. To this purpose a broader analytical perspective, such as the regional innovation system approach, might be appropriate.

The RIS approach provides greater insight into strengths and competences at the regional level. As an analytical tool it can reveal functions of the system that need support in order to improve the overall innovation environment in the region.
3 Data for innovation studies

Following the recent decades’ interest in innovation studies and policy analyses solid statistical data has been provided by different authorities. However, for this study, it has been an analytical challenge that it is dealing with both geographical units and distinct technologies. H2FC are a new area of industrial technologies and data to describe and analyse its characteristics is rather limited. There are neither comprehensive time series established nor do the technology data necessarily match with regional data.

3.1 Geographical units

The main analytical focus in this study is concerned with the geographical distribution of H2FC activities in EU-27, Iceland, Norway, Liechtenstein and Switzerland. Data have been mapped at NUTS level 2 by the means of a geographical information system tool (GIS).

NUTS (Nomenclature d'Unités Territoriales Statistiques) is created by Eurostat as hierarchical classification of geographical units used for statistical production across the European Union. NUTS level 1 corresponds to a territory with a population of 3-7 million inhabitants. NUTS level 1 thus often reflects high administrative levels such as the German Länder. The analyses of this study is carried out on NUTS-level 2 (NUTSII) defined by Eurostat as ‘basic regions’ and comprise 268 regions in Europe. Basic regions are used by Member States for the application of their regional policies. Although this was the intention with the subdivision of NUTSII some countries are too small in terms of population to comply with Eurostat’s definition of regional geographical entities. For instance Denmark and Luxembourg are characterised as NUTSII regions even though they represent nations with national policy authorities. The more detailed level of NUTSIII comprises 1213 administrative regions in Europe.
3.2 Sources of data

Regional innovation system and industrial cluster analyses usually draw on the vast geographical oriented statistical material provided by national statistical offices and EuroStat. In Europe comprehensive statistical data are typically available as two entries: Geographical entries of the levels of NUTS and industry level based entries on the NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) codes. NACE is a European industry standard classification system consisting of a 6 digit code and data is provided by national statistical offices based on questionnaires filled in by individual firms (for example NACE code DJ.28.22 is “Manufacture of central heating radiators and boilers”). The challenge is that no codes are available for neither hydrogen nor fuel cells, and the dispersed field of energy technologies is spread over many different NACE codes. A recent analysis of self-declared hydrogen clusters in the Netherlands (Mans et al. 2008) is based on a database on 166 hydrogen related projects carried out in the Netherlands between 2000 and 2005 involving 250 Dutch actors. The database contains information on geographical information on each of the actors allowing analyses of geographical concentration of actors on the level of the so-called COROP areas. COROP divides the Netherlands in 40 COROP-areas. These areas are identical with Eurostat’s NUTSIII level. Such detailed databases are not yet available for a Europe-wide study like the present.

Technology specific innovation system analyses usually draw on slightly different types of statistical data than geographical oriented analysts. Bergek, Hekkert and Jacobsson (2007) have proposed a number of indicators and data to map the functions of technological innovations systems (TIS). Examples on indicators of the development and diffusion of knowledge are patents, bibliometrics (publications, citations), and governmental expenditures on R&D. Examples on indicators on market formation are size of the market (e.g. for fuel cells) and support schemes (e.g. public investments subsidies). In the context of the European Environmental Technologies Action Plan (EU ETAP) a variety of investigations have been car-
ried out on the concept of “eco-innovation” and indicators for this (Andersen, 2006). Much of such statistical information is available for energy technologies such as H2FCs. Consultancies such as Fuel Cell Today (www.fuelcelltoday.com) provide market based intelligence on the fuel cell industry. Fuel Cell Quarterly published by FuelCell.org provides a similar market surveys on both fuel cells and hydrogen technology. Patent statistics can be obtained using databases like Derwent, and bibliometrics (publications and citations) can be obtained from Web of Science – familiar to most scholars. The International Energy Agency (IEA) provides statistics on governmental expenditures on energy related R&D. But IEA has only included statistics on hydrogen and fuel cells since 2004 and data is still lacking from a number of countries. Seymour, Borges & Fernandes (2007) have discussed and applied indicators such as patents, publications and citations in an analysis of European countries public research in H2FC technologies. Similarly, Lee, Mogi and Kim (2008) have used the same kind of indicators to analyse scenarios for Korea’s industrial potentials based on these technologies.

For our use the problem is that these statistical data only is available on national level and not on regional levels. We are therefore left with doing analyses on what is available, and in the following sections we will analyse on data made available from the Roads2Hycom project (see description of data and the use of data below). Besides these data we have included data from two major studies of the spatial economy of Europe – The Regional Innovation Scoreboard and The European Cluster Observatory.

4 Hydrogen and fuel cells activities in Europe

H2FC technologies are emerging technologies and the markets for these technologies are still in the formative phases. Therefore, it is not yet possible to analyse existing industrial clusters based on these technologies. However, hints can be drawn on analysing available information. Available information provided by different parts of the Roads2Hycom project comprises the following data at NUTSII level:
- H2FC demonstration projects
- Hydrogen fuelling stations
- Registration of Interest (RoI) for communities undertaking large-scale H2FC projects and innovative applications

Comparing these data indicates which European regions (at NUTSII level) are involved in H2FC activities. Although the data may not give a complete picture of all H2FC activities in Europe it seems to be the best available and can give us a broad idea of where hydrogen activities are located.

We have classified the data (for each indicator) into four intervals based on natural breaks in the data, i.e. the biggest gaps in the dataset were used to classify the data into groups (Nelson, R. 1999). We used this classification method to ensure that similar observations were grouped together in the same interval. In order to be able to sum the three indicators into one total score for H2FC activities we then ranked the intervals with a score from 1-4. For example for the dataset on demonstration sites we first classified the data in five groups: 0, 1, 2-3, 4-5 and 5<. Next we ranked the intervals with the values from 0 to 4. The total score for each region was calculated by summarising the score for the three indicators: demonstration sites, fuelling stations and registration of interests. All NUTSII regions with a total score higher than three (15 regions) have been included in the further studies. Additionally we have included one NUTSI region (Wales, NUTS-code: UKL) because the data on the Regional Innovation Scoreboard (that we compare the regions with later) only exists for the English regions at this level. An adding up of activities from NUTSII to NUTS level I for the UK regions ranked Wales among the most active regions within H2FC.
4.1 Hydrogen and fuel cell demonstration projects

Based on existing and regularly maintained databases the European project Roads2Hycom has identified and analysed over 130 hydrogen demonstration projects within the European Union and the associated countries Norway and Iceland (Steinberger-Wilckens and Trümper, 2007). The demonstration projects were mostly related to transport, stationary use, and combinations hereof. The study included and distinguished between four types of demonstration projects: In planning, in operation, finished and interrupted. Only 2 of the projects comprised portable use of H2FC technology.

The NUTSII regions were ranked based on data for demonstration projects using the following score: 0: no demonstration projects, 1: 1 demonstration project, 2: 2 to 3 demonstration projects, 3: 4 to 5 demonstration projects, 4: more than 5 demonstration projects.

Demonstration projects were located in 15 countries. Most in Germany (24%), but also France, Denmark and Italy hosted each more than 10 percent of the total. Steinberger-Wilckens and Trümper (2007) conclude that an early clustering of demonstration projects seems to appear in the German Rhein-Ruhr/Rhein-Main area and in the cross-boarder region of Denmark and southern Sweden.

4.2 Hydrogen fuelling stations

Hydrogen fuelling stations are a prerequisite for developing the use of hydrogen in the transport sector. Based on a study by German consulting firm Ludwig-Bölkow-Systemtechnik the Roads2Hycom project has analysed the existing and planned hydrogen fuelling stations for vehicles (cars and busses) in Europe. The analysis included stations in operation, expired stations and planned stations (Perrin, Steinberger-Wilckens, Trümper, 2007).

By the time of the study (end of 2007) 35 hydrogen fuelling stations were in operation in Europe. Most of these were located in Germany. Furthermore, a large number of fuelling stations were planned especially in Scandinavia. In total, 72 operational or planned hydrogen
fuelling stations were analysed with geographical data on NUTSIII level. Data for the analysis of this study was aggregated at NUTSII level and ranked by following the natural breaks (see above) of the data set: 0: no H2 fuelling stations, 1: 1 H2 fuelling stations, 2: 2-3 H2 fuelling stations, 3: 4-5 fuelling stations, 4: more than five H2 fuelling stations.

We have not distinguished between planned and operational hydrogen fuelling stations in our mapping exercise in this study. We found that an aggregated count of fuelling stations ‘in planning’ and ‘in operation’ is adequate to indicate the level of activity. However, there is a risk that the planned fuelling stations never will be realised, but at present stage they indicate regions intention and can therefore very well illustrate the activity level.

4.3 Registration of Interest (RoI) for communities undertaking hydrogen and fuel cell projects

During 2006 the European project Road2Hycom launched a call for “Registration of Interest” for potential hydrogen communities in Europe (in this case: EU27, EEA and acceding and candidate countries). In an overall database 96 potential hydrogen communities were listed. Not surprisingly the largest number of potential hydrogen communities was registered in Germany with almost a quarter of the total. Also Italy, and UK had each more than 10% of the total number of communities. Collectively the five Nordic countries accounted for 17% of all projects (Shaw and Mazzucchelli, 2007). From the overall database a sample of 36 projects is included in this analysis. They are the communities who have responded on the Call for RoI for potential hydrogen communities. The call was launched in May 2006 and is regularly updated as new information becomes available.

Due to the low amount of registrations the maximum count in one region is three. The ranking of the regions are therefore as follow (with a maximum score of three): 0: no RoI, 1: 1 RoI, 2: 2 RoI and 3: 3 RoI.
4.4 European regions with a high level of hydrogen and fuel cell activities

Figure 1 indicates the total H2FC score of the NUTSII regions in Europe. Furthermore, the detailed result for 16 NUTSII regions with the highest H2FC score is shown in Table 1.

In many cases the clustering of activities in neighbouring regions matches the location of partnerships or corporative H2FC initiatives. The high score in the Scandinavian regions matches the location of ‘The Scandinavian hydrogen highway partnership’ (SHHP) that focuses their collaboration on South/South-eastern Norway, the Swedish west coast and Denmark (www.scandinavianhydrogen.org). SHHP is a collaboration between three national bodies: The HyNor (Norway), The Hydrogen Link (Denmark) and Hydrogen Sweden.

The score in the regions of the federal state North-Rhine-Westphalia in Western Germany illustrates the many activities carried out by ‘Fuel Cell and Hydrogen Network NRW’. One may note that the NUTSII level is well below the political entity of North-Rhine-Westphalia; looking at NRW requires an adding up of these activities.

In Northeast Spain it is the Aragon hydrogen initiative initiated by the Spanish Ministry of Industry in 2002. The high score in Northern Italy illustrates the many diverse Italian projects that have been carried out during the last decade. For example, In Lombardy: the Zero Regio project in Mantova, the Bicocca Project in Milan, and the Arese project in Arese; in Tuscany: the HBUS project in Florence and the Arezzo project. And in Piedmonte: the Hydrogen system laboratory in Turin.
Additionally, the German cities Hamburg and Berlin also score within the highest ranked regions as well as North East England, Iceland and Nord-Pas-de-Calais in France.

5 High-level H2FC regions and existing infrastructure and production capacities

In the following we will examine whether the 16 high activity H2FC regions are located in regions with existing infrastructure such as hydrogen pipelines and hydrogen production sites.

5.1 Existing hydrogen production capacity

Hydrogen is used as an industrial gas in many process industries throughout Europe. The total industrial hydrogen consumption in Europe is estimated to be about 61bn m³ (in 2003). The most of this hydrogen was consumed by two industries: in oil refineries (ca. 50%) and for production of ammonia (ca. 32%). The total production of hydrogen in European Union amounts to 80 bn m³ (Steinberger-Wilckens, Trümper, 2007) – which means that some over-capacity exists.

The number of hydrogen production sites in each NUTSII regions was counted. A ranking of the regions is based on the following score: 1: 1-2 production sites, 2: 3-5 production sites, 3: 6-8 production sites, 4: 9-14 production sites. It was not possible to look at the specific production processes of these facilities within the scope of this study.

Important clusters of hydrogen production are mainly in the Benelux-countries, the Rhine-Main area, Midlands in the UK, Southern France and in North Italy, but also regions in rim of the European Union such as Ireland, Finland Lithuania, North East Spain, and Romania have hydrogen production. Moreover it is interesting to note, that the new member states in total have many H2 production sites.
5.2 *Existing hydrogen pipeline infrastructure*

The Roads2Hycom project has identified 15 larger hydrogen pipeline networks in different parts of Europe with a total length of nearly 1600 km (Perrin, Steinberger-Wilckens, Trüper, 2007). These pipeline networks are operated by firms like Air Liquide, Linde Gas and Air Products. Pipelines are located in Western Belgium, Southern and Western Netherlands, the German regions North-Rhein Westfalen, Sachsen and Sachsen-Anhalt and in the three regions in eastern France (incl. South-East France). The length of the pipeline is measured in km and mapped at NUTSII level. A ranking of the areas is based on the following score: 1: 2-25 km, 2: 26-61 km, 3: 62-163 km, and 4: 164-284 km. Figure 2 shows the geographical distribution of respectively hydrogen production sites and hydrogen pipelines.

INSERT FIGURE 2 ABOUT HERE

5.3 *Relationship between high-level H2FC regions and existing hydrogen infrastructure*

A total score on existing infrastructure and production capacity was calculated by summarising the score for respectively production sites and the length of H2 pipelines. Then we grouped the NUTSII regions based on their score on existing infrastructure into 3 groups: High score: 4-8 points, Medium score: 2-3 points and Low score: 0-1 points. The distribution of the 16 high activity H2FC regions between the three groups can be seen in Table 2. Only 4 of the high activity H2FC regions score high on existing infrastructure and production capacity (Düsseldorf (DEA1) and Köln (DEA2) in Nordrhein-Westphalia, Nord – Pas-de-Calais (FR30) and Lombardy (ITC4) in Northern Italy). Half of the high activity regions score 2-3 points (Medium) on existing infrastructure and four regions score in the very low end, 0-1 point.

INSERT TABLE 2 ABOUT HERE
Therefore, we cannot conclude that existing H2 production capacity and H2 pipelines play a dominant role when regions decide on engaging in H2FC activities. However, the analysis point out four regions that have a high activity level and a high activity of H2 capacity: Düsseldorf and Köln in Nordrhein-Westphalia, Nord – Pas-de-Calais in France and Lombardy in Northern Italy. Provided that existing H2 infrastructure (production capacities and pipelines) is rewarding for H2FC development these four regions seem to have comparative advantages for carrying out larger lighthouse projects.

6 Match between regions’ level of H2FC activities and their score in EU’s Regional Innovation Scoreboard

The Regional Innovation Scoreboard 2006 was conducted by Maastricht Economic and social Research and training centre on Innovation and Technology (MERIT). It measures seven innovation indicators: human resources in science and technology, participation in life long learning, public and private R&D, patent applications, employment in medium-high and high-tech manufacturing. It indicates the general innovation climate based on quantitative data within a region. The scores of the scoreboard data lie within an interval of 0 to 1 whereby the region with the highest ranking scores 0.90 (Stockholm, Sweden).

For the purpose of this study the Regional Innovation Score can be split into three categories; the bottom third, the middle third and the highest third. Of the 16 highest placed H2FC regions 10 (or 62.5 %) are also among the top third most innovative regions. (See table 3).

INSERT TABLE 3 ABOUT HERE

This clearly indicates that H2FC activities take place in regions that are generally innovative. This confirms the general thesis in cluster theory that greater spill-over will happen where knowledge concentration is high on beforehand (so-called endogenous growth theory). Provided that these regions also perform better (which has not been analysed here) the result
suggest that innovative regions have been faster in their attempts to promote H2FC activities. It also suggests that innovative regions find it easier to jump on new technology paths or at least are keener to take chances on new and uncertain technologies.

The high activity H2FC regions placed in the medium third are the Italian regions – Toscana, Piedmont and Lombardy, the UK-region Wales, and the German region Düsseldorf. The only high activity H2FC region in the bottom third is Nord – Pas-de-Calais a major centre for heavy industry in the 19th century (coal mines and steel mills). After a heavy recession in 1970’s and 1980’s the region focuses today on tourism. This result also raises the question about to which extent H2FC demonstration activities can be used in a political agenda on improving regions innovative capabilities in general.

7 Assessing the presence of clusters in H2FC-regions

The following section compares the presence of likely future H2FC related industrial clusters in high activity H2FC regions. The aim is to investigate whether certain existing clusters are represented more frequently in high activity H2FC regions than in the rest of Europe.

The analysis is based on the cluster mapping carried out by the European Cluster Observatory. The European Cluster Observatory has carried out cluster analyses in 32 countries with NUTSII regions as the geographical unit. The analyses define clusters according to Michael Porter’s analysis of employment distribution in North America (Porter, 2003). The American study analysed the geographical distribution of employment in different industries and found different patterns depending on type of industry. The industries were grouped into three different categories showing their diverse geographical profiles:

- Local industries are present in all regions as they serve local markets. They are not exposed to direct competition across regions and are characterised by lower wages, produc-
tivity and rates of innovation. According to the European Cluster Observatory, local indus-
tries account for around 57% of all employment in Europe.

- Traded cluster industries experience advantages in choosing their location and serve
  markets across regions. They have a tendency to ‘cluster together’ and are characterised
  by wages above average and higher productivity and level of innovation. The cluster sec-
tor accounts for about 37% of European employment.

- Natural resource-based industries are located close to the deposits of the natural re-
  sources they exploit and are therefore also geographically concentrated but for other rea-
  sons. Around 5% of the European employment is employed in the natural resource
  based industry.

From the perspective of creating a hydrogen economy in all parts of society all three industry
groups will be affected. Local Industries will be affected either as users of new hydrogen
products or as retailers. The Natural Resource-Based Industries will be affected as hydrogen
is not an energy source in itself, but needs to be produced using fossil energy sources, bio
resources or similar. But in the development phase of a new technological trajectory the most
important industry actors should be found within the Traded Cluster Industries.

The European Cluster Observatory has divided the ‘Traded cluster industries’ into 38 cluster
categories (see www.clusterobservatory.eu). They have categorised a cluster’s strength in
accordance to size, specialisation and focus in order to measure sufficient critical mass to
develop the type of spill-over and linkages that creates positive economic effects. According
to the Cluster Observatory’s evaluation a cluster present in a given region receives between 1
and 3 stars depending on the strength of the cluster. However, in our study we do not distin-
guish between the amounts of stars but only focus on whether or not a cluster is present in
the given region.
We have calculated a Cluster Quotient (CQ) for each of the 38 clusters. The CQ is a measure for co-location of H2FC activities and clusters. The CQ compares the proportion of clusters (within the same cluster category) located in the 16 high activity H2FC regions to the proportion of the total amount of clusters (within that same cluster category) in all the 258 regions (see equation).

The Cluster Quotient is thus calculated as

\[ CQ_i = \frac{A_i}{B} / \frac{C_i}{D}; \]

where

- \( i \) is a cluster according to the Cluster Observatory, e.g. Automotive
- \( A_i \) is the number for \( i \) Clusters in all high activity H2FC regions
- \( B \) is the number of all high activity H2FC regions (=16)
- \( C_i \) is the number of all \( i \) type clusters (e.g. automotive) in all regions analysed by the Cluster Observatory
- \( D \) is the number of all regions analysed by the Cluster Observatory (=258)

A CQ>2 shows that the cluster are more frequently located in the high-level H2FC regions than in the rest of Europe. Table 4 shows the calculated CQ for the 38 clusters in Europe.

First and foremost it is important to keep in mind that Table 4 reveals a statistical measure for co-location of H2FC activities and clusters. The CQ is not measuring whether or not a causal relationship between certain clusters and H2FC technology exists. Furthermore, clusters are analysed by studying concentration of employment within industrial sectors. Employment with relevance for H2FC is most likely employed in companies’ R&D departments and comprises a small part of the total employment. R&D departments are often located where
companies have their headquarters or where there is a critical mass of skilled workers. Therefore, we presume that this co-location measure can give us some information on which clusters play a role in the H2FC development.

Generally seen, Table 4 reflects the result from the analysis above of the correlation between high active H2FC regions and the regional innovation scoreboard. Clusters with a high CQ (>2) generally score higher in the indicators that form the innovation scoreboard (Human resources in science and technology, participation in lifelong learning, public and private R&D, patent applications, employment in medium-high and high-tech manufacturing) than clusters with a CQ<2. Table 4 therefore confirm that an overall well-functioning innovation environment is important for regions’ engagement in H2FC activities.

H2FC technology is yet at a stage where the relevance for many of the established clusters is limited. We have identified nine cluster categories that most likely play a role in the development of the technology and in improving the state-of-the-art of the technology. The nine clusters are highlighted in Table 4 and presented in details in Table 5. Table 5 presents the nine cluster categories, examples of industries and some examples of companies involved in H2FC development.

Of the nine clusters with high relevance for H2FC technology seven have a CQ higher than 2. Only transportation and heavy machinery have a CQ less than 2.

Transportation covers inventories and logistics and distinguishes itself from the other clusters by being a service sector providing transport and not the technology for transportation. The transportations sector will be among the large end-user groups of H2FC based transportation technology. Heavy Machinery clusters are located in 4 out of the 16 H2FC clusters so the result indicates, not surprisingly, that this cluster does not play a leading role in the regional H2FC activities.
Chemicals (3.1), Power generation and transmission (3.1), and Oil and gas (2.4) are three clusters that are in particular relevant in producing and distributing hydrogen. Automotive (2.4), communications equipment (2.9), aerospace (2.9), and production technology (2.9) are clusters with an interest in the various application options H2FC offer. The CQs show a high activity of co-location between H2FC activities and these clusters.

This result can be explained by taking the market maturity of H2FC technologies into account. Firms interested in developing and demonstrating H2FC technologies are in this early phase firms seeking business opportunities in producing these technologies and providing the hydrogen. Whereas, firms that potentially could become end-users of such technologies (such as transportation) are likely to become involved in a later state of the technologies market development.

Clusters, most unlikely to support the development of H2 and fuel cell technologies such as Footwear, Furniture and Processed Food (beer, dairies, glass packages/wrapping) have a CQ < 1. Also this seems quite naturally; firms in these sectors are only likely to become end-users of H2FC technologies when they are fully matured, and competitive with other energy technologies.

To sum up, a positive correlation is found between the presences of clusters assessed to be H2FC friendly and the high activity H2FC regions. This indicates that specific clusters may play a role in driving the development of H2FC technology. However, the most important result of the study of Cluster Quotients seems to be a confirmation of the correlation between innovative regions (hosting innovative clusters) and H2FC technology development. An in-
stitutional set-up with favourable conditions for innovation is therefore seen as extremely important in promoting innovation activities within H2FC.

This study of regions’ role in H2FC development has a preliminary character and has to be followed up by more in-depth studies. In particular studies of the relationship between certain clusters and H2FC technology will be of interest. A study of the institutional set-up at the regional governance level and how to improve this through innovation policies would also be very interesting and would be fruitful for the regional engagement in H2FC development in the future.

8 Conclusion

In the introduction of the article we raised a number of research questions. In the following we will try to answer these questions and discuss their implications for energy and regional policy.

First of all we can conclude that geography and cluster aspects seem to matter in establishing a European H2FC technology innovation system. It is obvious that some regions are more active in the formative phase of H2FC innovation systems.

Regions with the highest level of H2FC activities are found different places in Europe and in many cases the clustering of activities in neighbouring regions matches the location of partnerships or corporative H2FC initiatives. In Southern Scandinavia the regions matches the location of ‘The Scandinavian hydrogen highway partnership’ (SHHP). In the federal state North-Rhine-Westphalia in Western Germany might benefit from the activities carried out by ‘Fuel Cell and Hydrogen Network NRW’. In Northeast Spain it is the Aragon hydrogen initiative initiated by the Spanish Ministry of Industry in 2002. Also in the case of Northern Italy it reflects projects that have been carried out during the last decade. For example, In
Lombardy: the Zero Regio project in Mantova, the Bicocca Project in Milan, and the Arese project in Arese; in Tuscany: the HBUS project in Florence and the Arezzo project. These geographical patterns of H2FC activities indicate that some European regions are building up critical-mass within H2FC.

Second, the relationship between early adopting H2FC regions and existing hydrogen production capacities as well as pipeline infrastructure is weak. Small projects can indeed be done with on-site hydrogen production and do not require existing production or pipeline infrastructure. The latter should therefore not be seen as preconditions for the engagement with H2FC. However, the existence of production capacities and infrastructure is without a doubt a positive factor for the implementation of large scale projects and the development of H2FC clusters.

Third, it can be concluded, that regions which are very active in pursuing H2FC deployment typically also are generally innovative regions. This finding is consistent with endogenous growth theories and thus confirms the hypothesis that innovative regions can more easily engage with and advance in H2FC technologies. Less innovative regions may therefore need specific support schemes to help them engage with H2FC. However, such support should be subject to the condition that the less innovative region in question disposes of some other success factors (e.g. hydrogen production infrastructure) which promise to make the investment a rewarding one. In any case it is important to be aware of the extent of the hydrogen chain and that efforts are needed at all steps. It is yet too early to tell where the breakthrough will happen that can make hydrogen competitive with incumbent technologies. Less innovative regions might be engaged in development paths which can lead to breakthroughs in niche markets that can improve the overall state-of-the art of the technology. It is therefore not recommendable to cut-off less innovative regions from funding sources.
Fourth, the most active regions in the field of H2FC are characterized by the location of innovative clusters which confirms the importance of an overall well-functioning innovation system for the development of emerging technologies. Some of the industrial clusters located in the highly active H2FC regions can furthermore be characterised as favourable for the development of H2FC. This relation is particularly strong for clusters in chemical products, power generation, production technology, oil and gas, automotive and aerospace, which reflects the early stage of H2FC market development. In fact, the investment in other H2FC applications depends on the advances in hydrogen generation and fuel cell technology. The relative importance of industries that provide end-use applications (such as transportation) is likely to increase in a later stage of the technologies market development. The decision of local authorities and/or the European level on whether to support a regional initiative should therefore take the specific regional cluster structure and the general stage of market development into account.

These findings might help to develop a comparative assessment scheme and support ensuing policies across European regions. This article has only provided a preliminary insight into the economic geography of H2FC development. Additional studies of the character of regional innovation systems and how they can facilitate the H2FC development through innovation and cluster policy is necessary in order to pave the way for a hydrogen economy. Another interesting issue this article has revealed is the benefits and synergies the clustering of activities in neighbouring regions seem to have for the H2FC development. Also this relationship needs further study before qualified policy implications can be drawn.

9 Acknowledgement

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10 References


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http://www.ricardo.com/roads2hycom/pub_download.asp?PageIndex=1

Tables (including captions)

(Note! Figures uploaded separately, figure captions added on the last page of this document)

Table 1: Distribution of H2FC activities in the 16 most active regions in Europe within H2FC. Listed according to NUTSII identification code.

<table>
<thead>
<tr>
<th>NUTSII region</th>
<th>Demonstration Sites</th>
<th>Fuelling stations</th>
<th>Registration of Interest</th>
<th>H2FC-SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>count</td>
<td>point</td>
<td>count</td>
<td>point</td>
</tr>
<tr>
<td>DE11 Stuttgart</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>DE21 Oberbayern</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>DE30 Berlin</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>DE60 Hamburg</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DEA1 Düsseldorf</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DEA2 Köln</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DK00 Danmark</td>
<td>17</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>ES30 Comunidad de Madrid</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>FR30 Nord - Pas-de-Calais</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>IS Iceland</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>ITC1 Piemonte</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>ITC4 Lombardia</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>ITE1 Toscana</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>NO04 Agder and Rogaland</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>SE0A Västsverige</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UKL Wales</td>
<td>4</td>
<td>4</td>
<td>0</td>
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</table>
Table 2: Relationship between 16 high-activity H2FC regions and existing infrastructure

<table>
<thead>
<tr>
<th>Total existing infrastructure and production capacity score</th>
<th>Count of high activity H2FC regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High score on existing infrastructure (&gt;3 points)</td>
<td>4 (25%)</td>
</tr>
<tr>
<td>Medium score on existing infrastructure (2-3 points)</td>
<td>8 (50%)</td>
</tr>
<tr>
<td>Low score on existing infrastructure (0-1 points)</td>
<td>4 (25%)</td>
</tr>
</tbody>
</table>
Table 3: Distribution of the 16 high activity H2FC regions over the 358 NUTS II regions’ score in the European Regional Innovation Scoreboard

<table>
<thead>
<tr>
<th>Score in the Regional Innovation Scoreboard</th>
<th>Number of high activity H2FC regions (top 16 in Table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest third</td>
<td>10</td>
</tr>
<tr>
<td>Medium third</td>
<td>5</td>
</tr>
<tr>
<td>Bottom third</td>
<td>1</td>
</tr>
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</table>
Table 4: Cluster Quotients

<table>
<thead>
<tr>
<th>Cluster Category</th>
<th>CQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical Devices</td>
<td>4.7</td>
</tr>
<tr>
<td>Publishing</td>
<td>4.4</td>
</tr>
<tr>
<td>Distribution service</td>
<td>4.3</td>
</tr>
<tr>
<td>Analytical Instruments</td>
<td>3.9</td>
</tr>
<tr>
<td>IT</td>
<td>3.9</td>
</tr>
<tr>
<td>Biopharmaceuticals</td>
<td>3.1</td>
</tr>
<tr>
<td>Power generation and transmission</td>
<td>3.1</td>
</tr>
<tr>
<td>Chemicals</td>
<td>3.1</td>
</tr>
<tr>
<td>Sporting</td>
<td>2.9</td>
</tr>
<tr>
<td>Production Tech.</td>
<td>2.9</td>
</tr>
<tr>
<td>Aerospace</td>
<td>2.9</td>
</tr>
<tr>
<td>Communications equipment</td>
<td>2.9</td>
</tr>
<tr>
<td>Forest products</td>
<td>2.8</td>
</tr>
<tr>
<td>Lighting</td>
<td>2.8</td>
</tr>
<tr>
<td>Plastics</td>
<td>2.7</td>
</tr>
<tr>
<td>Entertainment</td>
<td>2.4</td>
</tr>
<tr>
<td>Jewelry</td>
<td>2.4</td>
</tr>
<tr>
<td>Oil and Gas</td>
<td>2.4</td>
</tr>
<tr>
<td>Automotive</td>
<td>2.4</td>
</tr>
<tr>
<td>Business Services</td>
<td>2.1</td>
</tr>
<tr>
<td>Building Fixtures</td>
<td>2.0</td>
</tr>
<tr>
<td>Constr. Materials</td>
<td>2.0</td>
</tr>
<tr>
<td>Tobacco</td>
<td>1.9</td>
</tr>
<tr>
<td>Education</td>
<td>1.6</td>
</tr>
<tr>
<td>Leather</td>
<td>1.5</td>
</tr>
<tr>
<td>Heavy Machinery</td>
<td>1.4</td>
</tr>
<tr>
<td>Finance</td>
<td>1.4</td>
</tr>
<tr>
<td>Agricultural</td>
<td>1.4</td>
</tr>
<tr>
<td>Textiles</td>
<td>1.3</td>
</tr>
<tr>
<td>Transportation</td>
<td>1.3</td>
</tr>
<tr>
<td>Fishing</td>
<td>1.3</td>
</tr>
<tr>
<td>Hospitality</td>
<td>1.2</td>
</tr>
<tr>
<td>Metal manufact.</td>
<td>1.1</td>
</tr>
<tr>
<td>Footwear</td>
<td>0.9</td>
</tr>
<tr>
<td>Apparel</td>
<td>0.8</td>
</tr>
<tr>
<td>Furniture</td>
<td>0.7</td>
</tr>
<tr>
<td>Food</td>
<td>0.7</td>
</tr>
<tr>
<td>Construction</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table 5: Cluster categories with interest to H2FC development

<table>
<thead>
<tr>
<th>Cluster categories</th>
<th>Industry examples</th>
<th>Examples from European H2 and Fuel Cell Technology Platform’s NEW-IG members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil &amp; Gas Products and Services</td>
<td>refineries</td>
<td>Statoil Hydro ASA, Gaz de France, Shell Hydrogen BV, Total France, Intelligent Energy, ILT Technology</td>
</tr>
<tr>
<td>Heavy Machinery</td>
<td>tractors, locomotives</td>
<td>Wärtsilä Finland, Gruppo Sapio, Ansaldo Fuel Cells, Nucellsys</td>
</tr>
<tr>
<td>Chemical Products</td>
<td>chemicals, industrial gases</td>
<td>Linde Gas, BASF Fuel Cells GmbH, ILT Technology, BP International</td>
</tr>
<tr>
<td>Production Technology</td>
<td>tanks</td>
<td>Topsoe Fuel Cells, Nucellsys</td>
</tr>
<tr>
<td>Transportation and Logistics</td>
<td>freight, air transport</td>
<td>Rail Safety and Standard Boards</td>
</tr>
<tr>
<td>Aerospace</td>
<td>APU on aircraft</td>
<td>Intelligent Energy, EADS Deutschland</td>
</tr>
<tr>
<td>Communications Equipment</td>
<td>portable applications, mobile, computers</td>
<td></td>
</tr>
</tbody>
</table>
FIGURE captions:

Figure 1: Map showing combined H2FC activity level at NUTS2 level.

Figure 2: Left: Total H2 Production Sites in Europe, Right: H2 Pipeline in Europe