

Origins of Regional Innovation Systems Thinking and Recent Advances from Analysis of 'Green Innovation'

Schumpeter's dynamic evolutionary economic model is weakened by his lack of geographical perspective. By introducing Jane Jacobs' 'economics of diversity' to the little Schumpeter did write on spatial matters, we gain insight into one of the probably numerous sources of cluster emergence. In passing, we also observe the outlines of a Neo-Schumpeterian theory of regional evolution. This is achieved in the process of examination of the emergence of green clusters. These are focused upon the production of new forms of non-fossil fuel energy that contribute to the lessening of overall greenhouse gas (GHG) emissions from human economic activity. They reveal a curious feature of economic evolution the clue to which lies in the element of geographically proximate convergence that characterises green innovation. As to be revealed first in the cases of northern and southern California, the type of Clean Technology or 'Cleantech' (also 'GreenTech') industry emerging there in clustered form evolves from convergence in agro-food, ICT and biotechnology. Testing these findings in two other cases to be presented – Jutland and Wales we see something comparable having occurred. This is despite selecting Wales as an intuitively difficult test of the insight. In each case Schumpeter's purest form of innovation – regional innovation – by means of 'railroadization' seems to have been something of an evolutionary 'trigger' from which successive innovations are still path dependent. Thus California's Cleantech emerges from ICT, biotechnology and nanotechnology, but also agro-food 'railroadization', while Jutland's wind and solar thermal clusters are found in Denmark's agricultural equipment and marine engineering regions and Wales' photovoltaics and biofuels in its mining equipment and agro-food histories. Brief reference is made to the case of Norway, where green innovation is clustered according to large corporate interests, themselves having passed through in-house 'related variety' episodes.

Los clusters «verdes», se centran en la producción de nuevas formas de energía de combustibles no fósiles que contribuyen a disminuir el conjunto de emisiones de gases de efecto invernadero que produce la actividad humana. La formación de estos grupos revela una curiosa característica de la evolución económica: analizaremos la convergencia geográfica que caracteriza a la «innovación verde». En primer lugar analizaremos los casos del sur y norte de California, donde el tipo de industria denominada tecnología limpia o cleantech (también GreenTech), que está apareciendo allí en forma de clústeres, se desarrolla a partir de la convergencia de las industrias agroalimentaria, TIC y biotecnología. En otros dos casos, Jutlandia y Gales, veremos que ocurre algo similar. En cada caso, la forma más pura de innovación de Schumpeter —la innovación regional—, gracias a la «ferrocarrilización» parece haber sido el «desencadenante» evolutivo del que todavía siguen partiendo sucesivas innovaciones. La tecnología limpia de California emerge de las tecnologías de la información y comunicación (TIC), biotecnología y nanotecnología, pero también de la «ferrocarrilización» agroalimentaria.

Kluster «berde»ak erregai ez-fosil izeneko energia-forma berrienekoizpenean oinarritzen dira, hau da, giza jarduerak eragiten dituen berotegi-efektuko gasen igorpen-multzoa beharrezko laguntzen duten energia-forma berrietan. Talde horiek eratzeak, bide batez, bilakaera ekonomikoaren ezaugarri bitxi bat erakusten du: «berrikuntza berde»a itxuratzen duen konbergentzia geografikoa aztertuko dugu. Lehenik eta behin, Ipar eta Hego Kaliforniako kasuak aztertuko ditugu, non teknologia garbia eta cleantech (GreenTech ere bai) deitutako industria mota, eta han kluster moduan agertzen ari dena, nekazaritzako elikagaien industrian, IKTen eta bioteknologiaren konbergentziaren bidez garatu baita. Beste bi kasutan, Jutlandia eta Gales, antzeko zerbait gertatzen ari dela ikusiko dugu. Dena dela, Schumpeter-en berrikuntza-modu garbiena —eskualde-berrikuntza—, «burdinbidegintza»ri esker lortzen dena, izan bide da bilakaeraren «txinparta», eta hortik abiatzen dira oraindik ere ondorengo berrikuntzak. Kaliforniako teknologia garbia, gainera, informazioaren eta komunikazioaren teknologietatik (IKT), bioteknologiatik eta nanoteknologiatik abiatzen da, baina bai eta nekazaritzako elikagaien «burdinbidegintza»tik ere.

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1. INTRODUCTION

As is well-known, for those interested in evolutionary economic geography, Schumpeter left almost no regional or spatial analysis of economic phenomena. From the evolutionary economic geography and policy viewpoints, this is clearly disappointing. His two brief allusions are highly time-space specific. The first concerns Schumpeter's fifth form of innovation, which he designated 'railroadization' – the phenomenon by which US agricultural lands were opened up to markets by infrastructural investments, not only in railroads but farms, grain silos and even agricultural manuals that the railroad companies of the western USA had printed so that pioneers accessing cheap land on the plains would know how to farm that land. This 'regional evolution' of land and markets was, rightly, considered an *externalised* organizational innovation

as compared with the *internalised* organizational innovation of a corporation adopting new management methods that gave it an, albeit temporary, competitive edge (Schumpeter, 1975). The second allusion is even briefer where Schumpeter mentions innovation such as the department store only being feasible in the large city due to the level of demand required to sustain such an innovation. Hence the city is seen as having some economic specificity from its scale attributes, but Schumpeter says nothing about the dynamics of the entailed processes (Andersen, 1994; Andersen, 2007).

However, this paper suggests that bemoaning Schumpeterian neglect of the spatial dimension may be misplaced. His category of innovation by railroadization helps understanding of regional innovation in which clusters 'mutate' through a

Jacobian (after Jane Jacobs, 1969) related variety operating at regional level in places like California, North Jutland (Denmark) and Wales (UK). Regional innovation through cluster mutation is illuminated by the interest of this paper in 'green' innovation, which is pronounced in those regions. These are the only regions to have been examined from a 'green innovation' perspective thus far to this author's knowledge¹. A possible reason for the illuminative aspect of taking a green perspective is that green innovation (such as the burgeoning *Cleantech* industry) displays a high degree of innovation convergence across fields like information and communication technology (ICT), nanotechnology, biotechnology, agro-food, health, environment, energy, production and materials management, and waste treatment. Thus innovation occurs laterally among distinctive parts of what may be described as an innovation *platform*. Other regions for which Jacobian clustering is probably true are those of the Third Italy, which has been studied from this perspective by Boschma (2005) also from an evolutionary economic geography viewpoint. He found that apparently different industrial districts displayed 'related variety' in their *engineering* competences and associated high lateral absorptive capacity towards innovations emanating from neighbouring industries and clusters. No claim is made here for the ubiquity of this process, on the contrary Jacobian cluster regions are probably not in the majority. But where they exist they can be propulsive in relation to national economies or aspects

of them. To that extent they make a contribution to understanding of regional and national unequal development between wealth and poverty, the issue that has animated economics since Adam Smith.

Having held out the promise of a Neo-Schumpeterian theory of regional evolution, that aspiration has to be severely qualified. For a more truly evolutionary theory of spatial dynamics we have to turn to the mid-twentieth century inheritors of Veblen's concept of 'cumulative causation'. A variant of the biblical 'Matthew principle' of 'to those that have, more shall be given' this profoundly disequilibrium perspective contains the missing dynamic element by virtue of Myrdal's (1957) elaboration upon the various 'backwash' and 'spread' effects associated with regional evolution. Spread effects, on occasions, caused the dynamic element to seek to accommodate growth beyond its original boundaries. Backwash effects sucked back temporary gains made by competing locations to the larger, predominating accumulating entity, such as a strong city or regional economy. Observations of static relationships in the spatial evolution of the 'knowledge economy' have led to the preliminary postulation of a knowledge capabilities theory of regional evolution based on the distinctive distribution of two key components of the knowledge economy labour market (Cooke, 2007). Foremost here are, first, the knowledge intensive business services (KIBS) such as finance, research, media, software and so on. While second, high technology manufacturing is a mainstay of the knowledge economy in computer and communications hardware, aerospace and biotechnology *inter alia*. Empirical observation of the static picture for the EU strongly suggested an urban-regional

¹ Subsequently, Israel's cleantech clusters were examined and found to be similarly convergent with agro-food, ICT and biotechnology. A new one at Be'er Sheva in the Negev actually coincides with the recent completion of the railway connection from Tel Aviv to that desert location (Cooke 2008c)

split between the locations of these. The former predominate particularly in primate cities (such as the major financial centre, sometimes, but not always, combining capital city administrative functions); the latter predominate in specialised satellite towns, often with appropriate knowledge centres like national research institutes or universities centred in them. This theory, in brief, is consistent with Myrdal-Hirschman² theses about 'cumulative causation' and metropolitan regional concentration of knowledge economy activities (Cooke, 2002). But as noted, the static picture merely hinted at the dynamism explicit in the idea of cumulative causation, which remained to be tested. The first such contemporary test was accomplished by access to and analysis of special runs of Israeli data in a dynamic perspective (Cooke & Schwartz, 2008). This paper relies on those findings and then explores innovation

outside primate cities where knowledge-intensive business services (KIBS) thrive to explore innovation at some distance from big cities altogether. Nevertheless Myrdal-Hirschman models postulate innovation as capable of occurring there because such cities tend not to localise high technology manufacturing (HTM). To that we would add that they do not tend to have functional regional innovation systems and they are often the home of specialised rather than related variety clusters. The next sections take these insights and exemplify this by reference to some 'cumulative causation' peculiarities of innovative industry regions. Those selected display innovative convergence among high technology sectors to contribute to cleaner manufacturing, food and energy production – the so-called *Cleantech* sectors, respectively (Cooke, 2008b).

² The Myrdal-Hirschman theory of economic development has been influential in the emergence of 'new economic geography' (e.g. Krugman, 1995). Anticipating the latter's solution to the neoclassical location theory impasse by positing 'increasing returns to scale' rather than the rubric of 'constant returns' thus demonstrating the growth of cities to be a function of spatial monopoly, Myrdal (1957) proposed spatial development to be characterised by 'cumulative causation' with associated 'spread' and 'backwash' effects. This implies increasing returns to scale (through 'backwash') and developmental 'spread' to other nearby areas. Hirschman's (1958) elaboration on this was that 'spread' would be driven by the innovative capacity of competing technology users. Under 'knowledge economy' conditions we hypothesise that, over relatively short time periods, primate cities grow through increasing returns (to knowledge) and 'satellites' of leading technology innovators 'spread' nearby. Our preliminary static pictures of EU NUTS 2 regions are consistent with this, while our dynamic picture of spatial divergence in Israel 1995-2002 (Cooke & Schwartz, 2008) is consistent with Myrdal-Hirschman rather than Krugman (2000), who himself admits his 'two-locations competing' models are misleadingly simplistic. In this respect, it can be argued, evolutionary economic geography trumps 'new economic geography.'

2. THE KNOWLEDGE ECONOMY: WHAT IS IT?

It is important to say straightforwardly that the deployment of *knowledge* in economic affairs is not a new thing. Making a fire is clearly a knowledgeable and, in the deep past, powerful, knowledge-based skill, as the Prometheus myth testifies. Hunting, farming, smelting copper, bronze and iron, later steel are knowledge-based activities. In turn these knowledges became the basis for science and its application in early industrial technology. From coal mining grew coal tar production, the origin of the German dyestuffs industry whose aniline products led to branching into pharmacology, the (re-) discovery by the Bayer Corporation of Aspirin and the birth of modern pharmaceuticals. This industry is now shifting from its synthetic

chemistry origins into post-genomics and other variants of molecular biology and the science-based biotechnologies of the future.

Thus the underlying idea of a knowledge economy refers to specific assets that consist in knowledge 'how to', 'who to' and 'what to' deploy to create value. It is an active economic practice rather than a passive information space, upon which it nevertheless depends, but in ways that express value through the scarcity of 'knowledgeable' expertise. Manuel Castells (1996) speaks of the knowledge economy being one in which productivity derives from the interaction of knowledge upon knowledge rather than upon raw materials. Nonetheless, it is wrong to dismiss traditional or 'old economy' economic activity as not belonging to the knowledge economy, as for example the OECD does. It places the food industry in the low technology category, although Smith (2000) shows it to be heavily *scientific* knowledge using more than producing. Nevertheless, while 'functional foods' occupy probably a smaller segment of total food sales than the competing organic food they are both intensive utilisers of biotechnology. Surprisingly perhaps, non-genetically modified knowledge is used in organic breeding via DNA or molecular 'markers' that speed-up the breeding process for plants and animals. Thus we may also usefully speak of 'pure' and 'applied' knowledge economy activity; the first captured in genomics, software and, for example, 'futures' or derivatives trading in financial services, or conceptual art. The second is in many other sectors that conduct or use R&D even though it is applied to, for example, food production, fashion design, or fire insurance.

This allows the following policy inference to be drawn from the application of Myrdal-Hirschman models: it is unlikely that regions aspiring to evolve upwardly in economic accomplishment will be able to do so if they concentrate on developing a full portfolio of KIBS since these are more attracted to large, even primate, cities. That is not to say that some KIBS are not needed, perhaps consultancy, management accounting, venture capital (attracted by university spinouts, incubators etc.), software and, above all, research both private and public. These latter may occasionally involve fairly mundane economic activity support for sectors such as agro-food, nowadays innovating in such areas as 'functional food' (food biotechnology), organic food (utilising biotechnology for enhanced crop and animal breeding utilising 'molecular markers') and of course renewable energy from biofuels. In other words KIBS can be important specialised supports in knowledge economy regions with HTM and medium-tech manufacturing (MTM) requiring also high-quality precision production that is difficult to outsource globally. Jena, for example, with its universities, polytechnic, research institutes and specialist opto-electronic corporations and spinouts has the current appearance of a relatively small-scale innovation system at sub-regional level. It has some similarities with some of the induced local innovation systems promoted in Sweden by the state innovation systems development agency VINNOVA through its Vinnväxt programme. This is an exemplification of regional innovation systems thinking translated from the academic arena into the policy field. The idea of regional innovation systems came from integrating a growing literature on networks of innovation at regional level

with another on innovation policies at regional level, as follows.

3. REGIONAL INNOVATION SYSTEMS: INTEGRATING REGIONAL NETWORKS AND REGIONAL INNOVATION POLICY

The enthusiasm for studying networks arose in a context of manifest decline in the co-ordinating capabilities of states and markets regarding leading edge research and innovation, which subsequent data (e.g. Chesbrough, 2003) shows set in from approximately 1991. But if the central state had become as debilitated as many large private corporations were to become regarding the lack of productivity from their large budgetary allocations to research and development (R&D), the 'regional state' seemed from empirical reportage of the kind discussed above to be on the rise. I was fortunate to observe the beginnings of such regional innovation policy elaboration in a leading industrial regeneration region, the Basque Country, whose currently excellent economic indicators are testimony to the far-sightedness of those 1980s regional policy makers. I conducted research in other Spanish regions like Valencia to notice the importance for different modes of regional innovation policy elaboration to fit distinctive economic and governance characteristics of very distinctive economic and cultural region specificities.

In the 1988-91 period when we researched the Basque Country RIS, there were many fewer innovative firms than now exist, but the governance framework was comparable to a few other EU regions although we realised the Basque government had relatively powerful ministries, assisted by an innovation agency

SPRI. But above all, the six EITE (now *Tecnalia*) sectorally-focused technological centres and further six funded by the three provincial governments (Cooke et al., 1991) pointed to a rich innovation infrastructure. Here three key things were visible: first, how a de-industrialising region depended upon possessing intermediary agencies with innovation and industry expertise, independent of government (though part-funded by so-called generic project-funding disbursed by the Basque government) and of the then new and not significantly research active university sector. These would project Basque industry into a new future different from the disappeared heritage of steel-making and shipbuilding. Second how *systemic* in terms of networking connectivity the whole and particularly some parts of the regional economy were, notably the Mondragon organisation, amongst the most innovative networks observable anywhere at the time. Third, how networks could sometimes take the form of 'industrial districts' or innovative clusters which, although composed of micro-firms and small-to-medium ones, could nevertheless exert global reach.

A parallel strand of research had evolved, which focused on regional innovation policy (e.g. Antonelli & Momigliano, 1981; Cooke, 1985). Thus the connecting concept of Regional Innovation Systems evolved from this even earlier thinking about 'regional innovation policy', in relation to 'regional innovation networks' (the 'systems view of planning' intruding again). This happened in two publications, the more widely-cited one being less theoretically and empirically rich than the almost totally uncited one. The difference between Cooke (1992) and (1993) lies in the absence of any bibliographical influence from the 'innovation systems'

literature in the 1992 paper, which thus has purer lineaments to economic geography. Contrariwise, the 1993 paper which shows the author had by then read Lundvall's (1988) contribution on 'innovation as an interactive process' to Dosi et al (1988) and was also influenced by Johansson (1991) and Grabher (1991) in probably the first proper book on regional development from a 'network regions' perspective (Bergman, Maier & Tödtling, 1991).

It seemed necessary to place these distinctive 'network and policy' concepts in relation to each other in a layered model. So, the innovation policy dimension evolved conceptually into the idea of a sub-system supporting with knowledge and resources the innovative firms in their networks. These formed a 'superstructural' sub-system dealing with actual innovation 'near market'. As we have seen, they had been spoken of as carrying out 'networking' with each other, not only laterally in alliances or partnerships and vertically in sometimes partly localised supply chains but also with the innovation policy and knowledge generation sub-system (Meyer-Krahmer, 1985; Cooke, Alaez & Etxebarria, 1991; Malecki, 1991; Rothwell & Dodgson 1991). So these also had sub-system characteristics related to the governance of innovation support. Each sub-system was also seen to interact with global, national and other regional innovation actors, and even through technological or sectoral systems of innovation. Open systems ruled.

Over the years the RIS framework has been analysed in terms of many different 'varieties of innovation' relating to localised, networked and hierarchical innovation 'governance' systems. Third Italy, Baden-Wuerttemberg and French innovative

regions exemplified each, respectively. Correspondingly, the 'exploitation' sub-system of firms, in the main, could be dominated by large firms or oligopolies - even foreign ones as with the Asian transplants to Wales in the 1980s and 1990s. Other regions, like Catalonia had a mix of large (SEAT) and SME 'district' type innovation relations, while other places might have innovation regimes in which only small, entrepreneurial firms predominated, as in places with observable 'industrial districts', not only Third Italy but also some newer technology 'clusters'. Later still, these, more entrepreneurial SME systems, living by venture capital and exploitation of public research from universities, could be differentiated further as 'entrepreneurial' (ERIS), market-led systems, compared with those, especially in Europe, where they were more 'institutional' (IRIS) where state support was pronounced and 'entrepreneurship' was less advanced (Cooke, 2004).

4. RECENT ADVANCES IN RIS RESEARCH

One of the most interesting research areas opened up in RIS research in the recent past concerns, once again, the insights of Jane Jacobs (1969) and can be referred to as addressing the challenging issue of 'cluster emergence'. In particular by examining the emergence of a number of 'green clusters' on a regional canvas, we see emphasis in 'green innovation' upon technological convergence among diverse industries. These include biotechnology, information technology and nanotechnology (but not limited to these high-tech activities) and among them we also see a process of

cluster 'species mutation'. Of particular fascination here is that some regions have the capability relatively rapidly to mutate many 'Jacobian' clusters – so-called because although different they display evolutionary characteristics of 'related variety' (Boschma, 2005). A clear definition is called for here to denote this new concept. The key is the evolutionary concept of variety, whereby some new combinations of entrepreneurial and innovative opportunity might present themselves in geographically proximate space. This would arise from the mixture of knowledge spillovers and rather high absorptive capacity among neighbouring economic activities.

Hence (Jacobian) variety is both a context and an 'evolutionary fuel' for cluster emergence as long as there is not too much cognitive dissonance or distance between neighbouring economic activities. Hence Jacobian clusters emerge from new combinations of knowledge cross-fertilising among, for example, high technology activities like biotechnology and information technology that may be foundations for a new clean technology cluster that adopts and adapts elements from both. But, for example, new combinations from agro-food and automotive industries that are historically not that close in technical terms may also arise if the new combination being sought is biodiesel or bioethanol. This is because adjustments in breeding of plants may have to be made if negative effects on engine performance cannot be made by the automotive side of the equation. Hence related variety is not fixed to sectoral relatedness but embodies also particular and contextuated technological convergences. In that respect it is much harder to predict cross-fertilization in the

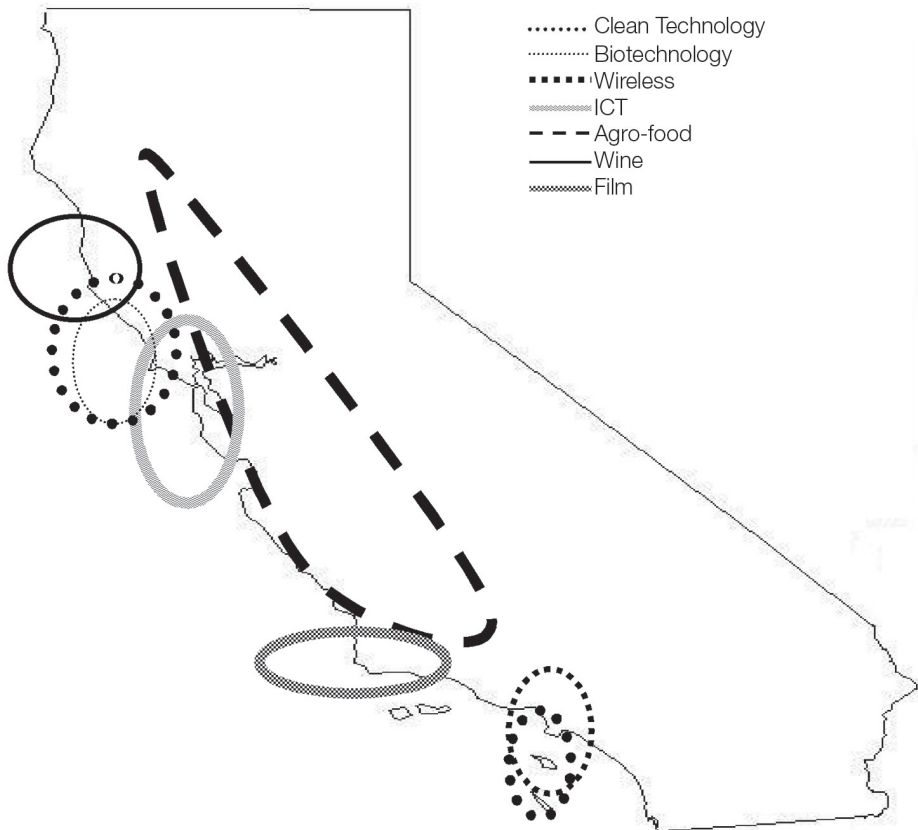
latter than the former case. But anyway, Jacobian variety rests not within but among the clusters according to this line of reasoning. Moreover it is likely to occur in the relative geographical proximity of regions. In what follows, empirical evidence is provided of regional evolution through innovation of differing intensities 'mutating' through processes of knowledge search and selection that happen to give rise to successive clustering phenomena in regional 'platforms' of related economic variety.

Jacobian Clusters

One such region is Northern California whose ICT, Biotechnology and Clean Technology clusters overlap in proximity to San Francisco but also near various agro-food clusters like wine in the Napa, Sonoma and Russian River valleys and varieties of horticulture in the San Joaquin and Sacramento river valleys (see Fig 1). But notice, Fig. 1 also shows Southern California having prominent Jacobian

The content of Fig. 1 is drawn entirely from secondary evidence supplied by the numerous studies of clusters in California as published in Porter (1998); Scott (2006); Saxenian (1994); Cooke (2007); Guthman (2005), Simard & West (2003). North Jutland in Denmark is another such region, as apparently is Wales in UK, as we shall see. North Jutland's economy is the global centre of the wind turbine production industry whose profile and evolutionary trajectory was a key beneficiary from the outset of varieties of innovation. As will be shown, this recently 'discovered' cluster has all the required characteristics to warrant the cluster designation, conjoining university

Figure 1
California's Jacobian Clusters



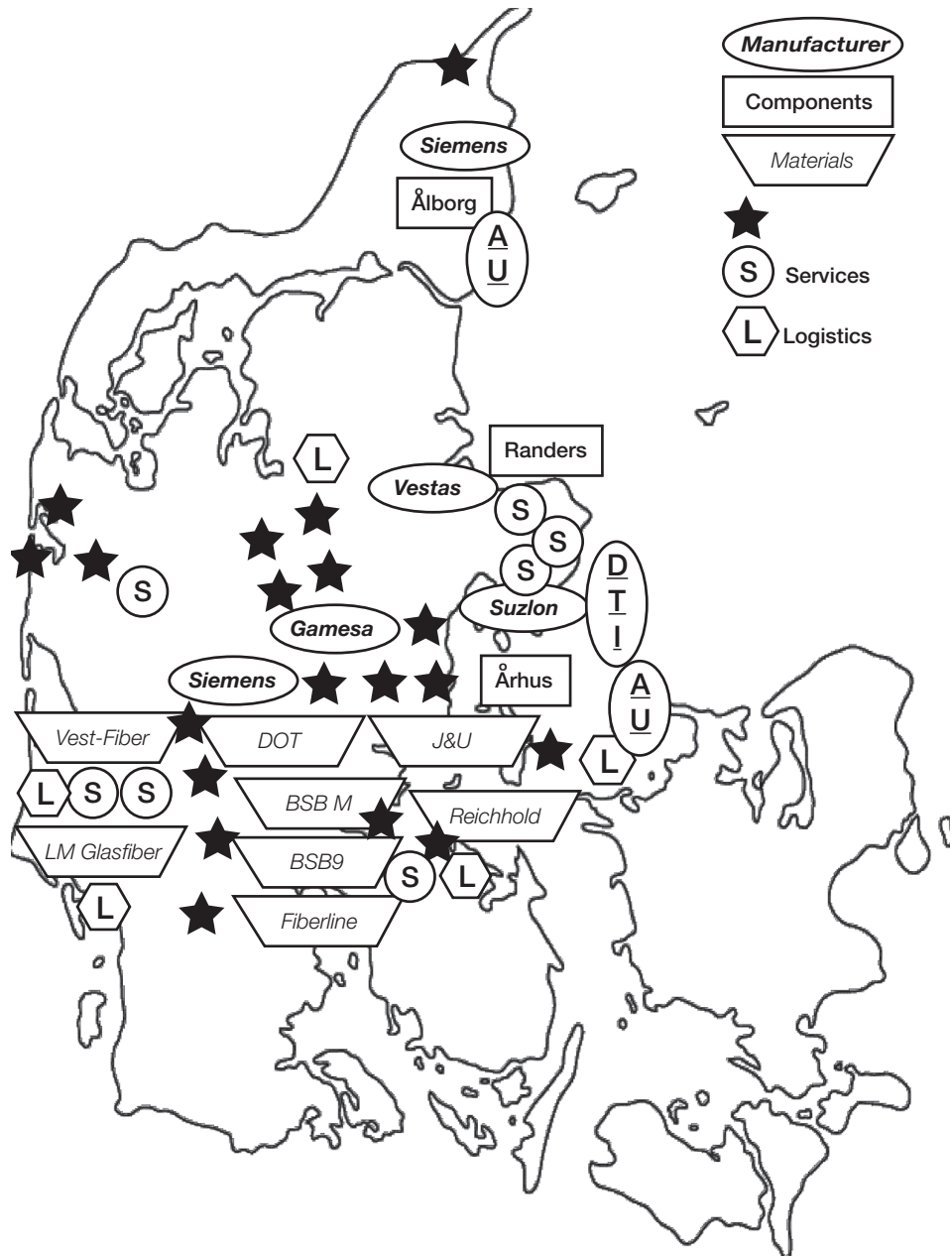
Source: Made by the author from Porter (1998), Scott (2006), Saxenian (1994), Cooke (2007), Guthman (2005), Simard & West (2003).

research at, for example, Ålborg and Århus Universities, the Danish Technological Institute (DTI) also at Århus, and both spinout firms and larger, indigenously established firms that are involved in 'green innovation'. Denmark's 'cluster' has no geographical specificity of the kind Porter (1998) was rather more sensitive towards. He referred there to a cluster as:

'... a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities'

With regard to such clusters the most important analytical task is to establish the extent of interconnections, commonalities and complementarities since this is what distinguishes a localised.

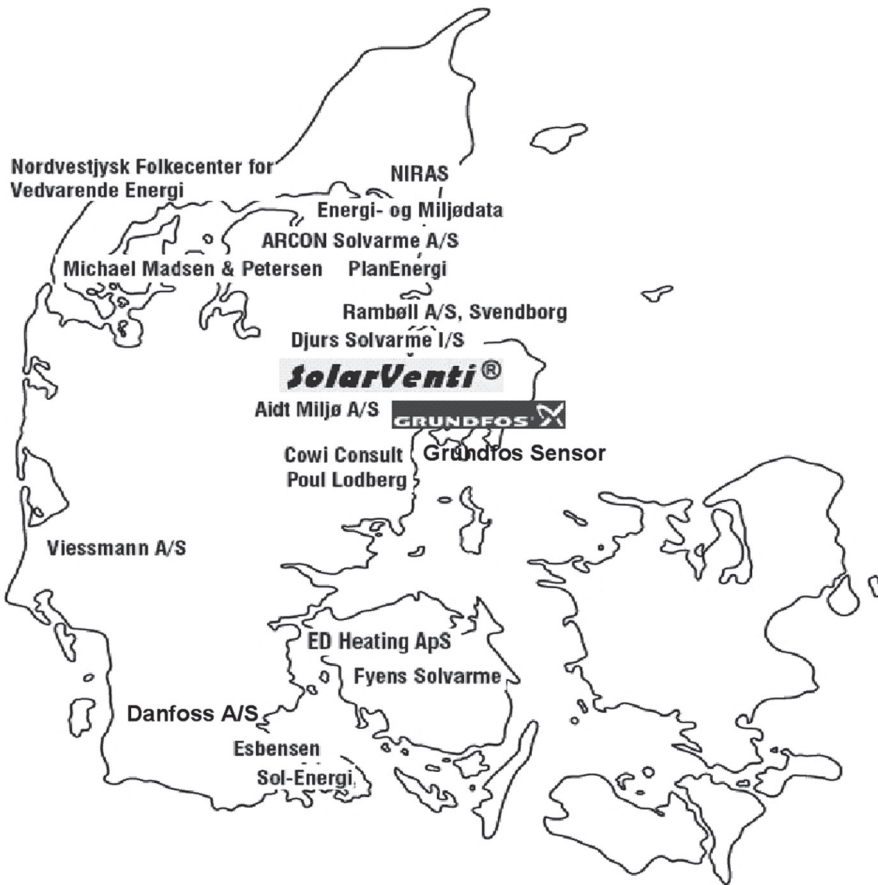
Figure 2
The North Central Jutland Wind Turbine Cluster



Source: Danish Wind Industry Association Statistics.

Figure 3

North Jutland's Solar Thermal Energy Cluster



Source: Composed from ESTIF Data.

Cluster, its specialisation or differentiation and its potential for exploiting knowledge spillovers for competitive advantage. In the research to be reported below, the Danish Wind Energy Association database was accessed and the details mapped by location and categorised according to point in the supply chain. Thus final

assemblers were differentiated from major module suppliers (e.g. fibre-glass blade manufacturers) and general components suppliers from them and services and logistics suppliers. Some fifty of the seventy members were found to be located in geographic proximity in Jutland, mostly in the more northerly part.

Of considerable interest here is Denmark's political commitment since 1970 to wind energy and what research reveals to be the North Jutland region's wind-turbine cluster has to be addressed. On this, Andersen et al (2006) point to the wind energy industry having passed through an early phase characterised by numerous small and medium-sized enterprises (SMEs) producing domestically-scaled wind power for individual farms and householders. But latterly, especially since the government subsidy to domestic consumers was removed in 2000, exports have risen, the scale of equipment has increased tenfold and sea power from large-scale offshore wind farms has come to predominate. As wind turbines have only some ten years life expectancy, most early wind turbines in rural Denmark will soon disappear if they have not already done so. So the current industry structure is large Danish (*Vestas*) or foreign (*Siemens*, *Gamesa*, *Suzlon*) producers and a supply platform of SMEs. There may be less local sourcing of key equipment like gearboxes than in the early days when North Jutland shipbuilding firms could adapt to meet the nascent wind energy demand. However, the scale and adaptability of German heavy engineering in cranes and related equipment means they now supply the Danish wind energy input market. Services and special logistics firms, the latter capable of transporting the now typically massive fibreglass turbine blades also exist in proximity as do a great many components suppliers (Fig. 2).

Stoerring (2007) agrees with this evolutionary profile pointing out that scale was also partly induced in the early 1980s by huge demand for wind turbines from the US and more particularly California.

Then, in the late 1980s this market collapsed because California's state administration removed its subsidy regime and the Reagan administration cut alternative energy research budgets. At this time many US turbines malfunctioned badly and even the superior Danish 3-blade design was prone to breakdowns. Thereafter, the industry recovered as demand in European and Asian markets rose. Nowadays (Fig. 2) around half global production capacity is accounted for by Danish firms like world leader *Vestas Wind Systems* of Randers, near Århus (acquirer of Danish firms *NEG-Micon*; *Nordtank*; *Wind World*) and *Siemens (Bonus)* at Brande and Ålborg. *Gamesa Wind Engineering*, Spain's largest producer of turbines is at Silkeborg, Jutland. *Suzlon*, India's leader is located at Århus. *LM Glasfiber* of Lunderskov near Århus in Jutland is the leading supplier of fibre glass wind turbine blades. The other members of the North Jutland cluster are in Fig. 2. Of the Danish Wind Industry Association's 70 members, 50 are in Jutland, mostly north-central Jutland. More is said on the etymology of this 'green cluster' evolution in the final section of this paper. Universities (AV) join DTI (see Table1) as a knowledge generation sub-system of the RIS.

As noted earlier, overlapping this substantial and globally leading wind turbine technology cluster is the main Danish solar thermal energy cluster (Fig. 3). This is smaller in scope but consists of largely indigenous firms and their suppliers. These involve firms in two types of supply chain as follows:

- Solar Collectors
- Glazed (Roofs)
 - (Flat Plate Collectors)
 - Glass
 - Heat absorbent copper/aluminium

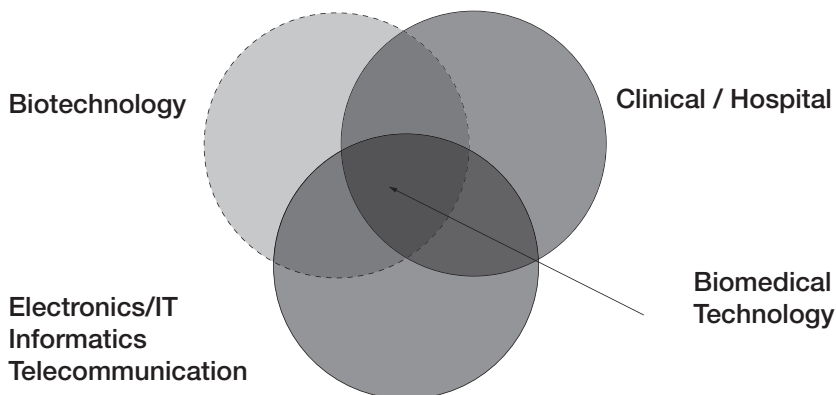
- Coatings, paint
- Pipes welded to absorber plate
- Vacuum Collectors
 - Parallel glass tubes
 - Absorber
 - Transfer pipes
 - Vacuum is insulator
- Unglazed (Swimming Pools) Long tubes
 - Synthetic absorbent material
 - Hydraulics in pool filtration system
- Heat storage & back-up heating
- Plumbing & Installation

Finally, exemplifying North Jutland's Jacobian cluster profile it is worth considering Figs. 4 and 5, the first of which reveals established cluster evolution in the shape of the NorCom wireless

communications cluster at Ålborg and the possibly emergent and overlapping biomedical technology cluster in close proximity (Stoerring, 2007). Here, the long-established wireless telecommunications cluster (Stoerring & Dalum, 2007) has given rise to possible cluster mutation by interaction with the healthcare activities associated with clinical trials and testing of biomedical equipment. Many of these activities are closely associated with science and technology commercialisation through academic entrepreneurship at Ålborg University. In Fig. 5 are shown the most prominent (though many have yet to be fully researched) of North Jutland's Jacobian clusters which are characterised as emergent clusters or established ones by their 'related variety' characteristics in relation to each other. This may be understood as follows in Table 1. In this graphic may be

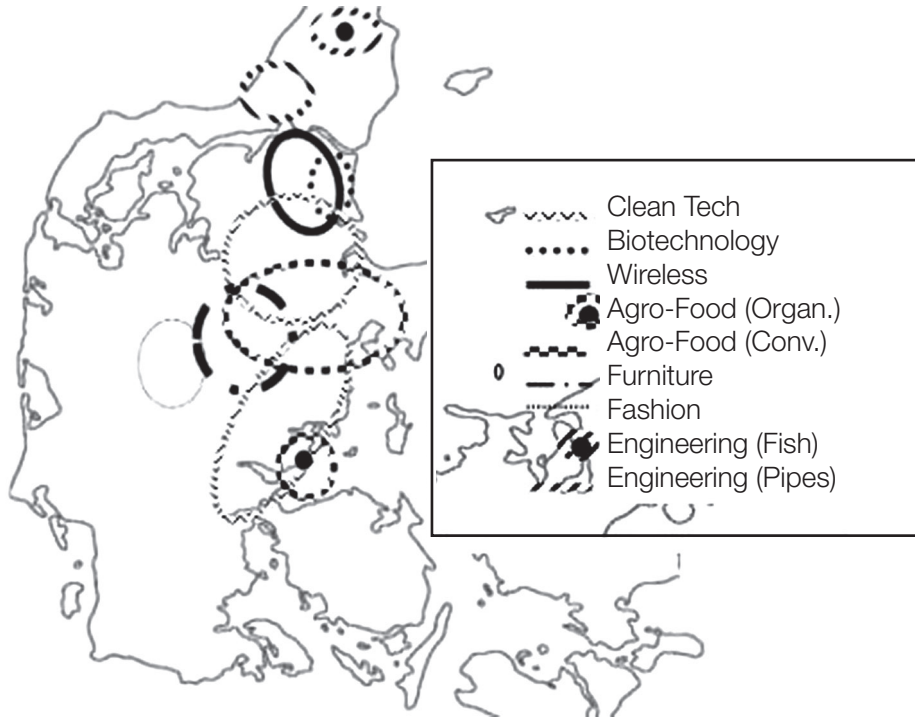
Figure 4

Jacobian Cluster Emergence in North Jutland



Source: Made by the author.

Figure 5

North Jutland's Jacobian Clusters & Related Variety

Source: Made by the author.

seen the stylised history of a significant part of the Jutland economy's evolution since it was radically transformed by nineteenth century railroadization as proposed by Schumpeter (1975). This process created certain path dependences or developmental trajectories. This kind of analysis is rather important and useful in explaining the ontology of such regional economies and their clusterization. Recall, for Schumpeter 'railroadization' was the purest, most radical kind of innovation based upon the creative destruction of a preceding state of nature (or at least non-farming economy). The massive

'entrepreneurial event' of 'railroadization' creates evolutionary trajectories that act as constrained opportunity sets for regional evolution. Activities displaying 'related variety' to the originating entrepreneurial event comprise the selected

Trajectories as in Table 1. These may foster varying intensities of innovation from disruptive (after Christensen, 1997) which cheapens (e.g. mobile telephony) an existing but specialised, uncommoditised technology (e.g. ship-to-shore radio) to incremental innovations around

Table 1
Jacobian Cluster Path Dependences

Technology	Path Dependence
Clean technology	Agricultural and Marine Engineering (e.g. wind turbine blades replicate plough and propeller design)
Biotechnology	Wireless ICT and Medical Technology
Wireless telephony	Ship-to-shore Marine Technology
Agro-food	'Railroadization' of undeveloped land in Jutland (conventional, intensive)
Organic Food	Reaction against conventional intensive food production in Jutland (mostly dairy)
Furniture	'Railroadization', craft schools and the local forestry tradition
Fashion clothing	Women's craft schools skilling farmer's wives
Fish equipment and Pipework engineering	Fishing and marine engineering

Source: Made by the author.

mobile telephony (first, second, third etc. generation mobile telephony).

There is insufficient space to offer a satisfying explanation for the Jacobian cluster mutation process in North Jutland but Kristensen (1992) underlines 'railroadization' as a key process where Jutland as a whole was opened up on a smaller scale but with similar inspiration to that of the Frontier West in the nineteenth century USA. With this came two key movements. The first was the farmer's co-operative movement where farmers supplied their own production and household needs, including banks. The second movement was the craft schools, established in over 350 centres, followed by the still flourishing Danish Technological Institutes from 1907. Together these made a form of social or

collective entrepreneurship possible. That is, infrastructure, education, technical support, finance and markets. Hence 'social capital' remains an important dimension of the SME-based collective entrepreneurship of North Jutland. It makes technological branching by means of related variety evolution possible. Finally, this is assisted by the existence of a RIS infrastructure of technological institutes, technical and craft schools and universities, which sustains entrepreneurship and localised knowledge transfer.

5. BIOENERGY FROM CROPS IN WALES

One of the most surprising, perhaps, but unquestionably innovative developments in the bioenergy field has occurred in recent

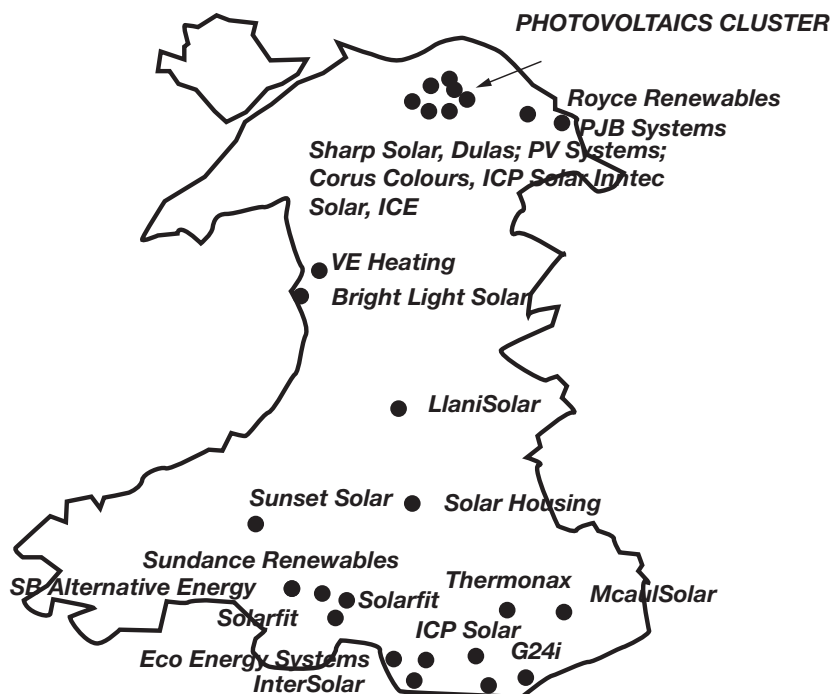
years in Wales. Descriptively speaking it involves patented knowledge derived by the Institute for Grassland & Environmental Research (IGER) based at Aberystwyth in rural, central Wales. This UK Biological Research Council-funded research institute has, for seventy years to 2007 been the UK's main, specialist grassland research institute. It was tasked from the outset with improving the quality of fodder for cattle and sheep feedstock, which is mainly grass. By the early 1980s research, which involved not simply breeding richer grasses but understanding the rumen of these ruminative animals, had revealed that a limit to quality on these mountain-bred animals occurred because the enzymes that broke down fodder into protein were actually consuming a significant portion of the nutritional value of the fodder consumed by the animal. Following many years of lengthy field trials and laboratory research, cross-breeding the basic rye-grass commonly utilised for cattle and sheep fodder with breeds possessing enhanced sugar content produced optimal results. The enzymes took some of the enhanced sugar content, transforming it directly into energy but left a substantial portion for the animal sufficient for the amount, nutritional value and flavour of the animal to be significantly enhanced. This came to the market at a time when consumer demand for leaner meat of the type raised in mountainous areas rose significantly and continuous improvement to the original *AberDart* strain of rye-grass, marketed by *Geminal Holdings*, over the intervening years led to it reaching 50% of the UK market. It further secured the status of Welsh Black beef and Welsh lamb as premium products and enabled significant improvements to occur in comparable upland cattle breeds such as Aberdeen Angus.

In 2003, it was realised that IGER had, in the form of these SugarGrasses, an indigenous product to add to its burgeoning portfolio of biofuels. Tests had shown that SugarGrass had twice the calorific value of sugar cane, the source of much of the world's biofuel. IGER thus evolved a second string to its grassland expertise by developing a renewables research division. One of the biofuel feedstocks in which it became supreme early on was the growing and processing of *Miscanthus*, more popularly known as Elephant Grass, an African tall grass that grows on marginal land. Accordingly it doesn't compete for land with food crops, one of the criticisms of the US and Europe's 'bolt for biofuels'. This has seen the ears and cobs of wheat and corn being turned into ethanol because of easy availability and major subsidy, causing up to 40% increases in the price of such cereals, and grief in developing country food markets.

Tellingly, IGER is widely perceived as in a global class of its own in these specific bioenergy sub-fields, the official view being that maybe University of California, Berkeley, may become competitive now they have received a \$500 million endowment for a Climate Change research institute from British Petroleum (BP). Apart from the University of Illinois, also mentioned as a possible future competitor, but only those two – IGER has a current lead on both of them. But in any case, SugarGrass is also twice as calorific as *Miscanthus* and SugarGrass is thus favoured as the technology with the best long-term prospect to replace oil. And IGER has the patent for SugarGrass, currently earning royalties of £100,000 per year from sales of seed varieties for fodder. But as the world awakens to the relatively simple processes

Figure 6

Solar energy equipment manufactures in Wales



Source: Made by the author.

of biorefining the product, these are likely to grow substantially.

So much so that agreement has been reached with Welsh Government officials about the promise of funds to help build an experimental biorefinery. Thinking had gone as far as to speculate that when oil ceases to be refined at the huge Milford Haven refineries in neighbouring Pembrokeshire, the pool of talent and infrastructural sunk costs would make them ideal candidates for becoming SugarGrass (and *Miscanthus*) biorefineries. These would continue to meet

a huge share of the UK's future energy. But it is not simply a spinout-venture capital model that is in mind. Possibly because a spin-out model doesn't yet work as well as a commercialisation outsourcing model in this nascent field. For example, *Molecular Nature*, the key spin-out of IGER, burnt-up its venture capital. But because of the value of its patent for biofuels potential as well as its fodder market, it was acquired by spin-in company *Summit*. Moreover, true to the traditions of co-operation among Welsh mountain farmers, IGER promotes a new vision of mixed farming whereby groups of

farmers grow *Miscanthus* on their poorest soil, devote some fields for SugarGrass fuel cropping and raise quality Welsh Lamb or Welsh Black Beef on their best SugarGrass land. Photovoltaics produce solar thermal energy as in North Jutland. In Wales, this has been studied by authors (Hendry et al., 2001) comparing the broader optoelectronics cluster, which also specialises in fibre-optic cabling, with those such as that associated with *Carl Zeiss* in Jena, eastern Germany. However, in relation to this present discussion about 'green clusters', it is the photovoltaics capability that comes to the fore. Fig. 6 reveals the presence of subdivisions of multinationals such as Japanese electronics corporation *Sharp* whose *Sharp Solar* subsidiary is based at St. Asaph alongside Corus Colours, a subsidiary of Corus, the UK-Dutch steel manufacturer, acquired in 2007 by Indian giant *Tata Steel*. Utilising polymer science and surface treatments Corus Colours has innovated radically a Solar Paint product capable of generating solar energy, especially from prefabricated steel buildings. Other firms in the photovoltaics cluster at St. Asaph are indigenous, such as Cardiff headquartered microprocessor firm *IQE* and 'green engineering' firm *Dulas*, headquartered in mid-Wales.

Hence, in conclusion, we see that numerous indications of clustering among small firms, but also some large firms, along with an applied and basic research infrastructure characterises important locations of 'green clusters' mainly, in this analysis, focused upon the production of non-fossil fuel energy that contributes to the moderation of global warming. A key feature to be discussed in the concluding section of this paper is that in some cases there is an element of cluster 'species'

multiplication which, from an evolutionary economic geography perspective can readily be hypothesised. As shown in Fig. 1, the California *Cleantech* clusters are to be found in juxtaposition to the ICT and biotechnology, food and wine clusters of the San Francisco region of northern California and the wireless telecom and biotechnology clusters of San Diego in southern California. Indeed, so-called *Cleantech* is widely seen as arising from the combination of biotechnology (including biopolymers and biofuels), ICT (sensors) and Nanotechnology (catalysts and filtration membranes). However, while agro-food is also one of California's key industries, agro-food path dependence seems even more pronounced in the cases of Jutland and Wales, as we have seen, while in yet another case forestry is important to Sweden's biofuels cluster in Örnsköldsvik (Cooke, 2007).

6. RELATED VARIETY BY OTHER MEANS: CLEANTECH IN NORWAY

The Norwegian model of developing green innovation usually involves large organizations evolving towards green innovation from intra-corporate related variety. Perhaps Norway's greatest strength in green energy is Carbon Capture and Storage (CCS). In 2007 the Norwegian government and Statoil made an agreement to establish a full-scale CO₂ capture and storage project at Mongstad (near Bergen, Hordaland). To limit technical and financial risks the project will progress in two stages. The first stage covers the Mongstad CO₂ capture testing facility which will be operational at the same time as the cogeneration plant starts operation in 2010. The testing facility/pilot plant will have the capacity to capture at least 100,000 tonnes

of CO₂ per year. The second stage involves full-scale capturing of approximately 1.5 million tonnes of CO₂ per year and will be in place by the end of 2014.

The technology development phase of the project is currently progressing according to the project execution plan. The main objective for the pilot is to develop more cost-effective technology for CO₂ capture for a wider international application, i.e. to develop, test, verify and demonstrate technology that would allow construction of full scale CO₂ capture plants with reduced costs and reduced technical and financial risks. A technology company will be set up to construct and operate the capture pilot, CO₂ Test Centre Mongstad. The government is currently in the process of inviting companies to participate in the technology company. The invited companies are potential users of CO₂ technologies and the aim is to establish a group of participants in May 2007. Several technological solutions will be tested in parallel in the project. This approach should ensure that technological developments in Norway could have broad international relevance. With the Mongstad CCS project we move from the research/small scale phase to actual construction of a full scale CO₂ capture facility.

Another larger firm with a leading position in Norway's solar energy industry is REC. This firm is the largest silicon foundry for photovoltaics in the world. The company has three divisions: first, REC is the world's largest dedicated producer of silicon materials for photovoltaic applications and holds all rights to its proprietary production technology. Solar grade silicon produced by REC can be used in the production of both mono and multicrystalline wafers, as well as wafers based on ribbon technologies.

REC is also the world's largest producer of monosilane gas, which in addition to being used internally by REC to make solar grade silicon, can be used by others in all types of thin-film silicon applications. REC is also the world's largest producer of multicrystalline wafers, with a history of rapid business expansion and introduction of leading production management techniques to increase productivity. REC combines high quality manufacturing equipment with proprietary technologies to achieve high productivity. Third, REC Solar's cell and module facilities are among the most automated plants in Europe, and REC is currently developing new technology to strengthen its competitiveness and ensure future growth. The facilities are focused on few products and customers, allowing a lean approach to production. REC's main production centres are at Sandvika and Porsgrunn in southern Norway (near Oslo) and Narvik and Glomfjord in the north. In each case a significant number of specialist suppliers are located nearby.

7. CONCLUSIONS & THEORETICAL IMPLICATIONS

By virtue of an examination of the emergence of green clusters, often involving the production of new forms of non-fossil fuel energy aimed at lessening of overall GHG emissions derived from human economic activity, a curious feature of economic evolution has been revealed. The clue lies in the element of convergence that characterises green innovation. As hinted at in the cases of northern and southern California, not studied in detail here but examined elsewhere (Cooke, 2007), the type of 'Cleantech' industry emerging in the clustered form described by Burtis et

al., (2004; 2006) evolves from agro-food, ICT and biotechnology. In North Jutland we see something comparable having occurred. Thus the wind turbine and solar thermal clusters are found in the more agricultural and marine engineering regions of Denmark. In writing the history of the former industry, Karnøe & Jørgensen (1996) and Jørgensen & Karnøe (1995) note how the Danish design of wind turbines defeated the main global competitor from where a significant renewable technology demand also arose simultaneously from the 1970s, namely California. As noted, Danish wind turbine blade design was influenced by the agricultural engineering industry, notably the design of modern ploughing equipment. In the experimental innovation phase when some thirty firms engaged in the design of prototype turbine blades, knowledge spillovers from the design of propellers by marine engineers in the Jutland shipbuilding industry were also absorbed. This resulted in a three blade solution and the idea that the greater efficiency in the operation of such blades came from pointing them into the wind. California's aeronautics tradition, by the 1970s predominantly relying on jet propulsion, led to the recovery of historic knowledge of propeller-driven aeroplanes. This suggested a two-blade solution pointing downwind. The Danish solution proved far superior to the Californian in this technological contest.

Hence in these multi-cluster locations, it is clear that a good deal of technological convergence is possible and probably necessary. But, interestingly, comparable technological assets do not necessarily produce optimum solutions from such Schumpeterian 'new combinations'. Nevertheless, it is clear that in some regions cluster forms can evolve quite readily from

other cluster forms, the cluster 'species' multiplication giving the region more of a cluster 'platform' characteristic to its industrial organization. On further inspection, both California and Jutland prove to have spawned many clusters. In the former case, wine clusters overlap the horticultural zones, Hollywood's film cluster is well-known and Porter (1998) also profiles other, sometimes highly specialised clusters such as the alloy golf club cluster at Carlsbad in the southern Californian desert. Further inspection of the cluster history of Jutland reveals the detailed cases of Salling (furniture) and Ikast (clothing), the even more closely studied NorCom wireless telephony cluster at Ålborg (Stoerring & Dalum, 2007), the emergent BioMedico cluster also at Ålborg, and as yet unexamined cluster candidates in insulated pipework near Ålborg, and fish processing equipment near Skagen, at Jutland's northern tip. At Barritskov, east Jutland is the estate that sustains the *Årstiderne Organic Food Network*, a co-operative retail network that delivers 30,000 boxes per week of organic food throughout Denmark. It could also be argued that there is a high degree of knowledge transfer from varieties of agricultural production to bioenergy production in Wales leading to possibly nascent cluster-formation, but also from glass technology to fibre optic cables and then photovoltaics by a different route into renewable energy in a multi-functional opto-electronics cluster. Species multiplication or mutation of this kind would be perfectly consistent with an underlying theory of evolutionary economic geography, especially that part referring to the opportunities for innovation and growth arising where there is *related variety* among industries. Absorptive capacity for adaptation to new combinations based on easily understood knowledge spillovers

would be the mechanism by which such species multiplication is explained, as the case of Jutland's wind turbine technology illustrates especially clearly.

In other cases focusing upon 'green innovation' cluster specialisation rather as ascribed to Marshall-Arrow-Romer (MAR) thinking seems on the face of it to be more convincing than the idea of Jacobian clustering (after Jane Jacobs' notion of innovation through variety). Yet even where limited clustering occurs, as in Rhineland or Brazil previously existing industries, whether the coal, steel and chemicals super-clusters of the Ruhr Valley or the sugar producing industry on Brazil are suggestive of the presence of important spillovers from knowledge of filtration and ventilation in the former and fermentation in the latter cases that were of profound importance to the evolution of new, convergent combinations of innovative products and processes. This tends to confirm clearly the widespread and common sense policy experience that clusters cannot be easily built *in vacuo* but may find it a less rigorous evolutionary trajectory to emergence where the regional context gives opportunities for Schumpeterian 'new combinations' from regionalised 'related variety'. Where such related variety is more attenuated, as perhaps with biofuels in Brazil or NE England, fewer 'Jacobian clusters' emerge.

However, that is not the whole of the explanation for Jacobian cluster mutation, rather it is an important contextual factor as noted, for example in the work of Cantwell & Iammarino (2003). Other key features that may be hypothesised, but further research is needed, is that Jacobian clustering benefits from other more social,

institutional, and organizational assets, such as those listed below, in addition to more economic assets concerning related variety, knowledge spillovers and high lateral absorptive capacity:

- Social Capital
- Collective Entrepreneurship
- Technological Branching ('new combinations' opportunities)
- Peripherality (perceived distance from key governance core)
- Infant Industry Subsidy
- Innovation System – Regional Research & Technological Institutes, Universities, Regional Innovation Platform Policy & Funding.

The key concluding point of this section is that, for the first time in regard to new industries, we see replication of processes that have historically underpinned successful regional economies that once spawned many traditional industrial districts or clusters. Evolutionists like Klepper (2002) for example would also highlight the transfer of routines from one to another industry by means of 'mobility of talent', as in the cases of the US, German and Italian automotive and engineering industries (see also Boschma & Wenting, 2007). Probably the key findings of this contribution in relation to evolutionary theory are the following. First, while Schumpeter had little to say about regional innovation, his concept of innovation by 'railroadization' proves to be highly apposite as an explanation of at least the case of Denmark's opening up of North Jutland and elsewhere in the west in the nineteenth century and its modern evolution into an arena of Jacobian clustering in related variety industries. Second, the green perspective somehow

threw the evolution of this kind of industry organization into clearer perspective because it focuses on a horizontal and convergent technology 'platform concept' rather than a more traditional industrial economics perspective that emphasises vertical structures like sectors or clusters. Finally, regarding cluster emergence within a Regional Innovation Systems context the research reported showed the importance of social capital, which even in California may be considered strong, as the work of Saxenian (1994) on Silicon Valley showed, as an evolutionary driver of certain kinds of regional innovation system. Indeed, whether as 'bonding' or more institutional 'bridging' social capital it is the key element of the hidden power of networks, both social and institutional, that has always been at the heart of the RIS approach to evolutionary science. Finally, it could be seen that the evolutionary processes described were capable of hosting differing intensities of 'innovative bursts'. Railroadization itself

was said by Schumpeter to be the most radical kind. Divergent, possibly disruptive, innovations like the semiconductor in California, mobile telephony infrastructure in N. Jutland cheapened and 'democratised' key technologies based upon new knowledge combinations. That other types of cluster-emergence can evolve, as around larger corporate interests in Norway, is beyond dispute and a different cluster biography from the dominant 'mutation' model discussed in this paper must be composed. In the main cases discussed here, incremental, narrowly path dependent innovation can evolve among cluster firms in proximity. History also shows there may be punctuated evolution with the more radical innovations around biotechnology from cancer-defeating therapeutics to fodder-based biofuels as knowledge evolves and broader economy regimes, notably that associated with the chemicalisation of fossil fuels, approach exhaustion and make way for a potentially cleaner bioeconomy regime.

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