Policymaking for the niche: successes and failures in recent UK marine energy policy

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Abstract

This paper examines the messy reality laying behind 'energy system transition' by looking at the formation and impact of recent policy and institutional changes in the UK marine energy (wave and tidal flow) sector. Within the timeframe considered by the paper (2003-06) the overall trend for the marine sector was positive, with growing levels of policy interest, investment and innovation activity. However, this overall picture disguises a more ambiguous processes of successes and progression, but also frustrations, conflicts and unintended consequences. Based on interviews with many of the actors involved, the paper explores these dynamics, and draws some observations in the context of wider recent themes in recent innovation studies.

1 Introduction

In the decade after its privatisation in the late-1980s, the UK electricity supply industry (ESI) was transformed by a policy and regulatory regime which emphasised short-term economic efficiency. While this was part of a wider international trend toward liberalisation and privatisation (MacKerron, 1994; Jacquier-Roux and Bourgeois, 2002), the UK ESI experienced a particularly dramatic transformation. Technologically, this was manifested in the 'dash for gas', the large-scale deployment of combined-cycle gas turbine power plants (Winskel, 2002; Watson, 2004); institutionally, in market-based and technology-blind mechanisms for wholesale power trading and renewable energy support (Helm, 2003; Mitchell and Connor, 2004).

The 1990s also brought about concentration of ownership, as most of the former publicly-owned electricity generation and distribution companies were merged together and/or absorbed into international companies (Thomas, 2006). This period also saw the loss of much of the industry's capacity to develop new supply technologies: the dash for gas was based on imported technologies, supplied to UK-based utilities on 'turn-key' contracts (Winskel, 2002).

This *liberal market* policy regime was eroded (though not wholly displaced) in the early 2000s, as growing concerns for climate change and security of energy supply provoked the re-emergence of a more contested energy politics, and a more fluid policy arena. After decades of very limited political and public debate on energy matters, the UK Government carried out two major reviews of energy policy (DTI 2003, 2006), and alongside these, there have also been numerous parliamentary debates, expert inquiries and consultancy reports.

As part of this, policymakers have sought to re-establish the UK energy system's technology development capacities, especially in renewable technologies. A detailed review of these reforms is outside the scope of this paper (see Winskel et al., 2006). The aim here is to examine their impact in a specific context: the marine energy (wave and tidal stream) sector. Within the wider remaking of policy, marine energy – a technology with a strong UK resource, a research base going back to the 1970s, and the potential for transfer from established industries – has been identified as a good candidate for long-term industry building (PIU, 2002; Carbon Trust, 2003; DTI, 2003, Scottish Executive, 2003). A series of recent initiatives by policymakers and support agencies have catalysed marine energy innovation activity.

However, unlike some other 'new' energy supply technologies (such as solar photovoltaics (pv), and fuel cells), marine energy has yet to attract the significant interest of established energy and engineering firms, or large-scale public support programmes. Rather, given the early stage of marine energy generation devices, and the perceived technical and economic risks involved, recent innovation activity in the sector has been driven by small-sized independent device developer firms.

In a context of distributed innovation capabilities, much of the emphasis in recent policy initiatives has been on building partnerships and networks among developer firms, university research groups and established engineering and energy companies. These efforts represent an attempt by policy to stimulate early-stage innovation system building (Winskel et al., 2006). They can also be seen as an attempt to mobilise *social capital* in the emerging system. As this paper examines, the mobilisation of social capital in a sociotechnical system with a legacy institutional orientation to financial capital faces a number of challenges.

The paper proceeds, in Section 2, by reviewing the role of social capital in technological innovation, particularly in early stage renewable energy. In Section 3, the UK marine energy sector is first outlined, before a detailed empirical analysis of the experiences and views of prototype device developers. Finally, in Section 4, the case is used to comment on wider research issues related to social capital, interactive learning and financial capital.

2 Social Capital in Energy Systems

2.1 Social Capital and Technological Innovation

Though a somewhat contested term (see Tura and Harmaakorpi, 2005), social capital refers broadly to the potential of a social system to learn through interaction, rather than actors' individual capabilities. More precisely, the OECD defined social capital as 'the networks …. norms, values and understandings that facilitate co-operation within or among groups' (OECD, 2001, page 41). Under this definition, social capital is the *underlying resource* that enables effective 'learning-by-interacting' through mechanisms such as R&D networks. A distinction is often made between *bridging* social capital (manifested in interactive learning which connects together different types of actors), and *bonding* social capital (which supports interactions within a social group, or between the same kinds of actors) (OECD, 2001; Tura and Harmaakorpi, 2005).

While social capital has become a research interest across the social sciences (see Woolcock, 1998; Schuller et al., 2000), a sizeable body of work has analysed its role in technological innovation (e.g. Freeman, 1991; Lundvall, 1992; Saxenian, 1994; Edquist, 1997; Lundvall et al., 2002; Pittaway et al., 2004). A recurring theme here is the important part played by bridging social capital in early stage innovation, especially for more radical or 'disruptive' technologies (Christensen, 1997; Lundvall et al., 2002; Maskell, 2004).[1] For example, Cooke et al. (2000, page 152) suggested that social capital may be 'the most important missing ingredient' in poorly performing regional innovation systems.

A related research theme, of particular interest here, is the relationship between social capital and financial capital (such as venture capital) in innovation processes. Some analysts characterise innovation systems according to their levels of financial and social capital resources, and identify conflicts and trade-offs between the two. For example, Lundvall et al. (2002) called for a re-assertion of social capital, trust and cohesion in the governance of innovation systems, which, they argued, was being increasingly undermined by the instabilities and short-termism associated with globalisation and finance capital:

there are contradictions inherent in the economic process that threaten learning and competence building by undermining social capital … increasingly it is finance capital that judges what is 'good-practice' among firms as well as among governments … the uninhibited rule of finance capital gets into serious conflict with some of the fundamental prerequisites for the sustainability of the learning economy (ibid., page 225).

Cooke (2004) contrasted European *institutional* and US *entrepreneurial* styles of innovation system, and identified dangers associated with a trend, in Europe, towards more US-style entrepreneurial systems: their fragmented and unstable support structures, the primary role given to venture capital and the corresponding absence of the checks and balances seen in more institutionally rich systems. Cooke objected to the instability engendered by venture capital, and also its symbiotic ('some would say parasitic') reliance on public funding for innovation (ibid., page 5).

Noteboom (2000) compared national innovation systems for radical technologies in the US (a formal 'contract-based' system characterised by relatively mobile flows of capital and personnel) and Germany (a system based on trust and more stable social and financial arrangements). Noteboom concluded that these different national styles were suited to different types of innovation: the German-style system was likely to have advantages in cases where production technology was inflexible, knowledge was largely tacit rather than codified, and innovation relied on durable relations between and within firms. Similarly, Christensen (1992) argued that European-style 'credit-based' (or bank-oriented) systems and 'Anglo-Saxon' capital market-based systems had their respective advantages: credit-based systems provided a better environment for interactive learning, while capital market systems had advantages for project selection.

Innovation studies research on social capital, interactive learning and financial capital tends to focus on high-technology sectors such as biotechnology and information technology (Pittaway et al., 2004). Energy systems, which receive much less attention, present particular enablers and barriers to innovation – for example, they are especially prone to technical and institutional inertia and lock-in (Martin, 1996; Unruh, 2000). These particularities limit the relevance of wider research studies, and invite a closer look at dedicated research in this area.

2.2 Renewable Energy and Interactive Learning

Although still relatively under-researched, the remaking of energy policy internationally since 2000 has been associated with an expanded research effort on innovation in energy systems. Within this, a number of studies have focused on early stage renewable energy innovation. For example, in a comparative analysis of wind power development in Germany, the Netherlands and Sweden, Bergek and Jacobsson (2002) noted the advantages, in the German system, of a long period of interactive learning, network formation and institutional adaptation. A study of solar pv development in Germany (Jacobsson et al., 2004) found similar benefits from early phase interactive learning; it also highlighted the long-term advantages – given uncertainties in prototype performance and economic context – of prioritising design variety in this early phase, despite associated trade-offs in scale economies.

The Danish wind power industry has attracted particular research interest. For Jørgensen and Karnøe (1995, page 74) this emerged from the 'interactive co-evolution of institutions, technologies, organizational forms and social groups'. Garud and Karnøe (2003) highlighted the role of interactive learning between device developers, technology users, existing engineering firms, a prototype test centre, and policymakers and regulators in the Danish windpower system. Kamp et al. (2004) also noted a distinctive emphasis, in Denmark, on trust-based interactive learning between device developers, project developers and university researchers in the gradual improvement and scaling-up of device prototypes.

By contrast, a number of studies have associated poorly performing systems with weak interactive learning. Christiansen and Buen (2002) attributed the stagnation of wave power in Norway (in-part) to organisational rivalry between research groups, and weak university-industry links. Jacobsson and Johnson (2000) and Johnson and Jacobsson (2001) associated the failures of renewable energy in Sweden with undeveloped bridging institutions between technology developers and users. Arnold et al. (2003) observed a similar fragmentation in Swedish renewable energy R&D, and identified greater research successes where there was a relatively close association with industry. The US windpower system has also been seen as limited by weak links between device developers, component suppliers, project developers and the national test centre (Heymann, 1998; Garud and Karnøe, 2003). Kamp et al. (2004) found university-industry links in Dutch windpower inhibited by lack of trust and diverging backgrounds between different system actors.

Although social capital and interactive learning are rooted in social norms, they do not spring *sui generis* from a society. Rather, as various studies point out, they are developed (or stifled) in specific economic, organisational and political contexts. Economically, for example, Danish and German 'feed-in' laws have helped build links between renewables producers and utilities (Jørgensen and Karnøe, 1995; Bergek and Jacobsson, 2002; Garud and Karnøe, 2003; Jacobsson et al., 2004). By contrast, fiscal incentives in Sweden and the US failed to secure the significant participation of established firms in renewables development (Loiter and Norberg-Bohm, 1999; Norberg-Bohm, 2000; Jacobsson and Johnson, 2000; Johnson and Jacobsson, 2001).

Organisationally, a range of different groups: 'grassroots' technology developers, environmental pressure groups and industry associations were able to participate in or shape innovation processes in Denmark and Germany (Jørgensen and Karnøe, 1995; Garud and Karnøe, 2003; Jacobsson et al., 2004). In less successful cases, such as Sweden and Norway, influence often remained concentrated in established producer groups (Jacobsson and Johnson, 2000; Johnson and Jacobsson, 2001; Christiansen and Buen, 2002). Policy inconsistency over time has been associated with muted or interrupted learning processes in Norway (Christiansen, 2002), Sweden (Jacobsson and Johnson, 2000; Johnson and Jacobsson, 2001), the US (Loiter and Norberg-Bohm, 1999; Norberg-Bohm, 2000) and the Netherlands (Agterbosch et al, 2004).

Finally, another repeated research theme is the serendipity of more successful renewables innovation with crises in established technologies, or sudden shifts in the political economy of energy supply. These have provided 'windows of opportunity' for renewable technologies to break out of their niches (Bergek and Jacobsson, 2002; Garud and Karnøe, 2003; Jacobsson et al, 2004). Though unpredictable, these contingencies can only be seized on by already well-functioning renewables innovation systems – those which, research suggests, are likely to exhibit high levels of interactive learning and social capital.

2.3 Summary

Energy systems tend to inertia and lock-in, and disruptive technologies such as renewable energy struggle to gain adequate support from established interests. In this context, 'bridging' social capital has played an important role in a number of cases of more successful renewables innovation, mobilised through interactive learning between technology developers, users, suppliers and testers. Interactive learning of this kind has, over time, enabled the gradual improvement and upscaling of prototypes.

Different social settings – regional, national and supra-national – offer different conditions for building and mobilising social capital. Some analysts have identified fundamental trade-offs between social and financial capital, so that those societies (such as the US and UK) that give relatively free reign to financial capital will have a weaker social capital resources than those (such as continental Europe states) that operate more restrictive frameworks for capital flows. For the present case, this suggests tensions between a national economy and energy sector oriented to financial capital, and the relatively stable socio-economic conditions which provide the best conditions for long-term technological innovation. As such, the UK energy system presents an unlikely environment for developing marine energy technology. To explore these tensions in more detail, the next section analyses the impact of recent policy initiatives aimed at stimulating interactive learning in UK marine energy sector.

3 Marine Energy Innovation in the UK

3.1 Policy Background

Marine energy has a lengthy – though marginal – history in energy systems.[2] In the 1970s, the UK Government sponsored a *Wave Energy Programme* to partner together device developers (then at a very early stage of development) with large engineering firms. The Programme aimed to identify a prototype device capable of economic upscaling to a large power plant, but this proved to be an unrealistic target, and the programme was (controversially) cancelled in the early-1980s (Thorpe, 1992; Ross, 1995, 2002). For the rest of the 1980s and most of the 1990s, the international wave energy research community amounted to a handful of university research groups.

Changing political and economic circumstances provoked a resurgence of UK policy and industry interest in marine energy in the late-1990s. A new Labour government was more inclined to offer support to non-commercial emerging technologies than its Conservative predecessors, although this remained relatively limited. Around the same time, a number of expert and parliamentary reviews highlighted the unexploited potential of marine energy (OST, 1999; RCEP, 2000; HCSTC, 2001). The UK Government (and the European Commission) began to award R&D grants for prototype development to university research groups. A few private sector developer firms were now created to exploit the new funding opportunities in a more commercial setting.

This growth accelerated in the early-2000s. In its 2003 energy policy White Paper, the UK Government identified marine energy as a priority area, with the potential for enhanced R&D support to lead to a 'step change' breakthrough (DTI, 2003). At the same time, marine energy became a particular interest of the recently created Scottish Parliament and Executive (Winskel, 2007). The Executive identified an opportunity for Scotland to become a 'world leader and exporter of marine power technology' (Scottish Executive, 2003, page 13), while the Scottish Parliament declared that Scotland could 'become to wave and tidal power what Denmark is to wind power' (SPECC, 2004, paragraph 55).

Within a wider remaking of policy, a series of specific initiatives were made to stimulate marine energy innovation activity. These included expanded capital grant support for device prototypes under the UK Government's *Technology Programme*; the Carbon Trust's *Marine Energy Challenge*: a publicly funded programme of bilateral research partnerships between device developers and engineering consultants (Carbon Trust, 2006); *Supergen Marine*: a university-industry research consortium funded by the Engineering and Physical Sciences Research Council to carry out 'generic' R&D; the *European Marine Energy Centre* (EMEC), a test and verification centre for device prototypes; and the DTI's *Wave and Tidal Stream Energy Demonstration Scheme*, which offers tariff support to a few selected devices (DTI, 2005).

These and other initiatives represented a significant effort to promote marine energy, and led to the emergence of many new device developers in university research groups or small firms. Leveraging enhanced public sector support, a few leading developers were able to attract private finance, mainly in the form of venture capital funding. By the mid-2000s, the UK marine sector included over 20 device developer firms, and around 15 active university research groups (UKERC, 2006). The next section analyses device developers' experiences of, and views on, recent policy initiatives to promote interactive learning in the sector.

3.2 Marine Energy Device Developers

This section is based on discussions with marine energy device developers. The sample of 15 developers includes several UK and several overseas organisations, although many of the latter have recently set up UK bases. Most of the developers represented here are small private firms, although the sample also includes a few university-based groups. The interview material is used here to illustrate the challenges (and opportunities) of interactive learning in the UK marine energy sector. Given the relatively small size of the sector, the interview set represents a significant proportion of all marine energy device developers internationally.[3] To protect identities, the interviewees are referred to as 'D01' to 'D15', randomly assigned.

3.2.1 Financial Context for Innovation

As developers themselves recognise, marine energy is a challenging (and rather unlikely) area for small firm innovation: *it's very hard: it's a very lengthy process, and it's big stuff … it requires an SME to do the development work, but it's a 'big company' length and cost type of project* (D09). Innovation activity in the sector is being supported by a combination of public and private finance, and raising finance involves a considerable effort by developers: *there's a lot of little companies … spending a lot of effort on raising money; it's not coming easily* (D06). Given the recent expansion of public financing of R&D, securing private finance presents the greater challenge: *there's plenty of interest from a variety of public bodies to assist us, it's the private funds that are the bigger issue* (D11).

The prominent role for private capital reflects the liberalised economic context for innovation in the UK energy system. However, unless directed to do so by public policy, private organisations and finance are disinclined to engage in early stage innovation for energy supply technologies: *investors seem to be incredibly nervous of anything new … the general [position] is 'let's sit there and watch what happens' … there's no feeling of 'we ought to be getting in there early, trying to help'* (D05); *the utilities have a short- term focus … what they generally do is sit back, see which technologies survive … then come in and cherry pick … UK companies are very much short-term and market-driven* (D02).

Raising private capital becomes essential as prototype devices scale up from concept proving, tank testing, trials in seawater docks and eventually, open sea trials. After concept proving, public grant schemes typically require matched funding from the private sector: *after prototyping in a tank it's a gigantic step, and by that time you should have an extra investor* (D03). Some developers have established relationships with established engineering firms and power companies, but translating this into investment has proved challenging: w*e'd certainly like to get more involvement at an earlier stage from electricity generating companies … we have confidentiality agreements with some … but [not] money in the bank, which is what we need to match government funding* (D10). A few more advanced developers have formed industrial consortia with component suppliers and prototypes manufacturers, but even these links tend not to manifest as direct support for R&D: *our industrial partners are interested in developing schemes, but not in putting money into developing technology … they want to be involved when it's successful … getting them involved at the pioneering stage is more of a challenge* (D06).

3.2.2 Venture Capital and Marine Energy

In the absence of more significant industry or public financing, many developers seek venture capital (VC) finance. As developers have discovered, however, potential VC investors are uneasy with the technical and market uncertainties and long development timescales associated with marine energy: *energy investments are* *made over the long-term … VC investors are interested in when are they getting it out. The 'when' bit is a big problem for this type of investment* (D11); *we've made it clear we believe that it will be seven years plus before we've got something that's beginning to compete … venture capitalists … [are] looking for something big happening in a three year timeframe* (D01); *venture capitalists are … not concerned about taking a technology through to the full commercial market which might be a five or ten year time frame* (D02).

The mismatch between VC investment horizons and marine innovation timescales applies not only in the UK, but also internationally: *we came to the conclusion that UK venture capitalists would never fund it* (D05); *venture capitalists have been ice cold, both in the US and Europe* (D04). Another difficulty developers have encountered in their negotiations with potential VC investors is the absence of a discrete market for marine power: *a venture capitalist wants to know 'is there a market?' … you can point to the large electricity market … but it gets a bit more tricky when you [try to] point to the subset of that which is the supported market for marine energy* (D15).

Despite these barriers, a few leading developers have been able to secure VC finance. Within the wider community of developers, however, this success is seen as rather double-edged, given the accompanying conditions and expectations: *the way some developers are being financed means they've got to succeed quickly, so their storyline is 'we're doing this, and we're doing it quickly'; as soon as they don't do what investors want there's a problem* (D09). For some developers, these conditions are so onerous that they prefer to remain self-financed, even though this leaves them with fewer resources for development: *we've been quite happy not having external investors and keeping to quite a low budget. It means no one is pressurising us, so we can take quite diligent steps and keep control, testing every milestone, and gaining confidence in the changes we've made* (D03).

Other developers have been able to finance their R&D using revenue from established business areas: *most of the work has been done using money from our other industrial activities* (D04). This may also involve seconding staff from other parts of their organisation: *if we had to take on staff of our own, we'd end up having a very tight market schedule that might not be achievable; some companies are going to go bankrupt that way* (D09).

3.2.3 Financial Capital and Innovation Activity

Financial capital has a number of effects on developers' R&D activity. As described above, venture capitalists' demands for short-term returns present the danger of overly-accelerated development schedules: *you get this problem of high expectancy and the pressure to deliver and upscale rather rapidly and unrealistically* (D03). At the same time, developers' concern for 'investor confidence' have a stifling effect on innovation, with a tendency toward risk-minimising behaviour: *the kind of thinking that develops is 'better go to the shareholders with another study' than really doing things'* (D12).

In some cases, developers' awareness of financiers' sensitivities to risk means that they undertake expensive 'over-engineering' of their prototype devices, so as to reduce the chances of technical failure in prototype trials: *everything costs twice as much because we are not allowed to make mistakes* (D12); *we're having to over-engineer dramatically because it's much more important not to be seen to fail than design the cheapest possible solution* (D05).

These concerns have led to the suppression of technical problems encountered in prototype trials: *[referring to another developer] found out things during development, but were ashamed – they wouldn't go to their financers and tell them they'd made a mistake* (D12). They also mean that developers are disinclined to any wider dissemination of their 'learning-from-mistakes': *a technology that discloses its problems will become a loser, because the market … will go in a different direction … there is a risk of that technology shooting itself in the foot* (D02). These fears appear to have some foundation in experience, as past setbacks in prototype trials have carried significant knock-on effects: *every time there's a failure you lose a couple of months across the whole industry* (D09).

3.2.4 Intellectual Property and Interactive Learning

For almost all device developers, intellectual property (IP) is essential for attracting private finance and building-up their business over time. Developers' concerns to protect their IP are a powerful barrier to dissemination of their R&D results and prototype trials: *you have the disadvantage with a new technology that it's unreliable and expensive. But you have the advantage that you own the IP rights. If you're sharing information … you're in an almost impossible situation* (D05); *commercial institutions die unless they succeed, and succeeding is reaping working knowledge … you cannot share that* (D09); *it cost us a lot of money to get the results of tank testing, and that's part of our intellectual property, which is all the value the companies hold at the moment; obviously … [we] wouldn't want to disclose the details of that* (D10).

In this context, developers' recognise that they face having to undertake lengthy and difficult 're-inventing of the wheel': *developers will make the same mistakes, and these will increase the cost of development and the time over which the technology will be developed* (D02); *we're all doing exactly the same learning exercise, learning slightly different things and probably making the same mistakes … but you're not going to get us to share our mistakes because it has cost us a lot of money to learn that mistake* (D09); *every product developer is trying to get information from each other, but I don't think people work together* (D13).

Despite these barriers, it would be misleading to portray developers as wholly isolated from each another. Rather, there appears to be a modest level of sharing and dissemination: *we're quite happy to talk about general ideas, but not to disclose details* (D10); *there's certain things you can share – but not the majority of it* (D09). Another developer described interaction with their peers as a useful supplement to the primary R&D taking place inside developer firms: *you get inspired by things that you see around or communications that you have with others … [but] the solutions are created internally within the developer groups. You concentrate on solving certain problems, and protect that, if it's worth protecting* (D03).

3.2.5 Interaction with Universities and Public Research Infrastructures

Some developers expressed scepticism about the contribution of university research groups to marine energy innovation. Some identified basic conflicts of interest between developer firms and university research groups, suggesting a unwillingness to participate in industry-university R&D networks: *academics want to get as much information as they possibly can, especially new exciting stuff, so they can get a refereed paper out … That's totally contradictory to the interests of industry* (D05); *academia … get their reward by sharing information without cost. The government want [developers] to share too, because it's costing [public] money every time they sponsor someone, but [developers] won't do it, because it costs them money as well* (D09).

For one, the generic R&D undertaken in university-industry networks had a marginal role, compared to in-house innovation: *from our perspective, if there's something that's vital for us to do, then we should be doing it ourselves … if it is more generic then it's not really top of the list* (D15). Another developer suggested that there was only a limited, self-interested, engagement by the developer community in university-academic networks: *the industry will join [networks] to absorb information and find out what's going on, as opposed to necessarily contributing. I don't believe that when firms sign up they are proactively contributing and disseminating to the rest of the consortium* (D02). In another case, perceived IP vulnerability had limited its participation in research networks: *we keep an eye* *on what's going on, but we're not actively involved … we have patents, but like any small company, our fear is always that somebody's going to run away with the idea* (D11).

One developer's concerns to protect their IP had led to its withdrawal from a research network: *if we signed up we would [have been] obliged to reveal anything and everything … we've gone to a lot of risk and trouble to find out these things. Other people could come along … and harvest whatever looked really good, at our cost* (D05). Confidentiality concerns have also restricted some developers' engagement in the publicly-funded infrastructure for marine energy testing, such as the European Marine Energy Centre (EMEC): *you don't want to expose [your technology] to a team who are seeing someone else's devices next week or last week … [these] are publicly accountable bodies and once you've signed up with them you can find you're exposed, whether you wanted to be or not* (D06).

Other developers had some concerns about research partnerships such as the Carbon Trust's Marine Energy Challenge,: *the Marine Energy Challenge … wasn't ideal … [our partners] were working with a number of different [developers] … that is definitely an issue and probably … put a lot of people off getting involved* (D11); *we were concerned about how our information was being dealt with … [and] I can imagine that for other developers the rewards were not enough to share their information* (D03).

3.3 Summary

Different developers have responded in different ways to the challenges of their financial environment. For many firms, private finance has a prominent role, alongside public finance and institutional support. Established organisations in the electricity supply industry tend not to engage in long-term innovation, and although marine developers have successfully cultivated relationships within the industry, these have mostly not led to financial support.

In the absence of more significant role of industry or public funding, venture capital has assumed an important role in the sector. VC is seen as a double-edged sword; while a few developers have attracted VC support, others have tried and failed, and others have preferred to remain self-financed so as to define their own pace and direction of development. Although VC finance provides much-needed resources for R&D, it brings demands for short-term returns on investment. VC investors' sensitivity to technical risk also places developers under pressure to over-engineer their prototypes, and suppress any learning-from-errors in prototype trials.

For most developers, protecting and building IP value is fundamental to their business strategy, outweighing any public policy signals to disseminate results from prototype trials. As developers themselves recognise, this emphasis on private/in-house innovation, rather than interactive learning, leads to repetition of effort and resources. A perceived conflict of interest with public research networks and infrastructures prohibits meaningful networking for some developers.

Despite the barriers to interaction presented by VC and IP protection, it is misleading to portray device developers as being isolated from their peers, academia or wider industry. The overall pattern that emerges is of moderate and mostly informal interactions between developers, and across university-developer networks, and, for a few, stronger and more formal partnerships with industrial partners.

4 Conclusions

Marine energy first emerged in the wake of the 1970s energy crisis. A series of policy initiatives in the early-2000s have stimulated renewed innovation activity in the technology – but in a very different institutional context. In the intervening period, the UK energy system developed an embedded commitment to financial capital. Despite some reforms since 2000, the system's dominant institutions and organisations remain oriented to short-term market efficiency and disinclined to support long-term innovation. As a result, contemporary marine energy innovation is being driven by small private firms, who operate in an investment climate intolerant of technical risk, yet which imposes high short-term expectations.

The policy initiatives to promote marine energy innovation in the early 2000s were essentially grafted-on to a system with a continuing orientation to financial capital. The social capital needs for effective learning were left largely unaddressed, and the initiatives have faced many barriers in their efforts to promote interaction. Rather than promoting bridging social capital across the sector, much of the recent activity in sector has drawn on (and reinforced) bonding social capital within developer teams. The case confirms many of the tensions and misalignments between financial capital and social capital identified by others.

At the same time, the present case (and previous studies) suggest a more complex relationship between social and financial capital than a straightforward 'zero-sum' trading-off. Instead of counterposing financial and social capital resources as incommensurables, this paper has sought to analyse their co-existence and interaction in contemporary innovation. Although venture capital and intellectual property present powerful barriers to interactive learning, they are also cornerstones of most developers' innovation activities, including their networking. For a few firms, IP value and VC finance have enabled the formation of strongly co-ordinated networks of suppliers, manufacturers, and project developers. In these instances, rather than being wholly inimical to interactive learning, financial capital can be seen as helping to mobilise social capital.

Developers accounts' have revealed powerful barriers to the more open kind of interactive learning that played an important role in the emergence of renewable technologies in the past. Despite the analogies drawn by some, recent UK policy initiatives cannot hope to reproduce these learning processes; the equivalent social capital resources are not available in the contemporary UK context.[4] Rather than consigning recent initiatives to failure, however, it suggests that the kinds of learning they enable will draw on, and reflect, local resources and opportunities.

Energy systems are making much more haphazard, piecemeal and faltering responses to climate change than is suggested by much of the transition management literature. Rather than being well ordered and co-ordinated, the emergence of new policies typically reflects particular political and organisational interests, resources and remits – including perceived opportunities to 'make a difference' in a crowded policy landscape. Further, the impact of such initiatives are marginal to (and heavily conditioned by) historically embedded layers of power, interest and commitment.

In this context, processes of change (and policy impacts) are often the outcome of serendipity – a fortuitous coming together of different interests and opportunities, or a deliberate, pragmatic and temporary alignment of particular shared interests. However, the achievements of policy are almost always partial and limited, so that the policy process involves successive rounds of identifying problems and forming solutions. Over time, sociotechnical systems testify to these multiple interventions.

The danger of all encompassing multi-layer and systemic analytical frameworks is that they suggest a rationalistic and straightforwardly steerable 'governance' of technology. The essential unpredictability of change – its conditionality on R&D outcomes, local context and coincidence with other events – is underplayed. They may, for example, rely on an unrealistic level of co-operation among actors in the niche. More generally, this may mean that policy reforms are unable to deliver on their promises, are insufficiently customised to the needs and capabilities of local actors, or are implemented too rigidly to respond to changing events and opportunities.

Notes

1. Bonding social capital has been associated positively with incremental innovation, but, because it tends to reinforce established practices, it is often negatively associated with radical innovation (Ehrnberg and Jacobsson, 1997; Tura and Harmaakorpi, 2005).

2. For an introduction to marine energy, see IEA-OES (2003); Duckers (2004).

3.The interviews were one-to-one semi-structured discussions of around one hour with the firm's founder-director in most cases, or other senior directors in a few cases. The interviews were conducted between October 2004 and January 2006. The interviews were recorded and transcribed, and the data arranged thematically, as presented. The research fieldwork also involved interaction with academic, industry and policy actors at a number of conferences and workshops.

4. At the same time, innovation systems oriented to financial capital may harbour significant latent social capital resources. In the present case, the long history of marine energy since the 1970s provided an important (rhetorical and substantive) resource for the re-emergence of the technology in the 2000s, notwithstanding the criticisms of earlier innovation activity by some contemporary device developers.

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