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Industrial Strategy in Scotland: A review of cluster-based initiatives

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June 2021

http://dx.doi.org/10.7488/era/1366

Executive Summary

Scotland's low carbon transition is increasingly framed as an opportunity for the commercialisation of low carbon technologies, green economic growth and the creation of green jobs. This report considers historic efforts of industrial clustering in Scotland. Although historical examples have some differences to contemporary experience, they do highlight opportunities and challenges of cluster policy making across both manufacturing and innovation. The report is part of an ongoing CXC research project analysing green industrial strategy in Scotland, particularly in relation to the low carbon heat sector.

The first part of the report provides a brief review of international research on industrial clusters. It covers issues such as the characteristics of industrial clusters, including geographic proximity and knowledge exchange networks and the dynamics of cluster growth. It also provides an overview of policy mechanisms to encourage cluster formation and efforts to shift away from historically entrenched but unsustainable clusters.

Key findings:

1. **Clusters are not simply an agglomeration of actors from similar industrial sectors in a concentrated geographic area.** Rather than simple physical proximity, there is a need for strong social links between research institutes, suppliers, manufacturers, trade groups and government; it is from these interorganisational and interpersonal connections that many of the benefits of cluster membership are derived. These range from the efficient use of shared infrastructure, to the exchange of mutually valuable skills, knowledge, and expertise.
2. **There is a need to ensure proposed new clusters are well suited to the industrial, economic and social characteristics of the locality and the industrial sector of focus.** Policymakers must pay attention to the capacity and maturity of the industrial sector in question. Consideration is needed of the presence or absence of a diverse 'ecosystem' of suppliers, manufacturers, and

research providers, and also of the existing level of social linkages between industry actors. Government should develop a comprehensive understanding of the strengths and weaknesses of a proposed cluster, and provide support measures to bolster elements that are missing or underdeveloped. This approach is vitally important in addressing issues of 'lock-in' and transitioning away from well-entrenched but old industries.

Case studies

The second part of the report consists of three case studies of cluster initiatives across a range of industrial sectors in Scotland from the 1950s up to the present day. The cases illustrate the key findings from the review above.

Case 1: 'Silicon Glen'

'Silicon Glen' was a cluster of high technology and electronics firms that operated throughout central Scotland until the early 2000s. Favourable international market trends coupled with longstanding government support of inward investment to drive industrial growth. The cluster was, however, largely restricted to manufacturing and assembly work on behalf of foreign-owned multinational corporations. This case demonstrates the potential for policy interventions to achieve rapid industrial expansion. However, it also illustrates risks for smaller regional economies in dealing with large technology firms with global, highly cost-sensitive supply chains.

Case 2: Intermediary Technology Initiative (ITI)

ITI was a specific policy initiative that aimed to improve the innovative, rather than manufacturing, performance of three distinct sectors of the Scottish economy. Aims included translation of Scotland's considerable – and largely university-based – research capacity into new technology-based spin-off companies, and to capitalise on what the ITI identified as emerging global commercial opportunities. ITI's inattention to the peculiarities of Scottish economic, financial, and industrial landscape appear to have hindered the programme's overall success. In particular, the chosen ITI focus sectors did not consider Scotland's pre-existing strengths, and did not sufficiently account for the ability of the private sector to take advantage of the ITI approach.

Case 3: Wave Energy Scotland (WES)

Like the ITI, WES is an attempt by policymakers in Scotland to accelerate innovative activity and boost technological development in a specific industrial sector. The case study considers how the WES programme represented a new model of support for the wave energy sector in the mid-2010s. In its design and conception, it sought to address the social and financial issues facing the sector. As with the ITI, IP management and intra-sectoral collaboration have been a challenge for the WES programme. These are areas for consideration as the WES programme is now in the process of being extended.

Lessons for policy

To avoid the issues faced by Silicon Glen, **policymakers need to take steps to ensure that foreign investment is not limited to relatively low-cost and low-skill 'screwdriver shop' work**. As Silicon Glen illustrates, shifts in global economic or market trends can easily erode the competitive advantage – such as an inexpensive labour pool – that initially make a given locality attractive. It is important for foreign firms – and indeed all industrial actors – to be well 'embedded' into the local economic and industrial landscape. Silicon Glen also shows how an industrial sector lacking robust linkages to the local supply chain – either due to a paucity of indigenous actors, or low levels of embeddedness – can rapidly decline with the loss of key foreign firms.

The ITI and WES cases focus more on *innovation clusters* rather than *manufacturing* ones. The cases share some features with nascent low carbon heat technologies such as hydrogen (and related components such as electrolysers). Significant R&D activity continues in these areas and fully market-ready solutions have yet to emerge. A persistent challenge for ITI and WES was successful intellectual property management. The ITI was criticised for its involvement in a complicated and inflexible commercialisation process, and there has been a lack of progress in the WES programme towards intra-sectoral knowledge exchange and IP sharing. **Future innovation cluster policies should be developed with a stronger connection to their target sectors or industries**. For example, to avoid ITI's low of take-up from the domestic private sector, programmes should focus more strongly on pre-existing strengths of Scottish businesses.

To sensibly draw lessons from history, Government must be aware of the differences, as well as similarities, to the present. The experiences reported here range across diverse sectors, time periods, and policy approaches, but they can nevertheless inform contemporary efforts at green industry strategy and green recovery. Future work in the project will examine the links between historic experience and current policy initiatives in more detail.

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1 Introduction: Policy Context

In 2019, Scottish and UK governments set enhanced legally binding net zero carbon targets. While these were particularly ambitious, they were also part of an international response to better align national policy commitments with the global commitment made as part of the Paris Agreement, with national net zero targets for around mid-century (Black et al., 2021; ECIU, 2021). The Chinese Government has pledged to be carbon neutral by 2060 (IEA, 2020a), while the new presidency in the USA has committed to net zero by 2050 (President of the USA, 2021).

Covid-induced Economic Stimulus

In 2020, the Covid-19 global pandemic forced much of the world's economic system into the deepest recession for a century (IMF, 2020). How the pandemic and its economic consequences affect global efforts to address climate change has been subject of much interest and debate. Governments around the world have already delivered (or are in the process of developing) economic stimulus packages that seek to boost economic growth at the tail end of the pandemic. There have been numerous calls from a wide variety of private and public actors for a 'green recovery' (IEA, 2020b; Johnson, 2020; Scottish Government, 2020b; von der Leyen, 2021), and some national economic stimulus measures have explicitly focussed on low carbon sectors.

Investing in "Green Growth"

A confluence of increased decarbonisation ambitions and the return of 'big government' associated with the pandemic have led to a prioritising of green growth. However, in recent times there are other examples of policy measures seeking to promote low carbon sectors. For more than a decade there have been calls within political circles for more coherent public investment in the anticipated industries of the future, and the infrastructure necessary to support them. This led to the creation of Department for Business, Energy & Industrial Strategy (BEIS) in 2015, the launch of the UK Industrial Strategy in 2017, the UK Labour Party's 2019 manifesto commitment to a 'Green Industrial Revolution', and plans for a European Green Deal (European Commission, 2019).

Scotland has decarbonised faster than many other developed nations (CCC, 2020, p.34). Since the Climate Change (Scotland) Act in 2009, emission reductions have largely been led by changes in the electricity sector. Growth in onshore and offshore wind energy in the UK has been accompanied by remarkable cost reductions, with the cost of offshore wind falling by almost 75% in 5 years (Evans, 2019). Wider plans for a low carbon transition are framed as opportunities for the commercialisation of low carbon technologies more widely, alongside green growth and green jobs. The Scottish Government recently announced a 'national mission to create green jobs' (Scottish Government, 2020a) with job creation and economic development fundamental in the wider narrative of Scottish Climate Change Plans (Scottish Government, 2018; Scottish Government, 2020b) and sector specific decarbonisation strategies (Scottish Government, 2021).

Securing a Just Transition

At the same time, rising attention on how to secure a 'just transition' reflects the potential for climate change mitigation to disrupt existing industries and to lead to job losses and regionally disparate economic impacts (Jenkins et al., 2020). While the loss of jobs from existing fossil fuel industries is acknowledged (Johnstone and Hielscher, 2017), a lack of ability to attract emerging green industries is also a concern for some regions. For example, while the UK leads the world in offshore wind implementation there is growing disquiet at the lack of associated jobs for UK firms (Fraser, 2020; GMB, 2020). While securing green jobs and green growth are important for the legitimacy the net zero transition at a national scale (McDowall et al., 2013), more local efforts to capture these benefits are likely to give rise to competition between regions. These efforts are also not without their risks for communities and policymakers (EEFW Committee, 2021).

The low carbon heat sector is a particular focus for Scotland's efforts at green recovery and the creation of green jobs (Scottish Government, 2021). While there is a widespread assumption that low carbon technology costs will reduce as market deployment expands, some low carbon heat technologies are relatively well established internationally and further capital cost reductions may be modest (CCC, 2020). More emergent low carbon heat decarbonisation may have greater prospects in terms of cost reduction, but their starting costs are substantial and their commercial prospects uncertain. The contribution of more emergent technologies may also be limited by the sheer pace of envisaged change in the heat sector. Manufacturing, servicing and supply firms face transformational change in the next 20 years.

Lessons from Historical Industrial Clusters

In the above context, this report considers historical efforts at industry clustering in Scotland. Although there are some differences to contemporary cases, opportunities and challenges of industry clustering policy are highlighted. Examples here include both more mature manufacturing sectors and earlier stage innovation sectors. The report is part of an ongoing CXC research project analysing green industrial strategy in Scotland, particularly in relation to the low carbon heat sector. Future work will examine the links between historic cases and current policy initiatives in more detail.

2 Cluster-based Industrial Strategy: A literature review

2.1 What Are Clusters? Geographic and Social Dimensions

At its most simple, a cluster is "an agglomeration of related business and organisations, in geographic proximity, which benefit from co-localisation and collaboration" (Jaegersberg and Ure, 2017, p. 13**)**. The UK Government defined clusters as "a concentration of competing, collaborating and interdependent companies and institutions which are connected by a system of market and non-market links" (UK Parliament, 1999) which emphasises both a network of professional and intellectual linkages, as well as the perceived importance of geographic proximity between cluster members.

Building on this definition, Brown (2000) emphasises the competitive advantage and mutual benefits that make cluster membership attractive: "clusters are taken to mean a group of business enterprises and non- business organisations for whom membership within the group is an important element of each member firm's individual competitiveness" (*ibid*, p. 4). Brown also cites a definition from Scottish Enterprise, which describes potential cluster members as including not just private companies but also "customers, suppliers, competitors and other supporting institutions such as universities, colleges, research bodies, financial institutions and the utilities" (*ibid*, p. 5).

There is broad agreement in the literature that deep collaborative and cooperative engagement between members is a key element to a cluster's success. However, questions surround the importance of geographical proximity as a precondition for fostering those linkages.

One of the first scholarly investigations of the industrial cluster phenomenon was by Marshall (1890/2013), who analysed the 'industrial districts' of small manufacturing firms in the United Kingdom in the 1880s and 1890s. According to Marshall, much of the success of these districts could be linked to the highly localised nature of industrial activity, and how the concentration of the same kinds of activity in a small geographic area led to the development of an "industrial atmosphere" (Marshall, 1919). This allowed for the ready, and oftentimes tacit, transfer of trade-skills and expertise between firms, as well as the sharing of expensive machinery and other community assets.

Marshall's concept of an "industrial district" proved to be influential, and was adopted by scholars in Italy ('Third Italy'; Becattini, 2002), France (the GREMI group; Camagni, 1991), Germany (Maennig and Ölschläger, 2011), and elsewhere as a means of describing other examples of localised industrial activity. Again, central to these analyses is the need for cluster members to be 'embedded' within a common social, technical, and political milieu in order to facilitate the collaborative and knowledge sharing exchanges held to be critical to a cluster's success (Jaegersberg and Ure, 2017).

Michael Porter's 'diamond' model (1990) has been used as a conceptual framework for most modern scholarly discussions of industrial clusters (Brown, 2000; Bergman and Feser, 2020). Porter's work, which arose from Marshall's initial studies on industrial districts, is centred around the interconnectedness of various actors – manufacturers, suppliers, finance and funding agencies, academic institutions and government – in a given sector and locality, which he argues is the source of a region's competitive advantage in a national or international context. The four elements that constitute Porter's diamond are (Porter, 1990; Bergman and Feser, 2020):

- 'factor conditions': natural resources; educated and skilled labour; technical and research expertise; industrial, transportation, or communication infrastructure
- 'demand conditions': including consumer demand for foreign versus domestic goods, and local industrial demand for intermediate goods.
- 'firm strategy, structure, and rivalry': historical and cultural norms regarding relations between government, labour, and private enterprise; attitudes regarding inter-firm competition, rivalry, and cooperation
- 'related and supporting industries': including potential collaborators such as suppliers and service firms, as well as successful competitors and rivals.

Crucially, Porter frames these four elements as being mutually reinforcing and interdependent, underlining the point that a successful cluster requires a broad ecosystem of actors, as well as material resources and policy support.

Porter places less emphasis on the issue of geographic proximity, and he notes that the more successful a cluster becomes, its linkages with other 'outside' firms, sectors, or even other clusters, will likely expand geographically, beyond the cluster's initial locality. The French economist Francois Perroux (1950) argued that focusing on a business's place in geographic space was "banal,". Linkages and relationships between industrial actors will develop in a global context, seeking out whatever business conditions are most favourable, in a way that "transcend[s] the nation and the national economy" (Perroux, 1950, p. 104; see also Bergman and Feser (2020).

Ironically, despite its prevalence few policy initiatives fully adopt Porter's model or undertake the extensive regional 'cluster mapping' of the diamond model's essential elements (Lagendijk, 1999; Enright, 2000). For some, Porter's analysis is too idealised and lacking in specific details, making its application to 'real-world' cases challenging (Bergman and Feser, 2020). Scholars also recognise that "clusters are often highly place-specific and public policy towards clusters should be flexible enough to accommodate varying industrial, institutional and political conditions" (Brown, 2000, p. 5).

Porter's initial conception of the 'diamond model' has also been criticised for focussing more on managing market forces to ensure the availability of 'factor conditions' such as labour or research capacity, and less on the internal cluster dynamics that mediate access to these resources, and impact collaborative and competitive relationships between members (Jaegersberg and Ure, 2017). Later work by Porter seeks to address these critiques, noting the limits of using size and scale – both in terms of geography, and in cluster membership – as a measure of cluster activity (Porter, 1998). While the presence in a given region of large numbers of manufacturers and supplier firms, or a robust research and development community, are necessary preconditions, they are not on their own sufficient for cluster formation.

In a more expansive view on the nature of industrial clusters, Gordon and McCann (2000), identified three distinct types:

(1) The canonical Marshallian 'industrial district,' a densely concentrated agglomeration of various actors, who draw mutual benefit from tight association with other cluster members
(2) 'industrial complexes,' designed and oriented around the material and service requirements of a small number of end-market producers
(3) 'social networks,' defined by inter-firm and inter-personal relationships, where social capital and mutual trust is more relevant than mere geographic proximity.

Others, including Morosini (2004) and Li et al. (2015) argue that clusters should also be viewed as social entities, rather than strictly geographic ones.

A number of empirical studies have added to the discussion surrounding the geographic and social characteristics of industrial clusters. A study by Wever and Stam (1999) focusing on industrial clusters in the Netherlands raises questions about the necessity of regional concentration in geographically small countries. On the basis of their analysis, the authors conclude that for the Dutch high technology sector "regional clusters hardly exist," (*ibid,* p. 398) and instead the focus is on having nationwide linkages, beyond the spatial bounds of what would generally be considered a concentrated industrial cluster. They assert that this is largely due to the Netherlands' relatively homogeneous distribution of resources such as labour, financing, and research institutes. This, combined with the relatively small size of the country, means it is difficult to identify discrete concentrations of particular industries in particular regions. The authors add that this does not discount the existence of mutually beneficial knowledge exchanges and collaborative networks between Dutch high technology firms, but instead that the focus of these linkages is on a national, rather than local or regional scale.

Beugelsdijk and Cornet (2002) note that much of the previous work on proximity and knowledge spill-over looks at case studies in relatively large countries – compared to the Netherlands – such as the United States (Saxenian, 1996), the United Kingdom (Cooke, 2001; 2002) or Germany (Sternberg, 1999), where regional differences could be more pronounced (Jaffe et al., 1993; Audretsch and Feldman, 1996). Beugelsdijk and Cornet found little evidence to suggest that, in a small country such as the Netherlands, knowledge spill-overs between two firms correlates with their geographic proximity (although they did find that proximity was an important factor in collaborations between firms and universities and research institutes). They summarise their findings with the assertion that "a far friend may be worth more than a good neighbour," noting that geographic proximity, while convenient, is not a necessary precondition for cooperation. I It is the overall attractiveness of a given linkage which is the primary driver for collaboration. As for what constitutes 'attractiveness', Beugelsdijk and Cornet highlight the contributions of scholars including Eskelinen, et al (1998) and Nooteboom (1999, 2000) and their work on the role that "mutual trust and understanding and a common language, shared norms and values" (Beugelsdijk and Cornet, 2002, p. 171) play in facilitating knowledge exchange.

2.2 Cluster Growth: Path Dependency and Lock-In

A body of work explicitly addresses the historical dimension of industrial cluster growth. This work focusses on how established clusters tend to persist and grow in a given locality over time, as the range of economic and industrial activities in that region often become increasingly narrower and more specialised as the concentration of similar firms and actors intensifies.

Central to this scholarship is the concept of 'path dependency,' a well-documented phenomenon in the field of technology and innovation studies. It is used to explain the success of a range of technologies, from the proliferation of the QWERTY-style keyboard (David, 1985; Liebowitz and Margolis, 1990) to the dominance of VHS videotapes over their Betamax rivals (Cusumano et al., 1992; Puffert, 2018). A key result from these analyses is that the more successful technology is by no means the 'best' or most advanced version available; rather, the success of a winning design is usually attributed to small initial advantages, which often arise due to chance decisions or historical coincidence. From a path dependency perspective, these initial gains compound over time, resulting in a kind of systematic inertia, or 'lock-in'. For example, studies of the persistence of different railway gauges in Europe demonstrate how lock-in can explain how certain industrial or technological artefacts endure in spite of increasingly undesirable externalities or economic inefficiencies (Puffert, 2002).

Brian Arthur (1989a, 1990) studied the growth of Silicon Valley through the lens of path dependency, modelling the increasing agglomeration of high technology firms as a stochastic process, where the probability of a new firm choosing that particular locality increases in proportion to the number of similar firms already present. This analysis led to the idea of "lock-in by historical events," which Arthur (1989a) used to describe a kind of positive-feedback loop where economic or industrial development was influenced by past events and decisions.

In a similar vein, Paul Krugman's (1991a, 1991b, 1994) analyses of the development of various manufacturing centres in the Northeast and Southern United States in the late 19th century highlighted several examples where the choice of geographic location could be described as economically 'inefficient' or even sub-optimal, in terms of availability and access to labour, natural resources, and customers. Nevertheless, these industrial clusters thrived and came to dominate their industries, persisting even as the geographic distance between them and the burgeoning resource extraction activity of the American West increased into the early 20th century. Building on Arthur's work, Krugman argues that the existence of favourable starting conditions in a given region are rarely unique, and that the emergence of an industrial cluster in one location over another can just as often be attributed to serendipity as it can to careful deliberation (Krugman, 1991a).

There are a number of critiques which view this interpretation of path dependence as being an inadequate explanation for how industrial clusters form (Liebowitz and Margolis, 1995; Boddy, 1999; Scott, 2004). In particular, Krugman's work in this area has been criticised as too reliant on fortuitous accident, failing to explain why certain 'chance events' are significant in some locations but ultimately unimportant in others (Martin and Sunley, 2006). Krugman is also said to have ignored important historical counterexamples which are difficult to ascribe to mere historical accident (Pinch and Henry, 1999), or instances where actors made deliberate choices to establish a particular industry in a particular place (Garud and Karnoe, 2001).

However, setting aside the issue of how a cluster may form, path dependence has emerged as a useful analytical framework for discussing how industrial clusters develop and grow. Indeed, Krugman noted that "there is a circularity that tends to keep a manufacturing core in existence once it is established" (Krugman, 1991b, p. 83) which he attributed to Arthur's "increasing returns and cumulative processes," (Arthur, 1989b, 2009). These processes range from reduced set-up costs for new entrants into an industrial cluster due to existing infrastructure, to 'learning by interacting' and other knowledge spill-over effects that can arise when concentrated groups of like-minded actors are working simultaneously to solve similar problems (Arthur et al., 1987).

While path dependency provides insights into how clusters develop and grow, the idea of lock-in also sheds light on how certain industries persist in certain localities despite growing negative externalities, as well as how this can hinder transitions to new kinds of industrial and economic activity. Indeed, Arthur's (1989a) initial use of the term was to describe an inherently inefficient, and undesirable, economic outcome, "a lock-in to something bad, or at least a lock-out of something better" (Liebowitz and Margolis, 1999, p. 982). Others characterise lock-in as a "gradual process of 'rigidification' and growing inflexibility," (Martin and Sunley, 2006, p. 415) where the ability of industrial or economic actors to compete or innovate progressively decreases. Grabher (1993) studied the decline of the coal and steel industry in the Ruhr Valley, which he argued was partially the result of an inability to adapt to technological innovations and wider market changes. Grabher postulated three distinct types of lock-in:

- 'functional,' founded in overly rigid relationships between firms and industrial actors
- 'cognitive,' related to a common worldview that is inexorably sceptical of new developments
- 'political,' due to inflexible institutions or systems that resist change.

2.3 Cluster Renewal and the Role of Policy

A number of studies have addressed the issue of lock-in as it relates to regional economic development and attempts to diversify or shift the focus of industrial cluster activity. For example, a case study looking at a developing renewable energy cluster in Portugal found that new firms struggled to compete against the already entrenched energy companies, who had long-standing formal and informal relationships with utility companies and government regulators (Jaegersberg and Ure, 2017, p. 63). The resulting bottleneck for new firms was linked to an overall lack of technological innovation and inter-firm competition that has frustrated the growth of the Portuguese renewable energy sector.

Lock-in cannot only hinder the entry of new actors into a sector, it can also complicate efforts of existing cluster members to innovate in a coordinated and effective manner. A study by Chapman and colleagues (2004) looked at a "mature industrial cluster," the Aberdeen oil and gas industry, and efforts by the firms within to diversify in order to remain competitive in a changing energy landscape. Cluster members undertook steps to diversify in a variety of different ways – for example, expansion into new geographic export markets, or shifting towards offering new kinds of products and services – according to what they identified as the more pressing issues to be addressed, or the most promising opportunities. This heterogeneous response called into question the longer-term viability of the existing cluster as a cohesive entity, and underlined the need for governments and policymakers to play a role in guiding cluster renewal and regional economic development.

Underthun and colleagues (2014) looked at successful efforts to revitalise the Grenland industrial region in Norway, through a combination of structural changes that include restructuring the existing process manufacturing industry, and the emergence of a nascent information and communications technology sector. The authors frame this case study, and its apparent success at overcoming industrial lock-in, as due to a combination of incremental ('adjustment') and radical ('renewal') innovations. However, they also argue that these structural changes can take advantage of the 'locked-in' nature of mature clusters. With their well-developed inter-firm relations and established supply chains, the Schumpeterian idea of 'adaptive restructuring' can arise. This requires judicious research and development investments on the part of large, well-established firms and industries, and appropriate institutional and policy support: "the creative redeployment and recalibration of existing competencies and capabilities, and the establishment of new, unrelated economic activities." (*ibid*, p.130).

Similar work by Trippl and Otto (2009) describes efforts to revitalise two "old industrial areas" in Germany and Austria, through a combination of diversification, and incremental and radical changes. Somewhat unsurprisingly, they found that the less specialised a region, the more able it is to accommodate economic development policies that aim for incremental changes. Such policies include the gradual diversification or reorientation of existing firms and sectoral actors into newer, growing markets and customer bases. This approach resulted in a diverse regional economy that was able to take advantage of existing industrial resources and expertise, with new firms growing alongside more established players.

In contrast, areas that were more homogeneous in terms of industrial activity – regions dominated by well-established clusters – struggled with more modest revitalisation attempts to leverage their existing industrial capacity. Here, policymakers were driven to undertake more radical changes to their region's economic makeup, shifting away from the existing industrial base and focusing more on promoting the growth of new industries, such as information technology and biomedical research, that often had little connection to existing firms, or the region's historic infrastructure or other economic and knowledge-based assets. As a general point, the authors note that in order to avoid the need for more drastic measures, governments and policymakers should take a more proactive stance towards minimising industrial lock-in, and regularly engage in the "search for and support of new clusters to broaden the economic base and to promote related diversification" (*ibid*., p.1232)

2.4 Why Clusters Are Formed: Policy Goals and Member Benefits

From the point of view of policymakers, clusters are generally seen as a means for promoting regional economic growth (Benneworth et al. 2003; Huggins and Williams, 2011; Vernay et al., 2018), and increasing regional competitiveness, productivity, and job creation (Feser 2008, Baptista and Swann, 1998; Iammarino and McCann, 2006; Mueller and Jungwirth, 2016). While not mutually exclusive, some of the benefits for individual firms are held to be increased productivity and efficiency due to the ability to share infrastructure and other resources, and reduced transportation and other transactional costs (Phelps, 2004; Wolman and Hincapie, 2015; Li et al., 2015). There is also some evidence that clusters can also serve as loci for attracting research and development funding and grants (Broekel et al., 2015).

Above all, one of the most commonly cited benefits of cluster membership is an increase in the innovative performance of both individual firms (Baptista and Swann, 1998; Baptista, 2000; Fromhold-Eisebeth and Eisebith, 2005; Mo et al., 2020), and consequently, entire regions and industries (OECD, 1999, 2001; Keeble and Wilkinson, 2000; EU Commission, 2002; Wolman and Hincapie, 2015). Central to the assertion that firms inside clusters innovate more than those outside is the idea of knowledge 'spillovers'. This idea is itself related to path dependence and the virtuous cycle of "increasing returns and cumulative processes," developed by Arthur (1989) and others (Krugman, 1994) to describe a range of positive externalities that accompany the agglomeration of an industry in a concentrated geographic locality. Porter (1990) also noted the apparent ability of members to maintain an overall competitive stance between rivals, while still engaging in formal and informal exchanges of expertise and know-how that tending to benefit all parties.

However, while the academic literature appears to generally – although not entirely (Martin and Sunley, 2003; Wolman and Hincapie, 2015) – agree that industrial clusters promote innovation, there are diverse views as how or why this is the case, as well as numerous ways of quantifying this effect. On the latter point, many studies (Wever and Stam, 1999; Fang, 2019; Li et al., 2015; Brachert et al., 2013; Broekel et al., 2015) refer to somewhat indirect econometric data, such as “sharing of professional services, sharing of specialized or skilled labor force, sharing of tacit knowledge and technical information” (Mo et al., 2020, p. 3) as evidence for increased innovative activity.

However, theorists such as Wolman and Hincapie (2015) have pointed out that due to the enormous variability with how clusters are defined and measured, it is difficult to amass a convincing body of empirical evidence to test the theoretical claims made about their impact, or to compare their performance in a systematic way against a ‘control group’ of non-cluster firms. Rosenthal and Strange (2004) noted that “agglomeration economies whose sources are knowledge spillovers, labor market pooling, or input sharing all manifest themselves in pretty much the same way” (*ibid*, p. 2146), making it exceedingly difficult to argue for the importance of any one factor over another.

In a similar vein, Martin and Sunley (2003) are highly sceptical of the utility of industrial clustering in general, and are particularly critical of what they argue is an inherently ambiguous and “chaotic concept” without a precise definition. This lack of clear geographic or industrial boundaries, and the consequent lack of a coherent theoretical framework for their evaluation or discussion, makes discussing the policy implications of clusters, or their potential impact on individual firms, nearly impossible. Indeed, Martin and Sunley go so far as to question the very existence of clusters as a valid, or at least identifiable, subject of study, asserting that the cluster idea may be little more than a highly successful metaphor or ‘brand’ rather than a true economic or industrial phenomenon.

2.5 How Clusters Form: The Role of Policy Support

There is a diversity of views in the literature as to how clusters form, and the best means of fostering their formation and growth. In their case study of a French renewable energy technology cluster, Vernay et al. (2018) investigated the extent to which governments can create clusters that are both “self-organising and vibrant”, but still maintain enough influence to ensure that policy objectives are being met. They found that as a cluster matures and becomes increasing complex in terms of collaborative linkages and internal organisational structure, the ability for governments to directly influence the focus and direction of cluster activities diminishes. Indeed, further government involvement at this stage can alienate some members from further participation in cluster activities, if their goals and ambitions are perceived to be in conflict. Based on these results, Verney et al. argue that policy-makers should exercise caution and to avoid overly rigid or prescriptive goals for cluster initiatives over which they may have gradually diminishing influence. They also note that incorporating a level of ‘interpretive flexibility’ (Pinch and Bijker, 1984; Smith and Kern, 2009) regarding the aims and purpose of a cluster increases the likelihood that the ultimate outcomes are meaningful for both members and policy-makers alike.

Some scholars are highly critical of any attempts by governments and policy-makers, arguing that it is “enormously difficult to point to any examples of deliberate cluster promotion programmes that have been unambiguously successful” (Martin and Sunley, 2003, p. 28). Guinet (2003) argues for the importance of private sector actors over those from the public sector, asserting that the creation of clusters “should result from market-induced and market-led initiatives” (*ibid*, p. 158).

Regarding the question of successful cluster formation attempts, Fromhold-Eisebith and Eisebith (2005, 2008) observe that focussing solely on initiatives led by government is insufficient, and may miss important examples originating from nascent cluster members themselves. Based on their study of automotive manufacturing clusters in Austria and Germany, they distinguish between two distinct phenomena (2005, p. 1254) :

- A 'top-down' approach comprised of "public initiatives and policy schemes that deliberately foster clustering, at least temporarily (co-)financed by public funds and directed by publicly dominated agencies"
- A 'bottom-up' category "primarily instigated, funded and governed bottom-up by private actors, mostly companies"

This is similar to work done by Lagendijk (1999) who described two principal routes to cluster formation: a 'bottom-up' approach driven by potential cluster members and their existing patterns of interaction and collaboration, and a 'top-down' approach based on the priorities and goals of policy-makers. Others (Brown, 2000; Enright, 2000) note that in 'top-down' situations, the choice of cluster focus can be somewhat arbitrary, with a tendency to favour 'fashionable' sectors such as biotechnology or entertainment, which may have little support or background in a given locality.

Fromhold-Eisebith and Eisebith also add a second dimension of categorisation, distinguishing between 'explicit' and 'implicit' cases, the former of which adopt "the cluster label in their name and/or expressly rely on the concept, however it may be defined," and the latter instead following "cluster related objectives without officially or consciously drawing on the concept and model" (*ibid*, p. 1255). According to Fromhold-Eisebith and Eisebith, these distinctions are meaningful, noting that private sector-led initiatives typically opt for the 'implicit' approach, perhaps because deep knowledge of or strict adherence to theoretical cluster models are seen as unnecessary or undesirable by some cluster actors.

Regarding the relative merits of an 'explicit top-down' versus 'implicit bottom-up' approach, Fromhold-Eisebeth and Eisebeth conclude that while appropriate use cases exist for both, noting the specific objectives of policy-makers, private firms, and other stakeholders, as well as the locality's existing industrial, technological, and innovative resources need to be assessed first. An 'implicit bottom-up' approach is best for situations where there already exists a strong infrastructure base, as well as "a set of 'first mover' companies […] with loose contacts to a sufficiently large number of value chain related firms and other organizations". Conversely, in cases where 'regional structures show a lack of material assets and entrepreneurs, and where most actors have so far been operating isolated from each other," an 'explicit top-down' strategy is more likely to be successful (*ibid*, p. 1265).

Feser (Feser, 1998; Brown, 2000) distinguished between 'cluster-specific' or 'cluster-informed' policy support schemes. The objective of a former approach is the emergence of a specific, well-defined cluster, which begins with a comprehensive mapping and assessment exercise to identify strengths and weaknesses. 'Cluster-specific' approaches generally involve a holistic suite of policy interventions, ranging from targeted business development schemes through to increases in infrastructure and educational funding, or tax and pricing incentives. In contrast, 'cluster-informed' approaches are more piecemeal, and tend to focus on enhancing (or creating) a particular area of a local industrial sector or supply chain, such as insufficient levels of skilled labour or anaemic consumer demand.

Rather than an endorsement of one approach over another, Feser's distinction between 'cluster-specific' and 'cluster-informed' is a reflection of the differing scopes and ultimate ambitions of policy-makers, as well as the existing industrial conditions in a given locality. Indeed, Feser asserts that cluster support policies can be viewed as attempts to target and leverage scarce developmental resources, an improvement over "a scattershot approach to economic development, [and which] provide a useful device for strategic planning and investment" (*ibid*, 1998, p. 7).

Alongside the question as to whether the driving force behind cluster formation is initiated by public or private sector actors, a recent study of industrial clusters in Hungary (Pecze, 2020) highlights the fact that cluster formation efforts must be carefully planned and tailored to local conditions in order to ensure long-term viability. The clusters in question are described as being a "bottom-up clustering process […] initiated in a top-down manner" (*ibid*, p. 1508), formed by local actors as a reaction to a state-funded financial subsidy programme, but without any further government planning or oversight. However, the relatively superficial nature of these clusters was highlighted by the fact that within 2 years of the end of the subsidy programme, over three-quarters had ceased operation. The study suggests that the rapid decline of these clusters is the result of a poor understanding of local competitiveness and industrial potential. In particular, there is a lack of engagement with regional 'cluster managers,' "who are typically on better terms with local actors and therefore have a better view of regional and local strengths and problems" (*ibid*, p. 1509) than centralised national agencies.

2.6 Conclusion

Among the many themes addressed in the academic literature on industrial clusters, two are particularly notable here. Firstly, clusters are *not simply an agglomeration of actors from similar industrial sectors within a relatively concentrated geographic area*. Indeed, while many scholars downplay the necessity of strict physical proximity, there is a broad consensus on the need for strong *social links* between research institutes, suppliers, manufacturers, trade groups and government. It is from these interorganisational and interpersonal connections that many of the benefits of cluster membership are derived, ranging from the efficient use of shared infrastructure, to the exchange of mutually valuable skills, knowledge, and expertise.

A second major theme, of particular salience to policymakers and governments, is the need to ensure that a proposed cluster is *well suited to the industrial, economic, and social characteristics of both the locality and the industrial sector of focus*. While this point is crucially important for 'top-down,' policy driven cluster initiatives, it is also relevant to more industry-led approaches. Attention must be paid to the capacity and maturity of the industrial sector in question, not only in terms of the presence, or absence, of a diverse 'ecosystem' of suppliers, manufacturers, and research providers, but also in terms of the existing level of social linkages between industry actors. A comprehensive understanding of the strengths and weaknesses of a proposed industrial cluster, in concert with support measures to bolster elements that are missing or underdeveloped, is also vitally important in addressing issues of 'lock-in' and transitioning away from well-entrenched, but superannuated, industries.

The subsequent sections of this report present three case studies drawn from a range of industries across Scotland. While diverse in their scope, these cases illustrate many of the points raised in the literature review, highlighting the importance of matching policy goals and commercial ambitions with existing economic and industrial realities, as well as the value of networking and collaboration between industrial actors, and some of the persistent challenges encountered in fostering these social linkages.

3 Case study 1: 'Silicon Glen' and the Scottish High Technology Sector

Silicon Glen is an example of how favourable international economic and market trends, coupled with longstanding government support of inward investment as a driver for industrial growth, resulted in the establishment of a Scottish high technology sector – albeit one largely restricted to manufacturing and assembly work on behalf of foreign-owned multinational corporations. While this case demonstrates the potential for policy interventions as a means for achieving rapid industrial expansion, it also illustrates some of the risks for smaller regional economies in dealing with large technology firms with global, highly cost-sensitive supply chains. Indeed, the example of Silicon Glen shows how a sector based largely on lower-skilled manufacturing jobs can be transitory, especially if foreign multinationals are not deeply 'embedded' into a region's economic and industrial landscape through strong linkages to local suppliers and spin-off firms.

3.1 Background: What is Silicon Glen?

Silicon Glen refers the cluster of high technology and electronics firms that operated throughout central Scotland from the mid-20th century until the early 2000s. Haug (1986), in one of the most comprehensive scholarly studies of the subject, sets the geographic bounds as the corridor defined by Edinburgh, Dundee, Greenock, and Ayr, with other reports also drawing attention to significant facilities in Livingston (Pollock, 1981), Glenrothes (Moreton, 1981; Beardsley, 1993), and Erskine (Egeraat and Jacobson, 2004).

The actual term 'Silicon Glen' rose to prominence in the 1970s as a reference to Silicon Valley (Saxenian, 1996), the famous high technology cluster in the United States. The use of such 'Silicon landscape' terminology to refer to similar high technology clusters is a worldwide phenomenon, with examples ranging from Silicon Fen around Cambridge, England, to Silicon Bog in central Ireland and Silicon Polder in the Netherlands (Owen, 2007).

However, according to Haug (1986) the roots of the Scottish high technology sector can be traced back to the mid-1940s, when British electronics firm Ferranti Limited moved a factory to Edinburgh in an effort to escape bombing raids in England. In the decades following World War Two, this initial example of inward investment from firms outside Scotland intensified. Throughout the 1950s – 1970s, a wave of manufacturing and assembly facilities built by major American corporations such as IBM, Honeywell, and Texas Instruments meant that by 1981, of the over 200 companies in the Scottish high technology industry, US-owned multinational enterprises (MNEs) and their subsidiaries comprised almost one quarter, employing over 40% of the workforce (Haug, 1986, p. 104). Beginning in the 1970s, successive waves of European and Japanese firms including Philips, Mitsubishi, and NEC began investing in Silicon Glen, with entrants from Korean and Taiwanese firms also opening facilities in the 1980s and 1990s (Collinson, 2000, p. 221).

While it is important not to overlook the fact that Silicon Glen also featured a handful of indigenous firms – hard disk manufacturer Rodime and PC assembly firm Mimtec being two notable examples (Egeraat and Jacobson, 2004) – the bulk of the investment, and industrial activity, was carried out by foreign-owned corporations. For example, Egeraat and Jacobson (2004, p. 833) compiled a list of major investments and plant openings in the Scottish computer components sector between the 1950s and 1998: out of 42 entries, only 11 were due to indigenous firms, with only 1 made after 1990. Similarly, Turok (1993a, p. 370) notes that throughout the 1980s, the proportion of employees in Silicon Glen working at British-owned firms fell from 58% to 49%, compared to a UK-ownership level of over 80% in the rest of the manufacturing sector. By 1991, nearly six out of ten workers in Silicon Glen were employed by foreign-owned firms (48% of which were American), compared to only 14% from Scottish-owned firms (*ibid*, p. 374).

3.2 Origins of Silicon Glen: The Rise of an Industrial Cluster

The growth of the Scottish high technology sector – and in particular, the high level of foreign-owned firms – can be linked to longstanding efforts on the part of policymakers to attract inward investment to the country. Starting in the 1950s, the UK Ministry of Supply, as well as the Scottish Office and the Scottish Council played an active role in using inward investment as means of expanding Scotland's industrial and manufacturing base (McCann, 1997, p. 696). Throughout the 1960s and 1970s the Scottish Development Agency (SDA), the precursor to Scottish Enterprise, targeted the electronics industry as "one of the three most important 'areas of attack' regarding inward investment" (Egeraat and Jacobson, 2004, p. 818). Within the SDA, the Locate in Scotland bureau marketed Scotland as a means for foreign – primarily American – firms to access both the UK and European markets, highlighting an English-speaking, highly-skilled and relatively low-cost manufacturing labour pool.

For their part, foreign MNEs had a range of motivations and rationales for locating in the UK, and Scotland in particular. Again, the size, availability, and nature of the Scottish workforce – English-speaking, skilled in industrial manufacturing, and relatively inexpensive – is mentioned in a number of scholarly sources as an important factor (McCalman, 1992; Turok, 1993b; McCann, 1997). Egeraat and Jacobson (2004, p. 824) also note the link between the availability of this "highly flexible workforce" and high levels of unemployment in post-war Scotland as a result of the decline of more traditional industries such as shipbuilding and heavy engineering.

Survey data collected by Haug (1986) from representatives of 14 American high technology MNEs with facilities in Scotland sheds light on some of the reasons why these firms chose to locate in Silicon Glen. As well as being in line with how the SDA had framed Scotland as a site for inward investment, these data show that European and UK market proximity, low initial start-up costs, and the availability of a skilled manufacturing labour pool were also seen as paramount by US firms. One noteworthy result, however, was the relatively low ranking that survey respondents gave to the availability of technicians, engineers, and scientists, which Haug asserts as evidence for the manufacturing, rather than R&D, focus of these foreign investments.

This point is further highlighted by the notable difference between this survey data from Silicon Glen, and those from similar surveys regarding the location choices for domestic facilities within the US, where over 90% of respondents rated the availability of "technical and professional labour as the leading attribute" (*ibid*, p. 109). Haug neatly summarises how these survey data reflect fundamentally different attitudes to the roles of domestic versus overseas facilities: "this indicates that facilities in the United States are the corporation's technology and product innovation centres and that foreign plants are established to initially expand manufacturing, and not technological, capabilities" (*ibid,* p. 109).

Haug's survey data also demonstrate the role that UK and Scottish government policy and economic development strategies played in influencing the decision of US MNEs to locate within Silicon Glen. For example, financial grants and other incentive programmes, beginning in the 1940s and 1950s with Industrial Development Certificates, and later in the 1960s and 1970s with Regional Development Grants administered by the SDA, were mentioned by numerous firms as essential reasons for locating production facilities in Silicon Glen, as opposed to elsewhere in the UK or in continental Europe. One specific case is mentioned from the 1950s where an MP actively pursued an American electronics firm, promising to construct a publicly-funded factory if they were to locate their business in his central Scottish district (*ibid*, p. 109). The existence of pre-built ‘advance factories’ and related industrial infrastructure, along with the SDA-operated industrial estates that first arose in the 1960s, were also mentioned by several respondents as important incentives, not least of all as they offered a quick and easy means of scaling up production and more rapid access to the burgeoning European markets.

Haug argues that, while in the 1950s and 1960s decisions by foreign MNEs to invest in Scotland were based on a combination of government incentives and an attractive labour pool, by the 1970s and 1980s the region had achieved a critical mass of infrastructure, suppliers, university connections, and other ‘concentration economies’. Indeed, the reputation of Silicon Glen as an industrial cluster and an attractive location to base manufacturing operations had begun to gain traction in the high technology sector. One of Haug’s survey respondents declared that “the Central Belt of Scotland has become the Silicon Valley of Europe,” a fact that made “it natural for [our firm] to locate [there]” (*ibid*, p. 111). Similarly, Hood (1991) enumerated some of the features that make Silicon Glen an attractive site for foreign MNEs, such as “the educational infrastructure, the supplier base (particularly for electronics), the track record of existing overseas companies, and the work of Locate in Scotland” (*ibid*, p. 20). In doing so, they described many of the characteristics of a well-developed industrial cluster, as well as the role that path dependency plays in cluster growth.

3.3 Decline of Silicon Glen: “A Low-Cost Manufacturing Business in a High-Cost Country”

Egeraat and Jacobson identify 1998 as the high-water mark for the Scottish computer assembly and component manufacturing sector, and Silicon Glen as a whole (2004, p. 822). Successive waves of plant closures and major job-losses which began in the mid-1990s accelerated in the latter part of the decade, with IBM, Sun Microsystems, Compaq, and a host of other firms ceasing operations in Scotland by 2002. Many of these plant closures were the result of corporate restructuring strategies on the part of foreign-owned management or parent companies, who invariably decided to move their Scotland-based operations to lower-wage economies such as Hungary, Czechia, Taiwan, and mainland China.

Building on interviews conducted with representatives of microcomputer companies, Egeraat and Jacobson argue that this exodus is due to the fact that, by the late 1990s, the main reasons why foreign firms initially decided to locate in Scotland – namely, “the flexibility of the labour force and relatively low labour costs” (2004, p. 825) – no longer existed. Throughout the post-war decades, Scotland – along with Ireland, who witnessed a similar rise and fall of their own technology manufacturing sector – had functioned as “the new semi-periphery of Europe” (*ibid,* p. 825) with labour costs well below neighbouring countries. These were ideal conditions for MNEs to locate facilities to undertake the “less qualified, more standardised and more factor-cost sensitive parts of the production chain” such as final-stage assembly work (*ibid,* p. 823). However, rising wages in the 1990s meant the loss of one of Silicon Glen’s major competitive advantages, making the increasingly industrialised economies of Eastern Europe and South-East Asia cheaper, more attractive alternatives for multinational technology firms.

In media reports from the 1990s and 2000s, a number of industry experts point to the nature of the work being done in the plants and factories of Silicon Glen as one reason for its decline, arguing that the Scottish sector had little in common with the American technology cluster whose name it alluded to. Former Sun Microsystems executive and industry lobbyist Hugh Aitken asserted that Silicon Glen was “as near to Silicon Valley as it is to the moon” (BBC News, 2003). Rather than engaging in the higher-value innovation and research work that have long been associated with the success of Silicon Valley (Saxenian, 1996), Aitken claimed that most operations in Silicon Glen were merely “screwdriver shops,”. He referred to plants that simply perform final-assembly operations of more complicated – and higher value – components that were manufactured elsewhere and that “the old screwdriver business is long gone: now, all that sort of thing is done in Eastern Europe". Jim Rigby, then an executive at Hewlett-Packard, a decade earlier, expressed similar concerns: “Where Silicon Glen has failed is that not enough companies have brought in chains of research and development and marketing expertise. If all you do is put something in a box, there’ll always be somebody who can do it cheaper” (Beardsley, 1993).”

A variety of scholarly sources support the above observations. In their detailed analysis of the nature of industrial activity within Silicon Glen, Egeraat and Jacobson (2004) note that until the 1980s, the sector was dominated by computer assembly work, with almost all of the higher-value component manufacturing work was done elsewhere and imported to Scottish facilities (Collinson, 2000). According to Turok (1993a, 1997), concerted efforts on the part of the SDA to expand and strengthen the supplier base in Scotland – either through indigenous firms or inward investment – achieved very modest success, increasing the percentage of locally-sourced components from 10% in 1979 to between 12 and 15% a decade later. Despite this improvement, a 1991 survey revealed that Scotland-based firms provided mainly ‘low-tech’ parts such as cables, metal cases, and printed materials, with almost all of the sophisticated, higher-value components being imported (Turok, 1993a). The rare examples of high-value component manufacture work being done in Scotland generally involved foreign-owned, rather than indigenous, firms, as was the case of Shin-etsu Handotai, a Japanese silicon wafer producer based in Silicon Glen for the express purpose of supplying the nearby NEC Semiconductors plant, another Japanese MNE (Collinson, 2000, p. 222).

3.4 Analysis: Why Did Silicon Glen Decline?

The academic literature identifies two distinct, but complimentary explanations for the ultimate decline of Silicon Glen. The first explanation focuses on the type of work being done in the factories and plants of Silicon Glen, while the second is related to the extent to which the high technology sector, and especially its foreign-owned actors, were significantly ‘embedded’ in the wider Scottish economy.

The first explanation arises from work done by Haug (1986) on “post-location investment patterns,” or the direction in which a given industry could, or would, evolve after an initial influx of foreign-owned manufacturing and assembly facilities. According to Haug, the development of a robust technology sector in Scotland would arise through four (largely, though not entirely sequential) processes (*ibid*, p. 104):

- successive periods of US inward investment
- post-location expansion in plant operations and employment
- the location and evolution of R&D activities in Scotland
- entrepreneurial spin-offs by affiliate engineers

It is interesting to note that Haug, writing in the mid-1980s using data collected in the early part of that decade, is quite sanguine about the progress being made towards these goals. Indeed, regarding the first two of the four stages, there is ample evidence to support the claim that the high technology sector in Scotland grew rapidly, in terms of employment and number of facilities, throughout the 1950s-1980s after heavy inward investment from US and other foreign firms (Haug, 1986; Egeraat and Jacobson, 2004).

Although examples of 'fourth stage' indigenous spin-offs are less numerous, Haug points to firms such as Fortonics and Rodime, started by former employees of Hewlett Packard and Burroughs, respectively, as early evidence for this phenomenon. Along similar lines, Firn and Roberts (1984) highlighted the role of university spin-off companies as an important source of indigenous technology firms, which arose as a result of their proximity to Silicon Glen's foreign actors.

However, evidence for robust, Scotland-based R&D activity – the crucial 'third stage' in Haug's development framework – is mixed. Again, Haug's analysis is optimistic: while readily acknowledging that the genesis and initial stages of Silicon Glen bore little resemblance to the more innovative and technologically sophisticated activity seen in other high technology clusters, he argues that by the end of the 1970s "similarities between Silicon Glen and Silicon Valley are readily apparent" (*ibid*, p. 114). For example, while noting that much of the initial industrial activity in Silicon Glen was limited to lower-value manufacturing and assembly work, Haug cites previously published work (Haug et al, 1983) as well as contemporary survey data as evidence that the level of R&D and other advanced technical activities in Scottish facilities increased significantly throughout the 1970s. However, Haug also notes that that the same data suggests that US-owned firms performed less R&D work in Scotland than their indigenous competitors, with research and scientific staff comprising only 9% of their workforce, compared to an average of over 30% for British-owned companies (Haug, 1986, p. 112).

Writing several years later, McCalman (1992) has a more critical assessment of extent of advanced technical and R&D work done by foreign-owned firms in Silicon Glen, describing the overall level of activity as "confusing." Referring to work published by Young et al. (1988), which suggests that some "limited" R&D capabilities have evolved – around half of subsidiaries report "some significant" R&D work, while 15% perform none – McCalman questions why this activity has not translated into significant spin-offs or local supplier networks. This assertion was supported by several academic publications, including his own previous work (McCalman, 1987; Clarke & Beaney, 1993; Turok 1993a; Collinson, 2000). While these studies generally concede that there were some improvements to the Scottish economy in terms of increased employment and expanded industrial infrastructure, McCalman asserts that "few commentators would suggest that the benefits reach any further". McCalman emphasises the point that "the attraction of inward investment in electronics has spectacularly failed in the attempt to make the industry Scottish in an ownership sense" (*ibid.*, p. 423-4).

Indeed, the second major explanation for the decline of Silicon Glen has to do with the 'embeddedness' of its foreign-owned actors within the wider Scottish industrial and economic landscape. The concept of embeddedness is related to the strength and depth of the linkages between actors in an industrial sector; historically, the growth of indigenous suppliers of materials, services, and machinery have been one of the main ways in which the benefits of inward foreign investment manifests itself in a local economy (Turok, 1993a). While the term is not typically used in the context of clusters dynamics, embeddedness has obvious similarities with the hallmarks of a well-functioning industrial cluster, many of whose benefits arise through collaboration and close partnerships between sectoral actors.

Even before the collapse of the late 1990s, scholars were debating the extent to which Silicon Glen was well-embedded into the domestic Scottish technology sector, with particular attention paid to the limited extent of local sourcing and to the paucity of spin-off enterprises from the subsidiaries and plants of the multinationals (Clarke & Beaney, 1993). For example, a pair of studies published by Turok in 1993 describe the relatively low, and decreasing, share of UK-owned firms in Silicon Glen (1993a), while also presenting evidence that foreign-owned firms contribute less to the Scottish economy, in terms of employment and impact on the local supply chain, than their domestic-owned counterparts (1993b). Turok accepts that the level of industrial activity in Scotland has undoubtedly grown as a result of the Silicon Glen phenomenon. However, Turok also states that the fact "that many of the materials and component were brought in from other parts of the UK or imported from abroad, with only final assembly undertaken at local establishments" (1993a, p.367) means that the overall value added to the Scottish economy was minimal.

This low level of embeddedness into the Scottish supply chain can be explained, in part, by the 'branch-plant' character of many of the foreign-owned facilities, which lack the authority to make product design or procurement decisions, or who are restricted by supply relationships dictated by parent companies (Turok, 1993b, p. 415). However, Turok also argues that a major barrier to increasing low levels of local sourcing is the relatively undeveloped state of elements of the Scottish high technology supply chain, many of whom struggled to match their global competitors in terms of the cost, and in some cases, quality or reliability of highly sophisticated products or components (1993b, p. 410). This point is supported in later work by Brand and colleagues (2000). When looking at the impact of foreign actors on manufacturing sectors in Wales, Scotland, and England's West Midlands they found that branch-plants of multinational corporations sourced a smaller proportion of their components and materials from local suppliers due in part to their access to, and existing relationships with, more sophisticated and cost-competitive global supply chains. Turok goes on to argue that while such technological and manufacturing challenges such as this are not insurmountable, many indigenous suppliers have struggled to upgrade their operations, often citing "the lack of long-term 'patient' resources from financial institutions or government agencies" (*ibid,* 1993b, p. 415).

However, in a publication written in direct response to Turok's work, McCann (1997) argues that the essentially global nature of the high technology industry – characterised by large, multinational firms and global supply chains– means that the expectation of high levels of embeddedness within Silicon Glen, or indeed any one regional technology cluster, is unreasonable (p. 701). McCann also downplays the relatively low levels of domestic ownership, arguing that such "a general change in the trend of regional technological ownership can take several generations" (*ibid.*) echoing the scholarly consensus that cluster growth, and the formation of deep linkages between sectoral actors, are held to be slow, multi-generational processes (see sections 2.2 and 2.4). McCann also asserts that comparisons between Silicon Glen and other clusters such as Silicon Valley are improper. The latter is more akin to a 'information-trading cluster' (McCann, 1995), whose primary focus is on knowledge exchange and intellectual property development, whereas the Scottish case should be more accurately thought of as a 'production agglomeration' arranged to make the most efficient use of industrial infrastructure. This includes transportation networks and skilled labour pools. McCann takes the view that, when compared with similar 'production agglomeration' examples such as the automotive industry, Silicon Glen could be considered a success; it is important to note, however, that this analysis dates from the mid-1990s and prior to the dramatic contraction the sector underwent over the subsequent decade. In contrast, later analysis from Collinson (2000) explicitly points to low levels of embeddedness, exacerbated by "the over-emphasis on attracting inward investment by policy-makers in Scotland," as a key reason why Silicon Glen lacked a "virtuous cycle of self-generating growth" that could have buttressed the sector against the eventual – perhaps inevitable – departure of large numbers of foreign-owned firms.

4 Case Study 2: Scotland's Intermediary Technology Initiative (ITI)

Unlike the case of Silicon Glen, the ITI is an example of a specific policy initiative that aimed to improve the innovative, rather than the manufacturing, performance of three distinct sectors of the Scottish economy. One of the ITI's main goals was to translate Scotland's considerable – and largely university-based –research capacity into new technology-based spin-off companies, in an effort to capitalise on what it identified as emerging global commercial opportunities. Towards this end, the ITI sought to build up early-stage industrial clusters by fostering collaborations and business relationships between fundamental research providers and technology firms in Scotland.

4.1 Background: Increasing Innovative Activity in the Scottish Economy

The origins of the Intermediary Technology Initiative begin with the "Smart, Successful Scotland" economic development strategy spearheaded by Scottish Enterprise in the early 2000s (Scottish Executive, 2004). In testimony given to the Enterprise and Culture Committee of Scottish Parliament in November 2003, Dr Janet Brown, director of competitive business at Scottish Enterprise, noted that there was a significant productivity gap between Scotland and the rest of Europe. She linked this to a lack of innovation and low levels of business-led research and development (Scottish Parliament, 2003, col. 307-8). According to Dr Brown, this hindered the ability of Scottish companies "to take advantage of new opportunities and to improve their production mechanisms and new product introductions," which she argued was "a significant contribution to the poor performance of Scotland's economy" compared to both the wider UK, and the OECD as a whole. With this in mind, Scottish Enterprise sought a means of 'jump-starting' private sector R&D and innovative activity, a way "to achieve a large corporate R&D focus in Scotland in the absence of large corporate R&D activity" (*ibid*.).

A Scottish Enterprise report *ITI Scotland – Realising Scotland's Potential* (Scottish Enterprise, 2003) further elaborates on the strengths and weakness of the Scottish economy, outlining the problems that the ITI was designed to solve. While noting that Scotland has "world class research in many fields, an excellent educational system and skilled, adaptive people," the report also asserts "there are too few high growth companies, integration and exploitation of technology is poor and research and development by companies is low" (*ibid.*, p. 3). Of particular relevance to the concept of industrial clusters, the report also observes that "few of Scotland's strategic industries are based on well-developed clusters", and those that do exist lack "critical mass, R&D intensity, and strong local linkages" (*ibid.*, p. 4). Finally, the report asserts that "developing our capacity for effective commercialisation of R&D" is a critical step to improving the performance of the Scottish economy (*ibid.*, p. 4).

4.2 Policy Objectives and Proposed Role of ITI

The Intermediary Technology Initiative was announced in December 2002, and officially launched by Scotland's Deputy First Minister Jim Wallace in September of the following year. (Scottish Enterprise, 2003; UK Parliament, 2004). The programme's projected 10-year, £450M budget was to be provided solely by Scottish Enterprise (Scottish Enterprise, 2003). The role envisioned for the ITI, as well as its institutional goals, is articulated in a variety of government reports, memoranda, and parliamentary testimony. These statements reflect a policy response tailored to the perceived weaknesses in the Scottish economy described in the previous section, particularly the anaemic levels of private sector innovation, and the low 'birth-rate' of new "high-value, high-technology companies" (*ibid.*, p. 2).

For example, in oral testimony given to the Enterprise and Culture Committee of the Scottish Parliament, Dr Janet Brown of Scottish Enterprise stated that the goal of the ITI "is to help to increase the number of companies that are actively pursuing new market in the global marketplace through high technology" (Scottish Parliament, 2003, col. 308). During the same hearing, Gordon Campbell, inaugural chairman of ITI, emphasised the "market-driven" focus of the organisation, noting that (*ibid.*, col. 309):

[ITI's] remit is to identify opportunities and to match fundamental research to those opportunities, not to operate the other way around. Some organisations look for markets for existing technologies but the ITIs take a different approach. They consider market requirements and match technology to them.

Later in his testimony, Campbell clarified these remarks, stating that the term "fundamental research" was inapt, as "I prefer to use the phrase "enabling research," because it is not the basic research, it is the next step down in development" (*ibid.*). One scholar, commenting on the testimony of Brown and Campbell, summarised the role of the ITI as "a link between the basic research in the universities and the further applied research needed to transfer that work to a market" (MacQueen, 2004, p. 6).

The "rigorous commercial focus" (Scottish Parliament, 2005) of the ITI is highlighted numerous times by other sources. For example, ITI management were keen to emphasise the organisation's "commercial credibility," and felt that it was important that it "be perceived as a "real business" led by "real business people,"" noting that nearly its entire staff had been recruited from the private sector (*ibid.*). Other reports and publications emphasise that the programme is not a replacement for basic academic research, nor does it give grants (ITI Scotland, 2003) and only funds a project when it can find both a credible commercialisation strategy and the opportunity for a clear return on its investment (Scottish Parliament, 2005). Identifying, funding, and supporting the development of innovative research projects would be only one part of the ITI's remit, and largely a means towards the programme's ultimate goal of commercialising new technological and scientific advances, either through the creation of new technology firms, or through licensing newly created intellectual property (IP) to existing companies. Both the ambitious nature of the ITI programme, and its commercial focus, are reflected in the performance metrics set by Scottish Enterprise, which anticipated the creation of 75 new technology firms as a direct result of the programme's initial 10-year run, a figure that was expected to reach 170 after 20 years (Brown et al., 2016, p. 1265).

4.3 ITI as a Route to Industrial Clusters

Although not explicitly driven by regional clustering objectives, many of the ITI's proposed means of addressing issues within the Scottish innovation system are congruent with the formation of industrial clusters, and increased levels of intra-sectoral partnership and collaboration. For example, in its *A Smart, Successful Scotland* report, the Scottish Executive notes how "real opportunities exist in extending the ability of existing business to 'pull' ideas and experiences from our research base," but that this would require close cooperation between knowledge generators in universities and knowledge exploiters in the private sector (Scottish Executive, 2004, pp. 16-17). Building on this point, a memorandum from Scottish Enterprise submitted to the UK Parliament's House of Lords emphasises the need to "increase the level of exchange between the research and corporate sectors in Scotland," as well as "promoting Scotland as an important centre for specific technologies" (UK Parliament, 2004).

Similar written evidence given to the Scottish Parliament states that one of the aims of the ITI is to foster new connections between sectoral actors, noting that "the ITI model relies on the long-term nature of knowledge-sharing collaborations and the continuity of interactions both with, and between academia and industry" (Scottish Parliament, 2005). Indeed, this memorandum also notes that the term 'Intermediary' was deliberately chosen to reflect how the ITI's role would be "to bridge the innovation gap between early-stage research and high-growth business opportunities" (Scottish Parliament, 2005), underlining how increased levels of collaboration and interconnectivity were viewed as one of the expected outcomes of the programme.

In a report prepared for Scottish Government detailing the strengths and weaknesses of various aspects of country's technology innovation landscape, Roper and colleagues situate the ITI as a continuation of what they consider "Scottish Enterprise's longstanding cluster approach,". They argue that its formation was motivated by a desire to "enable businesses to gain from complementarities, collaborations and 'knowledge spillovers' especially where related firms operate in geographical proximity" (Roper et al., 2006, p. 61). In Roper's analysis, the programme would also help to "overcome barriers to connectivity arising from the existence of established 'communities of practice'" (*ibid.*) by facilitating networking and collaboration between sectoral actors. As evidence for these claims, the authors cite various ITI-hosted networking events and informal meetings between investors, business leaders, and academics designed to "create trust, reputation, and communication channels among innovation constituencies" (*ibid.*). One final, noteworthy point raised in this independent report, and somewhat at odds with the ambitious goals and timeframe set by Scottish Enterprise for the ITI, is the assertion that robust intra-sectoral connections and fruitful collaborations would develop gradually. They assert that the rise of "industry groupings (clusters) with global status is likely to be a *generational* process" (*ibid.,* emphasis added).

4.4 The ITI Operating Model & IP Management

The Intermediary Technology Initiative was comprised of three divisions, or Intermediary Technology Institutes (also referred to, somewhat confusingly, as ITIs), each focused on a particular industrial sector: Life Sciences, based in Dundee; Techmedia (i.e. digital media, information and communication technology), located in Glasgow; and Energy (including oil and gas, as well as renewable energy technologies), operating out of Aberdeen. These Institutes were to fulfil a variety of business development and market support roles for actors in their sector, including the identification of both market-ready intellectual property in Scotland as well as potential global markets; commissioning new research to bring extant IP 'closer to market'; and assisting with the commercialisation and spin-off process (Huggins and Kitigawa, 2012).

In addition to being used internally to shape the priorities and focus of each Institute, the foresighting data compiled by ITI was also available to private firms through fees-based membership scheme. Membership in ITI was available at two levels (ITI Scotland, 2003, p. 5) :

- General membership, where for a £400 fee companies received proprietary market analyses, as well as access to "a global network of companies and researchers in key market sectors;"
- The more costly Programme membership, which claimed to give firms "the opportunity to actively participate in programme development," presumably influencing the research commissioning and commercialisation functions of ITI

Information regarding the membership application – or even possible recruitment – process is scarce; although according to a statement from ITI Scotland over 40 applications for General membership had been received as of March 2004 (UK Parliament, 2004). Perhaps surprisingly, given ITI's stated focus of increasing the level of innovative activity within the Scottish economy and improving the competitiveness of Scottish firms, there were no geographic or national requirements for participation in the scheme. One ITI publication emphasised that "membership is open to organisations throughout the world and is in no way restricted by the geographical location of each [Institute]" (Scottish Enterprise, 2003, p.10).

As Brown and colleagues note, the viability of the ITI model was heavily dependent on the ability of the three Institutes to execute sophisticated technological foresighting, as this data was then used by programme managers to devise potential research projects (Brown et al., 2016). Prior to being commissioned, each project was evaluated based on several criteria, including global market opportunities and potential commercialisation routes; the likelihood of the creation of new, patentable intellectual property; and existing Scottish academic and corporate research base, as well as the ability for Scottish firms to exploit the technology (*ibid.*, p. 1264). While both commercial and academic research providers were eligible, most projects commissioned by the ITI went to university laboratories and research institutes (MacQueen, 2004; Brown et al., 2016), an unsurprising result given that one of the driving forces for the ITI was the low level of private sector R&D in Scotland.

Intellectual property rights were of enormous importance to the ITI model, and the organisation sought to own the IP generated in any R&D programme it commissioned. ITI chairman, Gordon Campbell, framed the practice as a matter of expediency, a way to ensure "that the institutes can have the maximum flexibility in helping the commercialisation of the intellectual property" (Scottish Parliament, 2003, col. 310). Indeed, the IP-ownership aspect of the ITI model was an integral part of the programme's overall commercialisation process. In addition to licensing IP to firms – ideally from Scotland, although foreign candidates would also be eligible (ITI Scotland, 2003, p. 5; Scottish Enterprise, 2003, p. 10) – within the three Institutes' sector of focus, the ITI model anticipated the creation of new firms that would arise because of the availability of new, 'market-ready' technology developed within the R&D programmes. University spin-offs were expected to be a major source of these new firms, followed by entrepreneurial start-ups originating from existing technology firms in Scotland (Brown et al., 2016).

The stated commercial focus of the programme was on "increasing and sustaining the birth rate of indigenous high value-added, technology- based companies," and "creating a sustainable flow of market relevant technology companies," (Scottish Enterprise, 2003). However, there is relatively little documentary evidence available from ITI or Scottish Enterprise describing in detail how the commercialisation process would actually operate. As noted above, the ITI's ownership of IP generated within the programme meant that any commercialisation scheme would necessarily involve a licensing agreement between the organisation and a potential commercialisation partner (including spin-off firms that may have formed as a result of a 'successful' ITI-funded research project and been instrumental in developing the IP in question). Decisions on how, and to whom, to license IP would be made by ITI management, supported by a "Commercial Advisory Group," comprised of various industrial, legal, and financial stakeholders, although there are few details as to the exact composition or role of this group (Scottish Parliament, 2003, col. 312; Scottish Enterprise, 2003, p. 9).

Brown and colleagues report that support for the commercialisation process, and in particular assistance for new spin-offs that might arise as a result of the ITI programme, was left primarily as the responsibility of existing support mechanisms provided through Scottish Enterprise, such as the High Growth Start-up Unit (Brown et al., 2016, p. 1265). The assertion that ITI's own commercialisation functions were underdeveloped is supported by the fact that following an internal review by Scottish Enterprise in 2008, the decision was made to bring the ITI – which had operated since 2003 as an arms-length organisation with considerable autonomy – under the direct control of Scottish Enterprise (The Scotsman, 2009). This was an effort to allow "greater alignment with other SE commercialisation programmes and projects, bringing increased efficiency and impact" (Scottish Enterprise, 2009).

4.5 Analysis: Programme Outcomes and the 'Failure' of ITI

The incorporation of the ITI into the wider operations of Scottish Enterprise in 2009 coincided with a dramatic decrease in programme activity (Brown et al., 2016); according to a report in The Herald newspaper, in 2010 the decision was made to commission no new R&D projects (The Herald, 2013). As of 2013, having spent only £231M of its anticipated £450M 10-year budget, the ITI programme's operations had come to an end, having achieved the following outcomes across all three sectors (Brown et al., 2016):

- Twenty-two R&D programmes completed.
- Ninety-four patents registered
- Five new technology-based firms currently trading
- Twenty-four licensing deals (with £600 000 in licensing revenue)

Regarding the ITI's record for funding and supporting technological and scientific research, an earlier work by Brown and Mason offered a somewhat positive assessment. It referred to the number of successful R&D programmes and patents as an indication that the programme had, at the very least, "been a highly effective mechanism for producing new technology in the shape of new or 'virgin' IP" (Brown and Mason, 2012, pp. 37-38). Subsequent work from the same authors takes a more critical view. They argue that the number of patents generated over the lifetime of the programme "does not seem to constitute an exceptional output for the volume of expenditure committed," (Brown et al., 2016, p. 1265). They also note that the total number of patents linked to the entire run of the ITI programme (94) is less than one-half of the total number of patents issued in Scotland in a typical year (*c.f.* 207 patents in 2011).

However, given that research commercialisation, measured by the establishment of new technology firms and the growth of the Scottish technology sector, was always held to be the pre-eminent goal of the ITI, the definitive – and unfortunately, most critical – assessment must be based on these metrics. To that end, the programme fell well short of its 10-year goal of 75 new technology firms (Brown et al., 2016), having produced only 5 companies with links to ITI-funded research. While the ITI was more successful in concluding licensing agreements with existing commercial partners, the monetary value of these two dozen contracts – just £600,000, or an average of £25,000 each – was decried by critics as “a paltry return” compared to the programme’s total expenditures of over £200M (The Herald, 2013).

While the mismatch between these two figures is striking, it is important to place the role of licensing revenue in context. In her 2003 testimony to Scottish Parliament, Dr Janet Brown made it clear that it was never the intention of the ITI be a revenue source for its own sake. Rather than seeking to “maximise the return of intellectual property revenue to the ITIs”, its goal would be to prioritise company value and overall economic impact over “simply selling to the highest bidder” (Scottish Parliament, 2003, col. 311). Thus, criticisms that the ITI did not recoup the significant investments it made on its research projects arguably fail to understand the intended role of these licensing fees within the programme. However, the low sums that these licensing agreements earned does reflect the relatively low value that commercial actors placed on the IP that was produced by the programme, directly undercutting the ITI’s claim that due to its advanced foresighting ability the R&D work it commissioned would be highly sought after in the global marketplace.

Industry scholars and academics have pointed to a number of reasons to explain why the ITI programme fell short of its objectives. Many of these critiques point to a lack of awareness – or consideration – on the part of ITI of the peculiarities of the Scottish industrial and economic landscape. For example, Busch and colleagues (2018) cite the ITI as an example of a public sector support agency insensitive to the business pressures and economic constraints faced by small technology firms, such as the need for – and indeed availability of – private financing and venture capital in order to fund entrepreneurial activity.

Data from Brown and colleagues’ (2016, p. 1267) interviews with potential ITI licensees support this point, characterising the programme’s commercialisation process as inflexible, as well as prohibitively expensive for small firms – in some cases costing as much as £150000 for an exclusive license, in addition to ongoing royalties for any products developed as a result of ITI-linked IP. In one example cited by an interviewee, a small firm enquired about obtaining a less costly ‘demonstration license’ in order to display possible applications to potential clients and funders. This request was flatly denied by the ITI, and as they were unable to secure funding elsewhere, this potential licensee withdrew from the programme.

Other criticisms of the ITI programme point to a fundamental misunderstanding of the nature of existing Scottish technology sector, and their ability to exploit the R&D work being commissioned. At a basic level, Brown and colleagues (2016) argue that the very focus of the three sectoral Institutes – life sciences, techmedia, and energy – were poor choices that reflected the aspirations of Scottish policymakers rather than actual industrial or entrepreneurial activity in the country. ITI publications emphasise how these three technology sectors were chosen on the basis of their anticipated market growth potential (Scottish Enterprise, 2003, p. 5).

Brown and colleagues argue that these foresighting projections took precedence over any objective appraisal of Scotland’s pre-existing strengths in these areas, pointing to their own analysis of Scottish industry (Mason and Brown, 2012), which indicated that “the life sciences and the digital media sectors are both small in size and have few research-oriented SMEs” (Brown et al., 2016, p. 1269). While acknowledging that the Scottish energy sector is more well-developed, they note that many of the ITI’s energy R&D projects focussed on renewable energy technologies, a market that they characterise as “still embryonic in Scotland and dependent on subsidies” (*ibid.*). Overall, Brown and colleagues describe these three sectors as being “largely incapable of connecting to and ‘absorbing’ the outputs” from the ITI (*ibid.*).

While not referring specifically to the ITI programme, a report by Rosiello and colleagues mentions how previous economic development programmes run by Scottish Enterprise have taken a similar aspirational approach when selecting sectors to support. They note "for example, the biotechnology sector was identified by SE as a high priority mostly based on the research capacity in Scotland's university sector rather than any actual industrial presence" (Rosiello et al., 2015, p. 671).

Along similar lines, Lyall argued that any technology innovation support scheme in Scotland must also address "the mismatch between the capacity of the [Scottish] knowledge base and an industry base that is structurally unable to exploit it" (Lyall, 2005, p. 66). While written early on in the run of the ITI, this point anticipates many of the issues that Brown and colleagues described in their 'post-mortem' of the programme. Namely, that due to the ITI's focus on producing novel, 'cutting-edge' IP that could also be patented, many prospective commercial partners or potential spin-offs felt that the outputs from the R&D projects were too advanced, and beyond their capacity to effectively exploit without further practical development work (Brown et al., 2016).

In a similar vein, Hannon and colleagues (Hannon et al., 2017) highlight the risks of the piecemeal development of IP, particularly in high technology applications, without consideration of its ultimate end-use. Their study focuses on the Scottish marine energy sector and the technology support agency Wave Energy Scotland (to be discussed in more detail in section 5). One interview respondent compared the agency – unfavourably – to ITI, noting that both organisations focused on producing components or individual technological advancements "that were not immediately commercialisable on their own without integration into a larger device system" (*ibid.*, p. 85).

5 Case study 3: The 'Wave Energy Scotland' Programme

Similar to the case of ITI, the Wave Energy Scotland (WES) programme was an attempt by policymakers in Scotland to accelerate innovative activity and boost technological development in a specific industrial sector. The WES case is somewhat unique insofar as there already existed a nascent wave energy cluster in Scotland, including a number of established development firms and a history of technical and R&D expertise. However, worsening financial prospects in the mid-2010s, exacerbated by recurrent technical challenges and a lack of intra-sectoral knowledge sharing, meant that the Scottish wave sector was on the verge of collapse. With its stated goal of improving device reliability and performance by increasing the number of partnerships and collaborations and offering a patient source of project funding, Wave Energy Scotland was established to try and address the persistent social and financial capital issues within the sector.

5.1 Background: Wave Energy in Scotland

Due to its unique maritime geography, the waves around the UK – and in particular north-west Scotland – contain an estimated 70 TWh per annum available for potential electricity generation (AMEC, 2012). Although limited by the fact that many energy policy powers are reserved for the UK Government, the Scottish Government has shown longstanding interest in – and support for – the development of an indigenous wave energy industry.

In part, this interest in wave energy is driven by the Scottish Government's wider commitment to renewable energy technology, and its overall policy goals of energy system decarbonisation and greenhouse gas (GHG) emission reduction. The 2017 Scottish Energy Strategy and 2018 Climate Change Plan set targets for using renewable energy sources to provide 100% of electricity demand by 2020, as well as "the equivalent of 50% of the energy for Scotland's heat, transport, and electricity consumption" by 2030 (Scottish Government, 2017, p. 6; 2018). An integral part of the government's plan for realising these targets is to "continue to champion and explore the potential of Scotland's huge renewable energy resource" (Scottish Government, 2017, p. 7). Marine renewables – wave and tidal energy[1] – were listed alongside wind, hydro, solar, and bioenergy sources as having enormous potential for the Scottish (and UK) energy system, according to the Scottish Government (2018, p. 68).

In addition to the environmental benefits, the development of the wave energy sector also represents the potential for a Scottish-led industry centred on a renewable energy source abundant to Scotland, and the opportunity to become "a world leader and exporter of marine technology" (Scottish Executive, 2003, p. 13). In 2004, a Scottish Parliament report asserted that Scotland could "become to wave and tidal power what Denmark is to wind power," (SPECC, 2004, p. 55) referencing that country's enormously successful domestic industry based on the manufacture and export of onshore wind energy technology (Ryland, 2010; Gavard, 2016). This same report also highlighted the

[1] While often referred to under the umbrella term of 'marine renewables,' the wave and tidal energy sectors have had markedly distinct trajectories in Scotland (and the UK), with the latter generally seen as more mature in terms of both technological development and commercial prospects (CXC, 2017; OES, 2020). The WES programme – and this case study – deals only with the wave energy sector.

essential role of policy-makers in this process, noting that government must "put in place any additional measures required to ensure that Scotland achieves the ambition of becoming a leading economy for the development and production of marine renewables," (SPECC, 2004, p. 94).

5.2 Policy Support for Wave Energy Technology Innovation

Given the importance, and potential value, of wave energy industry, both the UK and Scottish Governments have implemented a series of policy measures and funding schemes in an effort to assist technological development and innovation in the wave energy sector.

Beginning in the 1970s as a response to rising oil prices and concerns about energy security, the UK Department of Energy initiated a Wave Energy Programme (WEP) whose goal was to identify a prototype device that could be scaled up to compete with large thermal power stations (Winskel et al., 2006). While this ultimately proved to economically unfeasible for the existing technology, the WEP was an early example of a policy intervention that aimed to partner device developers and with large engineering firms and other industrial actors, in order to collaborate on solving common technological innovation challenges (Winskel, 2007).

Following the cancellation of the WEP in the early 1980s, policy support for the wave energy sector received little attention from policymakers for nearly two decades. A series of reports and expert reviews in the late 1990s and early 2000s drew the attention of the UK Government to the potential of marine energy technologies (DTI, 2003; Winskel et al., 2006). As noted above, renewed interest in wave energy from Westminster coincided with a series of policy support mechanisms initiated by the recently created Scottish Parliament and Executive, eager to support a growing industry with strong ties to Scotland (Scottish Executive, 2003; SPECC, 2004; Winskel et al., 2006). While lacking the direct authority to set overall energy policy, Holyrood does have wide latitude to enact 'support-push' policies that "promote renewable energy generation and economic development" (Hannon et al., 2017, p. 29).

Following in the pattern set by the WEP, many of these programmes and policy initiatives prioritised – at least in their design – the formation of networks and partnerships between wave energy developers, academic researchers, and industrial manufacturers (Winskel et al, 2006; Hannon et al., 2017). For example, the Intermediary Technology Institute for Energy (discussed in section 4), was founded with the goal of finding routes to market for new renewable technologies, including wave energy, by building linkages between fundamental research providers and technology firms.

Alongside direct efforts to establish and support research partnerships and collaborations, several policy initiatives were launched in order to develop industry-wide performance and certification standards, and facilitate knowledge exchange between actors (Winskel et al., 2006; Hannon et al., 2017). Along these lines the European Marine Energy Centre (EMEC) a research laboratory and testing facility, was established in 2003. Located in the Orkney Islands, EMEC allows developers and manufacturers to test devices in 'real world' conditions, as well as in a series of state-of-the-art laboratories and indoor wave tanks. In addition to offering technical assistance and advice on engineering details like grid connectivity and meteorological monitoring, the centre also serves as an industry-wide nexus for support with certification, permitting, and regulatory issues (EMEC, 2021). Similarly, the Offshore Renewable Energy Catapult (OREC), founded in 2013 as a testing and certification facility, also serves a knowledge capture role with the industry, hosting an online database of research reports and datasets from a range of academic and industrial collaborators (ORE Catapult, 2021).

In addition to policies aimed to build up innovation capacity and R&D networks within the wave energy sector, both the UK and Scottish Governments launched several initiatives. The goals were to encourage the development of full-scale demonstration devices, with a view towards widespread commercial deployment; since the early 2000s, these commercially oriented programmes have constituted the majority of financial support available to developers from these two levels of government (Vantoch-Wood, 2012; Hannon et al., 2017). For example, in 2006 the UK Government announced the Marine Renewable Deployment Fund (MRDF), whose £42M support budget was restricted to full-scale devices that had already been shown to operate in realistic ocean conditions for between 6 and 12-months. The programme ran until 2011 without having ever been accessed by a single wave energy developer (Vantoch-Wood, 2012).

The Scottish Government created similar programmes, such as the Wave and Tidal Energy Scheme (WATES), and its successor the Wave and Tidal Energy RD&D Support Programme (WATERS). These programmes were again criticised for having criteria and funding requirements that prioritised rapid commercial deployment which favoured already established developers, making it effectively inaccessible to smaller firms (Vantoch-Wood, 2012, p. 9). The £103M Renewable Energy Investment Fund (REIF) was administered by the economic development agency Scottish Enterprise and backed by the Scottish Investment Bank. It was created to provide low-interest loans for wave energy developers funded full-scale marine renewable energy demonstration projects, including £12m for wave energy developers Pelamis and Aquamarine (Dickson, 2017, p. 28; Hannon et al., 2017, p. 37). A further £13m was awarded to Pelamis and Aquamarine under the Scottish Government's Marine Renewable Commercialisation Fund (MRCF), a programme announced in 2012 to assist the development of prototype devices and commercially viable wave energy arrays (Magagna & Uihlein, 2015; Hannon et al, 2017).

5.3 The State of the Wave Energy Sector in the Mid-2010s

Despite these policy support schemes from both the UK and Scottish Governments, by the mid-2010s wave energy technology was still not ready for commercial deployment (Blair, 2013). A government briefing note from 2015 aptly summarises the state of the industry (WES, 2015, p. 1):

> Notwithstanding considerable investment over several years, there is as yet no wave technology sufficiently developed to move from testing to commercialisation. This slower than anticipated development of technology has been accompanied by a reduction in private investment into the sector, and a withdrawal of some major energy companies and investors from it.

Indeed, in late 2013, private investment firms including Vattenfall, SSE and ABB, as well as potential customers such as utility companies E.ON and Scottish Power, either withdrew from the sector or scaled back their involvement (Dickson, 2017, p. 31). In addition, 14 wave energy developers entered into administration between 2011 and 2016, and despite over £200M of government support by 2017. The wave energy industry had yet to produce a commercially viable device (Hannon et al., 2017, p. viii), with the total rated capacity of test prototypes in UK having declined to less than 1 MW by this time (ibid., p75).

At a ‘wave summit’ convened in January 2014 by then-Scottish First Minister Alex Salmond it was made clear that private investors were sceptical about the viability of current wave energy technology, and that no industrial support would be forthcoming in the short term (Scottish Parliament, 2015b, p. 29). This left the Scottish Government as the only source of funding for the sector, which presented considerable legal and financial hurdles. For one, the Scottish Government was prevented from acting as the sole funder of beleaguered wave energy developers, as such ‘selective intervention’ would have been in violation of EU laws regarding market competition and State Aid (Scottish Parliament, 2014b, p. 9). Furthermore, setting aside the legal issues, the sums required to continue direct financial support of the wave energy sector were significant. Estimates from Scottish Enterprise suggested that for the market leaders Pelamis and Aquamarine, commercially viable devices were at least 8-10 years off, and would require between £100M – £300M of public funds before private investment would return (Dickson, 2017, p. 32). As Fergus Ewing, Scottish Energy Minister at time, noted “it did not seem possible for the Scottish Government to shoulder the total burden of the funding that would, according to experts, have been required to take Pelamis forward” (Scottish Parliament, 2015c, p: 97).

In the face of these legal and financial obstacles, in November 2014 the Scottish Cabinet decided against further investment in the wave energy sector (Dickson, 2017, p. 33). The effect of this decision was immediate: Pelamis entered into administration that same month (BBC News, 2014), and by January 2015 Aquamarine had “scaled back operations” (Scottish Parliament, 2015a, p. 1) and ultimately ceased trading by the end of that year (BBC News, 2015). The extent to which the Scottish Government had supported the wave energy sector meant that the loss of these two firms resulted in over £30M of loans and equity financing being written off (Dickson, 2017, p. 29).

5.4 Wave Energy Scotland: ‘A New Model of Support’

Underlining the upheaval that the loss of leading developer firms Pelamis and Aquamarine caused in the wave energy sector, the Scottish Government’s response was rapid. In November 2014**,** one day after Pelamis entered into administration, plans were announced for the formation of Wave Energy Scotland (WES). In their initial announcement, the Scottish Government noted both “the challenges affecting the wave sector in particular” and “the value of this wave technology development to date, and the large global market that can be developed through further technological innovation,” (WES, 2015, p. 1).

To that end, the WES operating model places a heavy emphasis – at least in its design and conception – on intra-industry collaboration, and a commitment to “share research findings and ensure that they are disseminated widely,” (WES, 2015, p. 3) in an effort to make more efficient use of resources and reduce unnecessary duplication of effort. In a speech to Scottish Parliament, Minister Ewing introduced WES as “a new model of support for the development of wave power technology,”. Further describing it as “the best way to ensure collaboration, to bring the best minds together, to harvest the IP and to ensure that we work to seek common convergence for both offshore and nearshore solutions” (Scottish Parliament, 2014a, pp. 4 -5). Thus, while not an explicit attempt to create a wave energy technology cluster in Scotland, the WES programme – with its aim to move the sector “away from a company-centred approach” (WES, 2015, p. 1) to a more integrated strategy for addressing common technical problems and innovation challenges – has clear similarities with an industrial cluster scheme.

In April 2015, the Economy, Energy and Tourism Committee of Scottish Parliament convened a hearing to discuss WES and the future of the wave energy sector in Scotland (Scottish Parliament, 2015c). Testimony was heard from key players in the marine renewable energy field who described what they felt were the problems facing the development of wave energy technology, as well as how WES might address them.

One of the main points expressed in this hearing was that the previous support regime for wave energy – both public and private – had placed an unrealistic emphasis on rapid scale-up and commercialisation, which according to Neil Kermode, head of the European Marine Energy Centre "pushed people towards going too big too quickly" (Scottish Parliament, 2015c, p. 11). Tim Hurst of WES argued that the technical difficulty of the problem was exacerbated by a public sector funding regime that was too focused on developing full-scale devices, oftentimes prematurely, which in his view, "resulted in us trying to push technology too far and to put things in the sea before they have been fully tested. The end result is that we have failed at the full scale" (*ibid*). Lindsay Leask, senior policy manager for offshore renewables at the industry association Scottish Renewables, expanded on this point, noting that private sector investment was also eager to see rapid development in the field. This created a support regime for wave energy that was pushing "towards array development for wave more quickly than we needed to be going" (Scottish Parliament, 2015c, p. 5).

However, despite the emphasis placed on the need for collaboration and collective effort within the industry by Minister Ewing's remarks and WES publications cited above, much of the testimony focused on the issue of regaining market confidence, and thus private sector interest, in wave energy technology. There was almost no discussion of how WES might encourage developer partnerships or the sharing of IP, or what role that increased collaboration might play in addressing the sector's innovation challenges.

5.5 'The How': The Operating Model of the WES Programme

WES is a subsidiary of Highland and Islands Enterprise, one of the Scottish Government's economic development agencies. Its yearly budget of approximately £13 million came entirely from the Scottish Government, which provided funding for a five-year period originally scheduled to end in spring 2021[2] (Parker, 2019, p. 27); as of early-2021, it had worked with over 230 organisations from 13 different countries, having invested £41.6M on 95 projects (WES, 2021b). This section discusses how two crucial elements – intellectual property management, and collaboration between researchers and developers within the wave energy community – were handled within the WES programme.

5.5.1 IP Management in the WES Programme

In contrast to the IP ownership arrangement in the ITI programme, developers retain the rights to any IP generated as a result of WES-funded activities, and are free to exploit this for commercial use. However, WES also retains an "irrevocable, perpetual" (Parker,

[2] As of May 2020, plans are being finalised for an extension of the WES programme beyond its original 5-year term. In addition, WES will be involved in the management of the forthcoming Europewave programme, an EU-focused wave energy technology development programme set to launch in summer 2021 (H. Jeffrey 2021, personal communication, 10 May).

2019. p. 30) right to license this same IP, with or without the original developer's approval, should a potential licensee express interest. This mechanism is seen as a way to ensure that IP developed within the programme is shared widely within the wave energy sector, in an effort maximise the value for money of research expenditures, and to minimise unnecessary duplication of research efforts. Broadly speaking, intellectual property in the WES programme can be divided into two categories, based on whether it was IP generated before or after the involvement of WES.

5.5.2 Pre-WES: Knowledge Capture and 'The Knowledge Library'

As noted above, one of the main drivers for the formation of WES was the desire on the part of the Scottish Government to ensure that technical assets, and especially intellectual property, were not lost when leading wave developers ceased trading in the mid-2010s. Towards this end, WES contracted Quoceant, an energy consultancy firm staffed by former employees of Pelamis, as well as the wave developers AWS Ocean and Aquamarine, "to capture the wider lessons learned by the sector over the last 20 years" (WES, 2015, p. 3). The results of this 'Knowledge Capture' project were used as the foundation of the WES 'Knowledge Library,' an online database for these archival data, in an effort "to help prevent repetition of past failures, duplication of effort or accelerate new technology" (WES, 2016). Along with information from commercial wave developers, a host of material from academia and university-based research has been added to the Library in recent years (Parker, 2019. p. 32). The Knowledge Library also serves as a portal for WES to disseminate information about the programme itself (WES, 2021a). Material available include presentations and literature from previous WES events and conferences, as well as details about the past and current projects funded by WES, including project summary reports submitted by developers.

The utility of the Knowledge Library, and the degree to which specific IP, or even more general technical knowledge, from the 'pre-WES' era has been incorporated into current work in the field is difficult to assess. Based on download statistics from the Library website, WES is able to keep track of the most frequently accessed material, and notes an uptick in activity when new items are made available, suggesting that the developer community does consult them to some extent (Parker, 2019. p. 32). Interviews with developers themselves confirm this general point: some of the pre-WES material has been occasionally consulted, although one developer noted that the usefulness of the Library is hampered by the fact that it is difficult to know what is available without first searching through the material, which would require a significant investment of time and resources (*ibid.*). Instead, it was simpler and faster to directly approach former personnel from Pelamis or Aquamarine – who are oftentimes still a part of the wider wave energy sector (e.g. Quoceant) – than consult archival material and summary reports (*ibid.*). WES appears to be aware of these issues, noting that it will be taking steps in the future to better index and organise the Library materials to improve its usability (*ibid.*).

5.5.3 IP Generated Within WES

In addition to safeguarding previously generated IP, WES's remit is to fund developers to build and research new wave energy technology, and thus create new IP. According to the *Wave Energy Scotland Briefing Note* (2015, p. 3):

> one of the fundamental objectives of WES is to share research findings and ensure that they are disseminated widely. Applicants to WES retain any arising IP, but they will be required to make it available to others on market terms.

Members of WES provided additional context for this statement in testimony made to Scottish Parliament. Tim Hurst described the WES approach to IP thusly (Scottish Parliament, 2015c, p. 16):

> Our idea is that, if a contractor comes into the WES programme, it will get the funding and own the IP, but it can keep the IP only if it does something with it—if it supplies its subcomponents or whatever into the market to stimulate growth and push us towards commercial wave devices. There will be a number of clauses in the contracts we sign that say, if a contractor does not use the IP for a period it will revert to WES.

Despite the ability to claim IP after a period of time (between 3 and 4 years, depending on the nature of the IP (Parker, 2019. p. 33)) Hurst goes on to note that WES does not want to own any IP, and that ideally, “IP is best kept in the private sector” (Scottish Parliament, 2015c, p. 17). This IP arrangement was seen as necessary to attract participants into the WES programme, noting that one potential model whereby WES would own the IP and license it back to companies was rejected due to industry reluctance (Scottish Parliament, 2015c, p. 18):

> If we create an environment that has IP arrangements that they do not like, that will discourage them from joining the programme— that is not just my view; I have tested that with a number of organisations.

According to interviews (Parker, 2019. p. 33) with WES staff, this ‘IP claw-back’ mechanism has never been invoked due to inactivity or a lack of use – admittedly unlikely, given the short history of the programme – nor has WES had to step in to broker a deal on behalf of a developer unwilling to license its IP to another party. Similarly, as of July 2019, there have been no formal IP sharing or licensing agreements involving any of the developers in the WES programme, according to interviews with both developers and WES staff (*ibid.*).

There are several reasons why this is the case. For one, WES is structured such that it only has a claim on IP specifically produced within the framework of the programme; any ‘background IP’ that a developer may own prior to being funded by WES is exempt from any sharing or disclosure requirement. Thus, while any IP generated in the WES programme is, in principle, open for other developers to license, WES admits that “realistically, that can probably never happen, because if they can’t get the background IP” (*ibid.*) then it is unlikely that that material would be sufficiently interesting or valuable on its own.

Comments from developers revealed further barriers to IP sharing. Despite the fact that WES staff appear to take a deep interest in the technical aspects of the developer’s projects, and that the programme requires detailed project reports, complete with extensive testing and performance data, this information is kept confidential. It is not accessible to other developers in the programme or to the wider public because, according to one developer “that’s how you protect IP commercially – you don’t put it out in the public domain” (Parker, 2019. p. 34). Although reports are published for each project (on the Knowledge Library), these ‘public versions’ lack detailed technical information, which made it difficult for other developers to identify relevant IP that might prove useful to license from another firm (*ibid.*).

5.6 Collaborations and Consortia in the WES Programme

One of the WES programme's stated goals is to increase the number of collaborative partnerships between developers within the wave energy sector, which it sees as a key step towards streamlining the sector's supply chain, as well as a means of identifying "optimum common techniques," (WES, 2014, p. 2) and encouraging greater standardisation and design convergence amongst developers.

WES takes a compartmentalised approach to wave energy technology innovation, as each of the programme's funding calls are organised around the development of a specific device component. Examination of the project profiles for each funding call (available on the WES website (WES, 2021b)) reveals that most are submitted by a consortium of developer firms or academic entities. However, when it comes to collaboration and consortium formation, WES has taken a deliberately hands-off approach: WES staff remarked that they were reluctant to intervene in this process, citing the wish to avoid being held responsible for distorting the market, or for unsuccessful projects that arise from consortia they had a role in shaping (Parker, 2019. p. 35).

However, while eschewing an active role in partnership and consortium building, WES does host brokerage events after each funding call is announced, in an effort "to facilitate networking and to develop new collaborations" (WES, 2016). One developer specifically mentioned these brokerage events as being a useful way of learning about other companies that they were unaware of, which has led to some collaborations (Parker, 2019, p. 35). Interestingly, there is also evidence of collaboration between nominal 'competitors' within a given funding call: for example, there are numerous cases where a firm is listed as the lead contractor on one project, while also serving as subcontractors or consultants on rival bids (Parker, 2019. p. 35; WES, 2021b).

Responding to the question of whether developers in the WES programme are competitors or collaborators, a WES executive claimed that they are both. They noted that before WES, there was a lot of duplicated effort in the sector, as it was filled with small firms who "designed and built everything themselves, and they competed with other companies who were doing the same things, building and designing the same components" (Parker, 2019. p. 35). This WES executive also noted that, while there is no explicit requirement to form partnerships or consortia, given the exacting standards of the funding calls issued by WES, a successful bid will generally need to be composed of a group of specialist actors who are each able to contribute a particular skill set. These are actors "who wouldn't have worked together had [WES] not had this prescribed content in each of the phases […] they're forming a consortium as a direct result of that" (*ibid.*)

In interviews, both WES staff and developers were quick to acknowledge that these interactions are not a new development, and that partnerships have long been a part of the wave energy sector (Parker, 2019. p. 36). Nevertheless, commenting on how the wave energy sector has changed since the advent of WES, one industry scholar remarked that because of the absence of larger companies such as Pelamis or Aquamarine, "who were relatively mature and progressed, and felt like they could do quite a lot on their own" (*ibid.*), more developers are now receptive to forming consortia. Similarly, one developer noted that prior to WES, it was more difficult to form partnerships with suppliers and subcontractors, given the uncertain economic prospects of the wave energy sector. However, collaborations with firms involved with the WES programme are now seen to be less risky, as potential partners know that approved projects are already fully funded (ibid.).

5.7 Analysis: The Impact of WES

According to the academic and expert analyses of the wave energy sector in Scotland, many of the industry's innovation challenges can be attributed to issues with either social or financial capital. Interestingly, the design of the WES programme reflected a recognition of the importance of a number of these same issues on the part of the Scottish Government and Highland & Islands Enterprise.

For example, there appears to have been broad agreement on the financial capital issues, notably the fact that, prior to WES, commercial and political pressures had pushed developers to advance wave energy too quickly. They focused on riskier, multi-device arrays rather than ensuring that the fundamentals of the technology were sound (Jeffrey et al., 2013, p. 1315; Hannon et al., 2017, p. 110; Scottish Parliament, 2015c, p. 10). The 'match-funding' grant-based support model was identified by academia, the industry, and government as being a contributory factor to this pressure, and in need of reform. To that end, the PCP framework is a novel approach to one of the acknowledged financial capital challenges that faced the industry. These changes to the funding model are also linked to an overall change in attitude across the entire sector, away from rapid commercialisation and towards slower, more methodical development and testing of the underlying technology. These were largely positive changes for the sector.

However, many of the social capital issues remain unresolved. These are particularly important to the question of industrial clusters, as they touch on issues of collaboration and partnerships. While not explicitly framed as a mechanism for cluster formation, both the initial announcements and publications from the Scottish Government, as well as parliamentary testimony from individuals involved in the design of WES, make repeated reference to the importance of elements that can be viewed as consonant with industrial cluster dynamics. For example, the need to "promote collaboration between industry and academia," (Scottish Parliament, 2014a, p. 4) and to "drive the technology development process through a collaborative approach" (Scottish Parliament, 2015c, p. 2) underline the importance that this kind of social capital was seen to have in addressing the challenges facing the wave energy sector in Scotland. Indeed, the importance of collective, industry-wide effort and "bringing together the best engineering and academic mind to collaborate on innovative projects," (WES, 2014, p. 1) was identified as essential to the wave energy sector's success. Furthermore, Minister Ewing made it clear in his initial announcement that that WES was the mechanism by which this could be achieved: "We believe that the best way to ensure collaboration […] is Wave Energy Scotland" (Scottish Parliament, 2014a, p. 4-5).

Some elements of the WES programme do provide the means for facilitating collaborative work and knowledge exchange, while falling short of formally requiring it. These practices – such as the brokerage and networking events held after each funding call – suggest that WES recognises that collaboration and IP sharing are generally positive developments for the industry, despite the fact that it does not – or sees itself as unable to – insist upon it. Similarly, the funding calls themselves are structured in a way that, in a practical sense, requires a consortium of firms to work together in order to submit a viable project. However, it is important to note that in this case, consortium formation is not WES's goal *per se,* but rather a consequence of the relatively small size of developer firms in the current wave energy sector. As noted in interviews (Parker, 2019), and supported by independent academic work (Hannon et al., 2017), it was unlikely that a single firm could meet all of the technical criteria on their own.

Yet, despite assertions that collaboration and knowledge exchange are key factors in "accelerating the development of wave technologies," (WES, 2014, p. 1) WES plays a relatively passive role in ensuring that they actually occur. For example, WES has full access to the technical details of every project in its programme, due to the extensive reports that developers are required to submit. As such, it could potentially play a larger role in identifying beneficial collaborations and opportunities for knowledge exchange between projects, a fact lamented by one developer (Parker, 2019, p. 41). Furthermore, the versions of these reports published to the WES Knowledge Library contain few technical details that other developers might find useful (*ibid.*, p. 40), essentially nullifying them as resources for knowledge exchange, or starting points for collaboration. This appears to be a conscious choice, and one that the founders of WES appear to have felt was unavoidable since, as was noted above, more demanding IP sharing requirements would likely have been a 'poison pill' that would have precluded the involvement of many developers.

Furthermore, while WES's novel licensing scheme and 'use it or lose it' approach to IP ownership was framed as a means of encouraging "deeper collaboration and less duplication of effort" within the industry, the fact that it has yet to be implemented is significant. Indeed, the reluctance of developers to share valuable IP due to the perceived risk it posed to future commercialisation, and the barriers this posed to fostering 'interactive learning' within the wave energy sector are well documented. The issue is long-standing, having been articulated both by developers themselves in the mid-2000s (Winskel, 2007, p. 482), as well as in response to questions from Members of Scottish Parliament in 2014. It was observed that "all too often, IP becomes the barrier to collaboration," and aggressive protection of IP could impede the development of wave energy technology (Scottish Parliament, 2015c, p. 19-20). As of mid-2019, with no formal IP sharing or licensing agreements signed, and little evidence of inter-consortium or inter-component knowledge exchange or collaboration, WES's approach appears to have had little impact on the social capital issues facing the wave energy sector; indeed, the evidence suggests that concerns about confidentiality and the preservation of commercially valuable IP persist.

Thus, when it comes to addressing social capital challenges within the wave energy industry, it is unclear whether WES represents a significant paradigmatic shift. For example, there is a long history of collaborative research efforts in the wave energy sector: programmes like the EPSRC's SuperGen Marine, and the Carbon Trust's Marine Energy Challenge in the UK (Winskel, 2007, p. 478), as well as EU-level networks (Hannon, 2017, p. 28-32) aimed to stimulate inter-developer interactions, similar to WES.

Despite statements about the importance of supporting the social capital of the wave energy sector, the emphasis, or at least the outcomes, of the WES programme appears to be geared more towards addressing financial capital problems. Indeed, senior WES staff (Parker, 2019, p. 42) readily admit that the organisation was structured so that it could operate under the PCP framework, which allowed for both the initial purchase of Pelamis' IP, and for WES to move away from the 'match-fund' model, and give 100% funding support to developer projects. While this approach is consonant with the financial capital organisational goals described in WES literature regarding the safeguarding of already existing intellectual property and know-how, and ensuring "value for money from public sector investment," (WES, 2014, p. 1) it appears to have come at the expense of the more social capital objectives.

5.8 Future Prospects for Scotland's Wave Energy Sector

The future prospects for the wave energy sector are complicated by a number of factors well outside the purview of WES. While plans are currently being finalised to extend the programme beyond its initial 5-year term, unresolved political and financial forces at the national and international levels mean that there remains enormous uncertainty – for developers, and potential private investors – for the Scottish wave energy industry, regardless of the technological outcomes of the WES programme. Thus, it is imprudent to evaluate WES solely in terms of its progress towards producing a commercially viable device, or drawing private investment back into the sector.

However, there are some potential bright spots and reasons for optimism within the Scottish wave energy sector. For example, Mocean, a developer that has worked closely with WES throughout the programme's tenure, announced in April 2021 that a full-scale prototype of its wave energy converter device will begin sea trials at EMEC's Scapa Flow test site in the summer of 2021 (ReNews.Biz, 2021). Notably, the Mocean device was manufactured entirely in Scotland, using hardware components and technologies sourced from a number of domestic suppliers, including fellow WES participants Blackfish Engineering Design and Rosyth-based Supply Design.

Furthermore, Malin Group – another firm with links to the WES programme – has begun development work on the Scottish Marine Technology Park, a 50-acre industrial complex on the Clyde River outside of Glasgow, which looks "to boost the river's traditional strengths in shipping, shipbuilding and marine engineering, while fostering new sectors" (Malin Group, 2021). Malin Renewables, a subsidiary of Malin Group, was contracted by WES-participant AWS to manufacture their 'Archimedes Wavespring' device (The Scotsman, 2020).

The extent to which these developments represent substantive, systematic changes within the wave energy sector remain to be seen. Nevertheless, it appears that regardless of outcomes, WES has struggled to adhere to some of its own guiding principles, focusing too much attention on issues related to financial capital, at the expense of social capital. The WES programme illustrates the persistent issues with addressing social capital problems – particularly around the issue of IP management, which remains a largely unresolved issue – and how even programmes purportedly dedicated to addressing these issues may still fall short of these goals.

6 Discussion

While drawn from a range of sectors, time periods, and policy approaches, the case studies presented here are relevant to the current discussion around the expansion of Scotland's industrial capacity for low carbon technologies. For example, there are clear similarities between the Silicon Glen case study, and the contemporary heat pump sector. In both cases, these sectors are dominated by large, multinational technology firms with global, cost-sensitive supply chains. While by no means discounting the possibility for further technological advances and innovation, both cases deal with relatively 'mature' technologies, with well-established routes to market.

Multinational Firms and Manufacturing Clusters

Silicon Glen offers some insights into the likely risks – and potential benefits – of an industrial strategy centred around leveraging high levels of inward foreign investment as a means to accelerate, for example, the domestic heat pump sector in Scotland. While such a policy approach may offer an improvement in overall industrial and economic activity, steps must be taken to ensure that these gains are not limited to the relatively low-cost and low-skill 'screwdriver shop' work. As the Silicon Glen case illustrates, shifts in global economic or market trends can easily erode the competitive advantage – such as an inexpensive labour pool – that initially made a given locality an attractive option for multinational technology firms. Silicon Glen demonstrates how important it is for foreign firms – and indeed all industrial actors – to be well 'embedded' into the local economic and industrial landscape; these strong interfirm, and interpersonal, linkages are essential elements of a thriving, mutually beneficial industrial cluster. Furthermore, the Silicon Glen example also shows how an industrial sector lacking robust linkages to the local supply chain – either due to a paucity of indigenous actors, or low levels of embeddedness – can rapidly decline upon the departure of dominant foreign actors.

Innovation Clusters, Intellectual Property, and Collaboration

While the case of Silicon Glen dealt mainly with increasing industrial manufacturing activity in Scotland, the Intermediate Technology Initiative and Wave Energy Scotland programme focused more on accelerating relatively early-stage activity: innovation clusters rather than manufacturing clusters. In addition to the obvious bearing this has on the ongoing discourse around the promotion of new renewable energy sources, these two cases share commonalities with nascent low carbon heat technologies such as hydrogen (and related components such as electrolysers), where significant R&D activity continues, and fully market-ready solutions have yet to emerge.

The ITI and WES cases illustrate the challenges that can arise when attempting to foster innovation-centred industrial clustering. For example, one of the more notable, and persistent, issues that arose was that of intellectual property management. The wave energy sector in particular provides a vivid illustration of the tension between open collaboration and knowledge exchange, and preservation of the vital technical assets of a fledgling developer or research provider.

The ITI and WES programmes had markedly different approaches to both the ownership and management of IP: the former sought full control of any ITI-funded IP, believing that it would be more adept at finding suitable market opportunities by dint of the foresighting and business expertise of its internal analysts and staff. In contrast, the WES programme made it clear that it had no interest in owning any programme-funded IP, explicitly leaving the exploitation – and sharing – of scientific or technological advances as the responsibility of the developers and research providers themselves. It is clear from the case studies that both approaches had their shortcomings, with ITI being criticised for their over involvement in what amounted to a complicated and inflexible commercialisation process, and the WES programme's lack of progress towards intra-sectoral knowledge exchange or IP sharing, despite these activities being putative institutional goals. Indeed, while it could be argued that as far as IP management is concerned the more 'open' WES model represents an innovation beyond the ITI approach – at least in terms of design and intent – significant barriers to knowledge exchange and collaboration remain.

Embeddedness in the Private Sector

While the Silicon Glen case study illustrated the hazards of a lack of supply chain embeddedness – the absence of strong links between the various actors in an industrial cluster – the ITI and WES case studies indicate the risks of innovation and technology development policies that are similarly disconnected from their target sectors or industries. For example, the WES approach to IP sharing arguably reflects a lack of 'policy embeddedness' insofar as it fails to recognise that the wave energy sector, with persistent low levels of social trust between developers and a historic tendency towards secrecy and IP protectionism would struggle to adopt more collaborative attitude towards knowledge exchange. Similarly, one of the major criticisms of the ITI programme was its preoccupation with potential global market opportunities, and the subsequent failure to account for the actual technological, industrial, and economic strengths and weaknesses of the three Scottish sectors on which it was ostensibly focussed. The lacklustre performance of these initiatives towards fostering innovation-centred industrial clusters can be linked to, in part, a lack of understanding of the innovation needs of the relevant industrial sectors.

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