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Governing technological zones, making national renewable energy futures

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A R T I C L E   I N F O

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A B S T R A C T

This article examines linkages between strategies and imagined futures by focusing on one, often neglected facet of governance: science and innovation policy. Using the case of renewable energy imaginaries in Scotland, the article explores how strategies are used to create technological zones and knowledge infrastructures. In creating strategies for low-carbon futures, Scottish nationalists draw on imaginaries of an energy-independent nation in order to enable specific futures. By incorporating these imaginaries into strategic planning documents, nationalists exploit a powerful narrative from which to manifest energy futures. Further, through creating technological zones and knowledge infrastructures, the Scottish Government can work to actualize these futures even though its political power is limited. While it can be tempting to view strategies as a series of steps that implement policies in order to progress toward a desired future, this case demonstrates the nuanced ways in which energy futures and imaginaries of nationhood can be made tractable through science and innovation strategy, illustrating the dynamics through which these socio-technical strategies enable specific futures and communities. The speed and scale of Scotland's energy transition also raises questions about what might be possible in terms of transitioning other sectors or collectives that are constrained in their political power.

1. Introduction

In recognition of the need to address both environmental degradation and economic uncertainties resulting from reliance on carbon-based energy supplies, governments around the world are considering transitions to more sustainable means of energy production and consumption (IEA, 2011). Correspondingly, national strategies are used to advance these transitions through governance mechanisms including policymaking and economic investment. Yet these renewable energy transitions do not occur in a stepwise process from idea to policy to implementation. National-scale sustainability transitions are enmeshed in national (Anderson, 1983), sociotechnical (Jasanoff, 2015; Jasanoff & Kim, 2009), and environmental (Peet & Watts, 2002) imaginaries, and ongoing work is required in order to cultivate these imaginaries and translate them through strategies, white papers, and long-term visions into actual futures (Verschraegen & Vandermoere, 2017). Yet, how are long-term strategies linked with these imagined futures? And, how can imagined futures take hold through strategies when political power is out of reach? This article examines this linkage by focusing on one—often neglected—facet of governance: science, technology, and innovation policy. This article, therefore, examines the relationships between national sociotechnical imaginaries and the strategies used to translate them into futures. To do this, I focus on the case of Scottish national energy imaginaries.

The example of energy strategy in Scotland provides a valuable case because it demonstrates science and innovation policy's potential effectiveness in generating imaginaries, and the reciprocal, linked, nature of imaginaries in sustaining strategies. This case is so productive because it enables an exploration of the creative ways that these linkages between strategy and long-term futures, or

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imaginaries can be linked to create community and identity in productive ways. The UK government reserves control of the majority of energy policy, including the ability to regulate supply and transmission. Despite this, the Scottish Government holds some limited powers related to energy, which it creatively employs in order to pursue its own energy strategy (RSE Inquiry, 2019). This includes the promotion of renewable energy generation and energy efficiency, land-use planning, domestic household heat, and environmental regulation. The legislative constraints in Scotland have led the government to encourage local authorities to grant consent to renewable energy projects, as well as support the renewable energy sector through infrastructure development and market investment (Cowell, Ellis, Sherry-Brennan, Strachan, & Toke, 2016). The Scottish Government has also been able to block the UK government from constructing new nuclear power plants within Scottish territory (which are opposed by the Scottish National Party). Yet, one of the most creative and, and some may argue, effective ways that the Scottish Government has taken control of its energy future is through strategizing and implementing science and innovation policy for renewable energy. Through these creative, long-term strategies, the Scottish National Party (SNP)-led government has been able to gain political power through setting out alternative national energy strategies that draw on imaginaries of a renewable energy future. As the SNP campaigns for *Scottish* independence, they have also developed a particular, and adaptive, national sociotechnical imaginary that focuses on *energy* independence: the SNP envisions a low-carbon, environmentally progressive nation to replace the "old" Scottish nationalism based on a sovereign oil economy.

Through this exploration of long-term futures and strategy, I explain how strategies are made tractable through science and innovation policy, especially through the creation of *technological zones* and *knowledge infrastructures* that employ particular sociotechnical imaginaries. I begin with an overview of these key concepts, which are helpful in locating the specific linkages between strategy and long-term futures. Next, I describe the case of renewable energy innovation in Scotland. In creating strategies for low-carbon futures, Scottish nationalists draw on specific imaginaries of an energy independent and "green" nation in order to enable specific futures. By incorporating these imaginaries into strategic planning documents, nationalists exploit a powerful narrative from which to manifest energy futures. But, further, through creating technological zones and knowledge infrastructures, the Scottish Government is able to actualize these futures even though political power is limited. While it can be tempting to view strategies as a series of steps that implement policies and progress toward a desired future, this example demonstrates the nuanced ways in which both energy futures and imaginaries of nationhood can be made tractable through science and innovation policy, illustrating the dynamics through which these sociotechnical strategies enable specific futures and communities.

2. Technological Zones and Their Knowledge Infrastructures

In this article, I draw on two concepts to demonstrate how long-term strategies are linked to sociotechnical (and national) imaginaries through science and technology policy. The first concept is the *technological zone*, which originates from geography and international relations. The second concept, *knowledge infrastructures*, draws from infrastructure studies, a sub-field of science and technology studies (STS). Although hailing from diverse disciplines, both technological zones (Barry, 2006) and knowledge infrastructures (Edwards et al., 2013) are concepts that describe how science and technology become stabilized in specific ways, as knowledge infrastructures form the material and conceptual basis of a technological zone. Combining these two concepts will demonstrate the nuanced ways in which futures–be they imagined communities, nations, or energy transitions–are made manifest through science, technology, and innovation policy, at the same time extending political power that may otherwise seem constrained.

Geographer Andrew Barry describes a "technological zone," as a "space within which differences between technical practices, procedures or forms have been reduced, or common standards have been established" (Barry, 2006, p. 239). Barry goes on to break technological zones into three types: 1) metrological zones, which include regions that employ common measurements; 2) infrastructural zones, in which materials and connections are made analogous; and 3) zones of qualification, in which common standards are adopted. Integral to these technological zones, therefore, are what are known in the field of STS as "knowledge infrastructures," which, in different ways, enable all three kinds of technological zones.

Knowledge infrastructures, are, therefore, the "robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds" (Edwards, 2010). Although emerging from a different literature, knowledge infrastructures include the elements that make up Barry's technological zones, including conceptual and regulatory elements such as measurements, metrics, and standards, in addition to material infrastructures such as instruments, test facilities, and networks. These infrastructures support the work that scientists do and influence the way that science is applied (Bowker & Star, 1999); their materiality and rigidity have legacy effects, and as such, their design has consequences for the science that results (Edwards et al., 2013). Infrastructures are also "paradoxical" in the ways that they both support and stifle adaptation and change (Star & Ruhleder, 1994). According to Bowker and Star (1999), this is due to the way they must be able to extend work practices across organizations and users through standardization while at the same time remaining locally useful and possessing a flexible quality. This tension becomes especially clear in large-scale infrastructures where sociotechnical systems have a spatially and temporally broad reach (Star & Ruhleder, 1994). Infrastructures can also be difficult to reverse, as they institutionalize norms, values, and virtues that endure into the future (Star & Ruhleder, 1994).

Although scientific practices may seem local and situated, they must also be made comparable across broader spaces in order to function (Ribes & Bowker, 2009; Ribes & Finholt, 2009). This requires work in the form of developing metrics, calibrating instruments, and designing protocols (Latour, 1987). The practice of *infrastructuring* (Pipek & Wulf, 2009) can be observed at both individual and organizational levels (Karasti & Blomberg, 2017; Ribes, 2014). While much of the work of "infrastructuring" occurs at the scale of the individual, lab, or discipline, the promotion and support of these infrastructures is sustained through processes of embedding and extension through policy at the national or transnational scale. Therefore, in order to facilitate national energy transitions, existing infrastructures must be adapted to align with new research trajectories. Alternatively, new knowledge infrastructures can be created.

Innovation policy therefore shapes the direction of energy transitions through regulation, subsidy, and the creation of metrics and standards (Kohler, Geels, Kern, Onsongo, & Wieczorek, 2017). These infrastructures, in turn, shape future scientific capabilities and programs.

Although technological zones and their infrastructures can operate in more-or-less distinct spaces, their borders do not necessarily correspond to those of nation-states. This means that different technological zones and the infrastructures that support them can extend political and economic power through sociotechnical policies and practices that may not align with national governments. In this case, the relatively small and politically constrained, "devolved region" of Scotland is enlarged and extended by Scottish nationalists through the emerging marine energy sector and imaginaries of a "green," energy-independent country. This is accomplished through employing strategies that buttress knowledge infrastructures and extend technological zones. Science and technology policy—and the long-term strategies that support these policies, are therefore powerful means to manifesting sociotechnical and national energy strategies. This can be observed in the way that metrics and standards for marine renewables testing have global reach beyond Scotland's seas. Further, technological zones and their infrastructures also highlight the role that long-term strategies in science and technology play in materializing and extending futures. Instituting strategies involves not only policymakers, but a complex and multi-sited network of actors that includes researchers, engineers, companies, and individuals. In this case, these individuals are all involved in renewable energy innovation. This case therefore demonstrates how technological zones are not only established through "strategic imperative" itself, but also through complex governance processes (Barry, 2006, p. 244), some of which play out through implementing—and making tractable—science and technology strategies.

3. The Case of Marine Renewable Energy Innovation in Scotland

This article draws on in-depth interviews, document analysis, and participatory research at conferences and workshops on

Fig. 1. Two images from political campaigns by the Scottish National Party (SNP). The image on the left, from 1980, features a caricature of (the then Prime Minister) Margaret Thatcher as an oil-sucking vampire. The image on the right was created for the "Yes" campaign (for Scottish independence from the UK) by Stewart Bremner in 2015 (Bremner, 2015). This poster was featured during the most recent independence referendum and features a marine energy device near the site of the European Marine Energy Center (EMEC) in Orkney. Taken together, these images illustrate how the SNP has employed shifting energy futures and their imaginaries in its campaign for nationalism.

renewable energy in Scotland, which took place through the course of over two years. Throughout the project, I conducted twenty-seven semi-structured in-depth 60-90-minute interviews with policymakers, researchers, engineers, and developers of marine renewable energy. I also carried out participatory observation at seven conferences on marine renewable energy, two in the United States and five in Scotland. In addition, I attended fifteen in-person and online webinars and workshops aimed at marine energy researchers and developers, including a week-long workshop on standards in marine energy testing at the University of Edinburgh. I accessed both analyzed both online and physical archives, including meeting minutes, historical political files, and policy documents from the Scottish Government, Scottish Parliament, and the Scottish National Party, among others. These materials were coded and analyzed using a modified grounded-theoretical approach, drawing from situational analysis (Clarke, 2005). The following case relies on these materials and methods.

3.1. Scottish Energy Strategies

The example of Scotland's effort to transition to renewable energy is interesting partly because it stands out as being uncommonly successful and bold. It is remarkable not only in terms of its energy transition, but also its technology innovation strategy and the unique way that it is implementing that strategy. But, first, I will give some background on the Scottish political scene. The ambition of Scottish nationalists is an independent Scotland. Yet, while Scotland is often referred to as a nation in the sense of constituting a distinct identity or community, it is not (according to the UN) a nation-state, but rather a devolved part of the United Kingdom. The devolution process granted some decision-making powers to Scotland upon the re-establishment of a Scottish Parliament in 1999, but power to govern and regulate energy was not devolved and remains mostly reserved with the UK government. This dynamic has forced the Scottish Government to look for creative ways to promote its stated goal of a transition to renewable energy supply and production, including 100% of electricity from renewable sources by 2020, a goal which it is on track to meet (Scottish Government, 2017, 2020). Strategies have thus been developed to enable this future, including promoting innovation in the renewables sector, especially in marine renewables—tidal and wave energy. The government has also worked to implement policy that will expedite spatial planning and permitting of renewable energy development on both land and sea. Additionally, the Scottish Government has heavily supported small-scale community-owned and off-grid energy systems: another way to skirt lack of control over the national grid. Due to its uniquely constrained governance situation and the speed and success of transformation in term of energy sources, the Scottish transition is, therefore, interesting in terms of the relationship between imaginaries and strategies and how they are linked.

The rise of nationalism in Scotland and its coinciding shift to a "green state" is an example of a rapid, concerted, and unusually successful sustainable transition. The social-democratic SNP was founded in 1934, but came to power during the leadership of Alex Salmond, an oil economist who argued that Scotland could be a wealthy, independent nation because of its rich natural resources, specifically North Sea oil reserves. Since the creation of the devolved Scottish Parliament in 1997, the SNP has worked to form a majority government, which has been in power since 2011. Based on this electoral support, the SNP held a referendum for independence in 2014, but was unsuccessful. Despite this, a focus on gaining more legislative powers from the UK and shifting them to Scotland is ongoing. In terms of energy, this continues to be backed by the imaginary of building a national economy and infrastructure based on energy independence (see Fig. 1). This independence is sought partly through a continued effort to transition to renewable energy production, consumption, and innovation, with the vision of eventually transforming the entire supply chain (Scottish National Party (SNP) Manifesto, 2017).

In 2008, less than 10 years after the Scottish Parliament was re-established, a strategy for a renewable energy future was put into play. Upon opening a public consultation period in September 2008, the Scottish Government set out an overview of their energy policy. In it, they state that "it is clear that there is an opportunity to exploit Scotland's comparative advantage in energy resources while meeting the carbon challenge" (Scottish Government (Scot Gov), 2008, p. 1). The document makes it clear that, although Scotland's power generation was, at that time, reliant on coal, gas, and nuclear power generation, "the main objective" was to "progressively increase the generation of renewable and clean energy" with a secondary goal to "maximise the retention of wealth… from the development of skills, intellectual property rights, and manufactured products." In this strategy document, a future is laid out, but it is *how* it is practically realized that is of interest here. Even though the Scottish Government's regulatory control of energy is highly constrained, long-term strategies and practical actions to implement them are still possible through creative governance, including creating technological zones and building knowledge infrastructures through science and technology policy.

For example, in 2008, basic knowledge about the current status of carbon emissions from Scotland as a whole was lacking. Therefore, the first step was to calculate and model current and planned emissions. Only then could policy options be identified. The expectations set out in this document therefore encompass a rich set of imaginaries and potential strategies, without yet having a clear roadmap or link to policy prescriptions. After this initial report, the Scottish Renewables Action Plan (2009) (Scottish Government, 2009) set out steps to work toward realizing this vision. The Action Plan was followed by The 2020 Routemap for Renewable Energy in Scotland in 2011 (Scottish Government, 2011). Both of these plans set out short-term policy actions that would need to be taken in order to meet 2020 targets for renewable energy. The 2020 Routemap also increased the Scottish energy target to 100% of electricity from renewable energy by 2020. In this way, strategy became, partly, a "promise of numbers" through baselines and benchmarks (see introductory essay to this special issue). As of mid-2019 (the latest figures available), this target was close to being met, and on some days, surpassed, with increases in renewable energy generation mostly driven by onshore wind power generation (Scottish Government, 2020). Because 100% of electric energy needs can now be met (on many days of the year) through renewable means, the focus has since shifted in the latest strategy, released in 2017. Now, the strategy is aimed at addressing other energy needs such as domestic heat and transport, which together encompass over half of the energy use in Scotland (Scottish Government, 2017), in addition to developing ways to convert and store excess electricity.

One discreet example of just how dynamic the transition to renewable energy in Scotland has been can be seen in the Scottish Government's shift in strategy on coal-fired power plants. In the 2009 Action Plan, the last remaining coal power station in Scotland was set to be retrofitted with state-of-the-art carbon capture and storage (CCS) technology. Instead, the Scottish Government surpassed their own expectations of renewable energy generation, and within a matter of years, coal power was deemed unnecessary. In 2016 the Scottish Government decommissioned the Longannet Coal Power Plant, and in 2019 the plant was demolished, ending the need for a natural resource that at one time had defined the industrial era in Scotland.

3.2. Renewable Energy Innovation and the National Imaginary in Scotland

The energy technology innovation system within the UK as a whole has undergone a unique and rapid shift since 2000 (Winskel, Radcliffe, Skea, & Wang, 2014; Cowell et al., 2016), but devolution of some spending and planning powers to the Scottish Parliament since that time has set off another round of national energy and climate change strategies, which, in turn initiated a wave of investment in renewable energy innovation (Winskel et al., 2014). Following the International Energy Agency (IEA), the Scottish Government emphasizes "accelerated" technological development as the key to facilitating a rapid energy transition (Winskel et al., 2014). The Scottish Government's 2017 Energy Strategy now sets out a plan for a full transition to a low-carbon economy by 2050. The strategy states that half of all energy (including heat and transport, in addition to electricity) will be generated by renewable sources by 2030. Although lacking power to regulate energy production and supply, the Scottish Government has still managed to demonstrate global leadership in the field of low-carbon energy, especially marine energy research and development: in order to meet its own targets, its strategies have necessarily been creative.

Most of the increased generation capacity necessary for the renewable energy transition in Scotland is being met by new onshore—and most recently, large-scale offshore—wind energy. Yet the strategies and imaginaries for an energy-independent nation are also cultivated through policies aimed at enabling innovation in the marine energy sector. These alternative strategies are partly due to the constraints in policy outlined above, but they are also borne out of a desire to set Scotland apart from the rest of the UK, as *the* place for innovation and development in marine renewable energy (Watts, 2018). Although not all initiatives aimed at marine energy have been successful, and utility-scale developments have seen both progress and setbacks over the last two decades, Scotland has nevertheless become a world leader in marine energy technology testing and innovation, due in part to the support of the Scottish Government (Hannon, van Diemen, & Skea, 2017).

This effort to establish an alternative national identity through creative renewable energy governance can also be identified in the Scottish Government's energy roadmaps and strategies discussed above. For example, the 2008 policy overview stated, "Scotland is rich in energy resources and we must be ambitious in their exploitation. We are planning now for the huge export potential of renewable energy and clean energy technology" (2008, p. 4). In order to realize this ambition, the Scottish Government invested heavily in the Saltire Prize for marine renewable energy, The Forum for Renewable Energy Development in Scotland (FREDS), as well as the Energy Technology Partnership (ETP). The government has also created a government body, Wave Energy Scotland, and they have established globally important marine energy test centers such as the European Marine Energy Centre (EMEC) for tidal and wave testing in Orkney, and the FloWave test tank at the University of Edinburgh. In addition to investing in marine energy innovation, the Scottish Government also promotes "decentralized energy networks," and has tripled funding for "community and micro generation." (2008, p. 5). While there are clearly many and diverse strategic efforts at play in facilitating the energy transition, the following section will focus on the ways that imaginaries of nation and energy are being strengthened and extended through the creation of technological zones and knowledge infrastructures to support marine renewable energy innovation.

4. Technological Zones and Knowledge Infrastructures: National Energy Strategy Through Creative Means

The goal of Scottish energy independence and control of resources is not new. A 1977 press statement from the SNP begins: "for generations the Scots have been conned by successive London governments into thinking they were beggars of Britain." (Scottish National Party (SNP), 1977) It goes on to discuss the oil revenues being "denied" by London, and the wealth of the country in terms of natural resources, including "hydro-electric, solar and wind power to heat our homes and supply our industries with reliable sources of non-pollutant electricity" (Scottish National Party (SNP), 1977). Even in 1977, the SNP stated hopefully, "we are also in the vanguard of developing wave power, one of the most exciting energy-producing options now open to the world" (Scottish National Party (SNP), 1977). Scotland is still considered a global pioneer in the ocean energy sector, with some of the first grid-tied generation taking place in Scotland's seas.

To facilitate its bold energy transition, while at the same time being constrained by the inability to regulate energy within Scotland, the Scottish Government has focused its support on innovation in the renewables sector in order to shape its energy future in creative ways. As such, over the past two decades, the government has launched several high-profile research enterprises and initiatives to support marine renewables (Graziano, Billing, Kenter, & Greenhill, 2017) and onshore wind projects (Cowell et al., 2016). For example, in 2003, the European Marine Energy Centre (EMEC) in Orkney was established, which remains the largest grid-connected tidal and wave energy test site in the world. Although some investment has come from the UK, other devolved governments, and the EU, the Scottish Government has used marine energy infrastructures such as this to successfully frame Scotland as a globally important location for renewable energy development (Hamilton, 2002). The speed and scale of this success raises important questions about what it might take to mobilize and transition knowledge infrastructures in societies globally, especially given the policy constraints that Scottish lawmakers have. Yet it also points to the nuanced ways that renewable energy futures and long-term strategies are linked and made tractable through science and technology. For example, in order to facilitate innovation, increase investment, and manage safety concerns, metrics and standards for engineering must be developed. This occurs through the creation, calibration, and standardization of marine energy test and lab facilities. Yet engineering standards do more than facilitate innovation, they also manifest futures—of both energies and nations. This is an example whereby strategy can be used to strengthen national identity and create imagined communities. By using innovation strategies, Scotland is able to forge new technological zones and extend imaginaries, thus creating its own energy future even though its political power remains more limited.

4.1. Creating Engineering Standards, Extending Technological Zones

It is critical to establish engineering standards in an emerging sector like marine energy. Interoperable and measurable standards are necessary because they enable both the physical energy infrastructure of cables and connectors to interoperate, but standards also facilitate testing, instrumentation, and environmental permitting for marine energy devices. These knowledge infrastructures include recommendations that help researchers determine what kind of instruments to use, how to test, measure, and model devices in tanks, and how to scale up device prototypes through well-defined stages from tank to ocean. Standards are important to the industry because they not only facilitate innovation and reduce uncertainty, but they also build confidence in the industry itself. This prevents what some people refer to as "cowboys," or individual developers, who are often deemed outsiders, from forging into the field without slowly "scaling up" a device first. A concerted effort led by both industry and government has tried to prevent the "cowboys" from going to the ocean with large-scale devices that are unproven in a test tank, because this can lead to public failure—and has in some cases—thereby making the industry "look bad" when a device sinks or washes up on a beach. To prevent this, international standards are being developed.

The International Electrotechnical Commission (IEC), established in 1906, is the global body that develops and manages conformity assessment for all electric technology. Through the IEC, a mix of industry, academia, and research laboratories form technical committees that create standards and certification schemes. For example, a standards assessment scheme was created for wind energy in 2010, and a marine energy standardization scheme is now being developed. Section 62600-103 of the IEC regulations is specifically aimed at creating "guidelines for the early stage development of wave energy converters" and "best practices and recommended procedures for the testing of pre-prototype devices." The standards committee has relied on international, and especially EU cooperation in designing them, mainly through the Equimar and Marinet projects which facilitate device testing and knowledge exchange. But many of the people involved in this committee work in Scotland, at marine energy test centers like EMEC and FloWave; two examples of knowledge infrastructures that facilitate the technological zone of Scottish marine energy.

IEC standards include tank testing standards and guidance on instrumentation for testing in wave tanks. FloWave, is a unique and state-of-the-art wave test tank at the University of Edinburgh, an institution with a long history of testing wave energy devices. The facility opened in 2014, but throughout its construction, engineers and researchers iteratively worked with the standards committees to make sure that the tank would conform with, as well as serve as an example of an IEC standardized test tank. The tank is the only circular, multi-directional tank in the world that can test both wave and tidal current simultaneously, and its location in Scotland contributes to building a knowledge infrastructure that is setting Scotland ahead of any other nation in terms of resources for marine energy research. Yet, in order for the tank to be useful, according to one researcher, it needs to be "informed by real-world conditions and site data." The goal, therefore, another researcher stated, is to "bring real-world ocean conditions into the lab."

In order to do this, the researchers turned to EMEC, in the Orkney Islands of Scotland. EMEC has garnered 36 million pounds in public funding, and it has both a nursery and full-scale, grid-connected test site for wave and tidal devices located in ocean waters. Orkney has big waves and strong tides, as well as an industrial infrastructure from oil and gas, as well as fisheries, making it probably the most well-equipped location in the world to test a marine energy device. EMEC has already gone through the regulatory process for their sites, enabling them to facilitate more rapid device testing by shrinking permitting time from two years to three months. The test center also provides networking and cyberinfrastructure, in addition to assistance with the creation of testing protocols.

Yet, in an example of the power of knowledge infrastructures to extend technological zones, EMEC also have their sea states replicated in the FloWave test tank in Edinburgh, enabling developers to "test out" the specific ocean conditions of the Orkney sites before getting their scaled-up devices wet in saltwater. In order to replicate the ocean in a tank, FloWave began with standardized sensors and instruments such a velocimeters and Waverider buoys that measure sea states, and whose data can be "fed into" models to create numerical and physical simulation of Orkney sea states in the tanks. In order to do this, Sam Draycott, an engineer with FloWave, along with a team of researchers, used directional spectra, data reduction, then validation to measure this "piece of the sea," in Orkney (Billa Croo) and replicate it in the tank (Draycott et al., 2019). It is a "stated ambition of the board of FloWave to become the accredited and validated gateway and enabling test centre for both UK and international device and project developers." (FloWave, 2019). In this way, they are not only developing standards that will be adopted globally through the IEC, but they are also establishing themselves as *the* place to test a device that will eventually be scaled up to Orkney's seas.

Engineers from EMEC are also shifting the culture of marine energy development from testing large scale devices to failure in survival sea-states, to a regulated, standardized, and careful testing program that slowly scales up a device from tank to sea to commercial use. As one researcher said: "don't go to sea until you think you have nothing to learn by doing so." While these seas may seem local in nature, the IEC standards extend beyond these local, (sub)national sites: not only do developers come from around the world to test their devices in "EMEC's seas," but EMEC also plays a role in setting standards for the industry. EMEC's engineers, along with others, have helped to establish standards for how to calculate an area of sea in terms of wave energy levels, measure electrical power, and assess the performance of devices. Some of these standards have been directly adopted by the IEC to become global standards. Yet, these standards and the marine energy testing infrastructures in Scotland are doing more than assisting innovation in marine energy in Scotland: by playing a large role in setting the standards and replicating their own sea states in the tanks, they are establishing Scotland as *the* place to test marine energy devices, and creating a baseline from which success and failure of marine energy devices will be measured globally.

5. The Power of Strategy and Imaginary

How, then, do imagined futures of energy and nation take hold through strategies? The example above demonstrates the importance of sociotechnical strategies—in this case, science and innovation policy—in enabling specific futures. Imaginaries are the "collectively held, institutionally stabilized, and publicly performed visions of desirable futures," and sociotechnical imaginaries are social formations enabled through science and technology (Jasanoff, 2015). While sociotechnical imaginaries are often viewed as ephemeral in nature, they can be performed in particular ways that make them material (Konrad & Böhle, 2019). These imaginaries can also become enrolled in governance tools and arrangements through anticipatory practices and policy instruments such as roadmaps, strategies, and targeted support for particular kinds of innovation (Konrad & Böhle, 2019). Through strategies and policy white papers, sociotechnical imaginaries can thus be used to address future challenges and can be taken up by policy-makers and made material (Verschraegen & Vandermoere, 2017). In other words, strategies can be viewed as sociotechnical imaginaries made visible *to* and implementable *by* policy makers. It is important to note that conceptually and materially, this future-making power travels in both directions, as strategies themselves also serve to create and bolster community identities. National strategies and roadmaps articulate the collective goals of imagined communities, whether they are nations, regions, or other collectivities. The national sociotechnical imaginary of an independent Scotland, as an energy independent "home for renewable energy" is thus both the aim of Scotland's energy innovation strategy and the catalyst for it.

The development of Scotland's renewable energy resources and the concerted promotion of innovation in low-carbon science and technology provide an example of a sociotechnical imaginary in-the-making. The "promissory" image (Borup, Brown, Konrad, & Van Lente, 2006) of Scotland as a place for renewable energy has been used to bolster the agenda of the movement for Scottish nationalism. Indeed, Scotland's scientific infrastructure has not emerged in isolation from the current politics of nationalism and its place within the European Union and the world, as Scottish nationalism has gained power over the past forty years. As the SNP campaigns for *Scottish* independence, but they have also developed a particular national sociotechnical imaginary that focuses on *energy* independence. This energy imaginary has adapted over time: the SNP envisions a low-carbon, environmentally progressive nation to replace the "old" Scottish nationalism based on a sovereign oil economy. Indeed, the SNP's 2017 Manifesto (Scottish National Party (SNP) Manifesto, 2017) cites a transition to renewable energy as a "Scottish success story" in which it will continue to heavily invest (p. 44). This is an example of what Levenda, Richter, Miller, and Fisher (2019) identify as an alternative kind of energy that is based on different "energy values" or "heterogeneous, historically specific, socially rooted, culturally shared ideals regarding the role of energy technology in (re) creating public good" (p. 2). These competing regional—or in this case aspiring national—imaginaries not only provide alternatives, but also serve to differentiate (Levenda et al., 2019). Scotland from the rest of the United Kingdom. In this way, strategies are "productive fictions" that link to imaginaries in persuasive ways that create a collective vision (see introduction to this special issue).

The aim of the Scottish Government's energy strategy, in other words, is not only about energy transition, but it is also about nation-building. One way to build a nation is through imaginaries (Anderson, 1983). Despite globalization, the national scale remains an important site for the advancement of imaginaries. One of the foundational studies in the "imaginaries" literature can, indeed, be traced to the field of nationalism studies, where Benedict Anderson (1983) first described nations as "imagined communities." Nationalism is not only imposed "from above," but is remade through the everyday (Billig, 1995), and energy and natural resource policy is one of these everyday sites where communities can be differentiated and made. According to Eckersley (2004), in some instances, the purpose of the nation-state is shifting "from environmental exploiter and territorial defender to that of environmental protector, trustee, or public custodian of the planetary commons" (p. 209). Some nations are even taking on the role of "norm entrepreneurs," working to strengthen new environmental norms through international environmental agreements (Slaughter, 2004). One example includes Scandinavian nations, which are relatively small on the international scale, and so less politically powerful in many ways, yet still find ways to challenge the status quo by becoming exemplars of environmental values (Ingebritsen, 2006). The Scottish Government has similarly envisioned itself as a "climate pioneer," positioning itself as different from the rest of the UK by drawing on the politics of territorial identity (McEwen & Bomberg, 2014). This demonstrates the powerful ways in which environmental imaginaries can become embedded in national discourse and backed by state power, strategies, and their creative implantation link these futures and imaginaries in productive ways.

Barry argues that technological zones do not necessarily have clear borders, and "increasingly do not correspond to the borders of nation-states" (2006, p. 239). This concept is useful for understanding the processes that are occurring in the renewable energy domain in Scotland. The case of renewable energy in Scotland demonstrates how actors can use technological zones to extend their political power and spatial reach, as well as their sociotechnical and national imaginaries. And, as this case highlights, this may occur in unexpected ways, such as through the work of calibration and standardization of instruments and test sites, and through the creation of knowledge infrastructures.

6. Conclusion

Political work is often carried out through the development of national scientific infrastructures—through classification and knowledge production that renders legible and governable subjects (Foucault, 1998; Scott, 1998), providing ideological frameworks that support nationalism (Zeller, 2009), or building a modern national identity (Harrison & Johnson, 2009; Hecht, 1998). Yet nationalism and science are not pre-existing. They are acted out and remade in the "reciprocal mobilization of each other" (Mizuno, 2011). This is especially true in times of rapid growth and investment in sociotechnical projects, which can help reinforce national identities (Hecht, 1998; Jasanoff, 2004; Ezrahi, 1990). It is important to recognize that these national sociotechnical projects are manifested through governance in particular ways that relate to both future imaginaries and national strategies. Yet, the speed and scale of Scotland's energy transition also raises questions about what might be possible in terms of transitioning other sectors or collectives that are constrained in their political power. What other ways might there be to mobilize and transition knowledge infrastructures and societies globally, when collective action on the global scale is constrained not in unsimilar ways?

While these questions are beyond the scope of this paper, I hope that the example of Scotland still demonstrates the potential to transform energy futures, even with limited power, using creative means. Through the use of creative science and innovation policy, the sociotechnical imaginary of Scotland as a future nation powered by renewable energy, has been amplified around the world, as the instruments, testing standards, and even the seas of Orkney become part of the global engineering standards of the IEC. These standards aren't "built on a blank slate," as one researcher noted. They have been developed from other standards, both from the oil and gas industry, and from wind energy. They have also been developed with input and collaboration from around the world. Regardless, Scotland is putting a firm mark on the standards for marine energy, as test tanks and laboratories across the world are measured, instrumented, calibrated and modeled in reference to EMEC's seas in Orkney, the FloWave test tank in Edinburgh, and the international standards that the IEC has adopted from them. Crucially, once these standards are created, they can become embedded difficult to change (Star & Ruhleder, 1994), meaning that the future imaginary of a small nation with constrained political power, is extended to the global sphere, amplified through technological zones and their knowledge infrastructures.

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