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The development of seaweed-derived fuels in the UK: An analysis of stakeholder issues and public perceptions

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ABSTRACT

Macroalgae (seaweed)-derived fuels are gaining increasing attention due to the high rate of seaweed growth, its lack of lignocellulose (which makes for energy-efficient processing), its lack of need for land or freshwater, and its potential suitability for commercial applications in the UK. However, while technological issues are progressively being solved, wider issues of stakeholder and public perception have largely been ignored, potentially hindering the development of this technology. This research fills this gap by conducting 19 interviews with stakeholders and 7 focus groups with members of the public to gain a deeper and broader understanding of perceptions of macroalgae-derived fuels. The results highlight the technological promise and confidence in the potential of macroalgae-derived fuels. However, they also emphasise conflicts and uncertainties among stakeholders (e.g. competition with other high-value products derived from macroalgae) and the general public (e.g. conflict with marine users). This paper provides insight into potential social resistance and key issues in the macroalgae-to-fuels supply chain. This information will enable two-way communication between everyone involved and increase the likelihood of successfully developing this supply chain. Key policy issues are discussed to facilitate this communication and encourage investment in the process.

1. Introduction

Significant academic attention has been paid to the development and acceptance of sustainable, economically viable alternatives to hydrocarbon fuels and their infrastructures in response to concerns about climate change (Diaz-Chavez, 2011; Batel et al., 2013) and government policy on the reduction of non-renewable sources. For example, the UK government committed to deliver 15% of the UK's energy consumption from renewable sources by 2020 (Department of Energy and Climate Change, 2011). Advances have been made in renewable and sustainable methods of generating heat and power, and use of electric vehicles for non-commercial transport has increased (Dijk et al., 2013). However, large-scale road and air transport, with its high energy demands, still relies on high-value, high-energy-density liquid hydrocarbon fuels that are favoured by the existing transport infrastructure (Zhao, 2017). Addressing transport issues is key to meeting climate-change targets (Lah, 2017). Hence, transport sectors have shown increasing interest in bio-derived fuels (Gegg et al., 2014) while acknowledging the need for government support to meet climate goals (www.iata.org). In 2018 the UK government published a bioeconomy strategy to 2030 (HM Government, 2018) and a response to a bioeconomy call for evidence (Department for Business, Energy & Industrial Strategy, 2018). Both documents note the importance of the bioeconomy in meeting long-term carbon-reduction targets and aim to create a supportive environment where all stakeholders can realise the full potential of the bioeconomy to meet day-to-day challenges. Government policy is also focused on the Renewable Transport Fuel Obligations Order, which requires fuel suppliers to ensure that a proportion of the fuel they supply comes from sustainable bio-derived sources (www.gov.uk/guidance/renewable-transport-fuels-obligation). However, the percentage of renewable sources in fuels has remained stubbornly low; only 4% of fuel supplies came from renewable sources in 2018 (https://www.gov.uk/government/organisations/department-for-transport/series/biofuels-statistics) and it is not clear whether they were used by commercial or non-commercial vehicles. In addition, while the number of commercial flights using sustainable aviation fuels is increasing (from 1 in 2008 to 100,000 in 2018) (IATA, 2019), there are no significant supplies of this fuel and establishing a supply chain is a major challenge (McGrath et al., 2016; de Jong et al., 2017). The UK bioeconomy strategy (2018) suggests that producing sustainable aviation fuels in the UK could be worth £265m GVA and create 4,400 jobs.

First-generation bio-derived fuels are controversial due to their

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impact on the supply of food (Gallagher, 2008). Meanwhile, second-generation bio-derived fuels – from feedstocks such as woody biomass and solid waste – have been attracting attention (Naik et al., 2010). Macroalgae (seaweed), mentioned in the UK bioenergy strategy (Department for Transport et al., 2012) as "an important source … of liquid biofuels" is garnering particular attention because it has a high growth rate (i.e. high photosynthetic efficiency), does not contain lignocellulose (which makes processing more energy efficient), does not require land or freshwater, and is expected to thrive in increasingly acidic oceans (Brennan et al., 2018). However, despite early optimism, full commercial development is yet to be secured (Kraan, 2013; Fernand et al., 2017) and UK liquid sourced biofuel feedstocks in 2017/18 were dominated by waste oil (providing ~ 78%) and food waste (providing ~ 12%) (Royal Academy of Engineering, 2017; Defra, 2019). The UK has a high density of seaweed thanks to its extensive coastlines, which have been proposed as appropriate for commercial seaweed farming and harvesting (Hermannsson and Swales, 2015) and may be capable of supporting a macroalgae biofuel market. However, uncertainties exist about the optimal methods of producing fuels from this feedstock (Watson and Dring, 2011; Steiner et al., 2012; Hughes et al., 2013; Fernand et al., 2017). In addition, compared with microalgae, for which a range of commercial organisations are exploring its use, only limited commercially operating projects are generating fuels from seaweed. One company is using macroalgae to produce fuels, food additives, animal feed and renewable plastics, but the scale of its biofuel production is unclear and its focus seems to be on agri-inputs (www.sea6energy.com). Current pilot projects that will provide technical detail on the potential for macroalgae-derived fuels include the MacroBioCrude Consortium (community.dur.ac.uk/p.w.dyer/page2/styled-2/index.html) and the BioMara project (www.biomara.org).

Using the Feedstock Readiness Level (FSRL) tool for aviation, it is possible to assess the further stages of development that are needed to bring macroalgae-derived fuels to maturity and commercialise their production (Verbong et al., 2008; Adenle et al., 2013). Current technological projects have demonstrated the basic principles, concept formulation and proof of concept (levels 1–3). Primary technical evaluation and process validation (levels 4 and 5) are taking place in the pilot projects. Current research needs to take macroalgae biofuel production to full-scale technical evaluation and certification (fuel approval) to pave the way to commercialisation and established production capacity (levels 6–9). While the FSRL tool suggests that macroalgae-derived fuels have achieved levels 3–5 from the technological perspective, work on policy lags behind. Few of the policy components in levels 1–3 are complete which includes formulating plans to address regulatory requirements and plans to address societal resistance and concerns (Moula et al., 2013; Gegg and Wells, 2017).

Niche technologies are traditionally characterised by a "technology push" approach, focusing on research and development (R&D) without considering the commercial prospects, societal embedding and legal procedures. This results in implementation problems from public perceptions (Burton et al., 2009). Gegg and Wells (2017) highlight that apart from limited research on the implications for marine policy (Hughes et al., 2013), there are no investigations into the potential socio-economic, environmental or political issues associated with macroalgae-derived fuels (Werner et al., 2004) for the supply chain or the general public. Indeed, a specific UK bioeconomy strategy (HM Government, 2018) has only just been developed. , a recent response to the bioeconomy call for evidence (Department for Business, Energy & Industrial Strategy, 2018) highlights that to support development in this area a joined-up review of the complex and diverse regulatory environment is needed. It is also not clear how the regulatory environment relates to seaweed-derived fuels.

In summary, seaweed is a potential source of fuel in the transport industry and interest is growing in the technological aspects of this use. This paper seeks to understand the social, political and economic implications of this technology for supply-chain stakeholders and the general public. These issues have been thoroughly investigated in the context of conventional biofuels (Gegg et al., 2014) and wind – both onshore (Wilson and Dyke, 2016) and offshore (Wever et al., 2015). Work has also been done on tidal (Devine-Wright, 2011a) and hydrogen (Sherry-Brennan et al., 2010) energy. Therefore, it is sensible to examine these aspects in the context of seaweed-derived fuels so that evidence-based policy and commercial decisions can be made (Goetz et al., 2017). Levels of public acceptance and commercial development differ across technologies, contexts and scales, so we cannot assume that reactions to seaweed-derived fuels will be the same as for other renewables (Wiersma and Devine-Wright, 2014). Public opinions could form barriers to growth; therefore:

> "building trust in new products and services needs a conversation with the very broadest range of stakeholders involved at all stages of a supply chain. It is therefore important that this task involves government, industry and the research community as well as NGOs [non-governmental organisations] and consumer bodies" (Department for Business, Energy & Industrial Strategy, 2018, p. 47).

This project focuses on ensiled seaweed, gasification and drop-in diesel because this process is expected to be environmentally and economically sustainable and produce fuel of a high enough quality for aviation and other transport (Milledge et al., 2014; Redden et al., 2016). In response to previous research on seaweed-derived fuels, this paper seeks to provide the perceptions of a wide range of stakeholders. Thus, it is structured as follows. In the next section we detail relevant studies on macroalgae-derived fuels and highlights the social, political and economic issues that were important in the development of other renewable technologies. We then present the research methodology, before discussing the results of our investigations and their policy implications.

2. Background and literature review

In this section we highlight research that has examined relevant macroalgae processes (such as cultivation, harvesting) and their impact. Much of this work has been done outside the UK context, particularly in Asia; therefore, it may not reflect the social, cultural and economic contexts in the UK. We also reflect on work on other renewable technologies and their infrastructures. However, perceptions of different renewable technologies vary considerably by context, technology and scale, so the variables that may be important for wind, for example, may not apply to macroalgae in the same way.

As noted, much attention has already been paid to the technological issues that apply to using seaweed as a source of liquid fuels for transport.[1] Although beach (naturally occurring) and cultivated (farmed) seaweed can both be used, we focus on farmed seaweed, which is expected to provide a more sustainable source. Removing large volumes of beach seaweed is problematic because it provides an important habitat for invertebrates (Wood et al., 2017). From a technological perspective, seaweed production and harvesting processes are still in the early stages of development (Fernand et al., 2017) and designs for seaweed hatcheries, storage and processing have not been tested on a large scale (Kraan, 2013 Dave et al., 2013; Msuya, 2013). Mechanical harvesting is currently banned in the UK. Roberts and Upham (2012) note that this could be done sustainably and would not

[1] Readers who are interested in the technological processes of developing fuels from macroalgae should consult the overview by Milledge et al. (2014) and specific papers on energy extraction (HM Government, 2010; Milledge et al., 2015), ensilage, anaerobic digestion and pyrolysis (Milledge and Harvey, 2016a, 2016b; Redden et al., 2016), beach seaweed (Gallagher et al., 2017), dewatering (Milledge et al., 2016a), products from seaweed (Milledge and Harvey, 2016c), and process hurdles (Stévant et al., 2017).

be as damaging as other aquaculture industries, but it would require local trials and a sustainable harvesting policy. A number of Life Cycle Assessments (LCAs) have been completed and although these have focused largely on biomethane/biogas production (with only Brentner et al., 2011 focusing on biodiesel production via transesterification) they note that seaweed production is relatively resource efficient and provides environmental benefits compared to microalgae and terrestrial plants such as maize developing on the exact cultivation methods, type of seaweed utilised (Aitken et al., 2014; Taelman et al., 2015; Seghetta et al., 2017).

The potential environmental impacts, such as the effect of seaweed farming on the physical and marine environment, have also been highlighted (Wood et al., 2017). Positive impacts discussed by stakeholders include improving the benthic ecosystem, increasing carbon sequestration, conserving local marine habitats and improving fish stocks (Hurtado, 2013; Kronen, 2013; Krishnan and Narayanakumar, 2013). Furthermore, seaweed farming does not use fertilisers and research suggests that macroalgae can purify polluted water by removing nutrients mitigating marine eutrophication (Haglund and Lingström, 1995; Tsagkamilis et al., 2010; Langlois et al., 2012). Potential negative impacts include seasonal availability (Gold, 2011), the potential for invasive species (Ramachandran, 2012) and transport between cultivation and processing sites (Roberts and Upham, 2012), which may also be a public concern. Furthermore, Marine Special Areas of Conservation (MSACs) may be important in determining support for the inshore cultivation and harvesting of seaweed. Research on other renewable energy sources has noted that the impact of noise and unpleasant smells is important for public acceptance (Perlaviciute et al., 2018).

From an economic perspective, any renewable technology must be economically viable and benefit the region in which it is situated (Gegg and Wells, 2017). In the commercial context of fuels, this viability depends on where and how the fuel is produced (Edwards and Watson, 2011; Nigham and Singh, 2011), seaweed prices (Neish, 2013; Hermannsson and Swales, 2015), and inshore cultivation is favoured (Hughes et al., 2013). In Asia, seaweed farming has benefited coastal communities by supporting farming and supply-chain employment due to its labour-intensive nature (Netalgae, 2012; Krishnan and Narayanakumar, 2013; Hermannsson and Swales, 2015; Fernand et al., 2017). Conversely, in Europe, profitable production has dropped significantly (Sakshaug et al., 2002). Here, negative impacts on other industries (e.g. fishing) have been reported (Angus, 2017) and many jobs are available only seasonally (Roesijadi et al., 2010). However, recent work suggests that if commercialised, a seaweed-derived fuel industry may foster economic development and create jobs, especially in rural areas (Adenle et al., 2013; Chanthawong and Dhakal, 2016). In the context of other renewable energies, the associated economic benefits have led to positive perceptions (Wiersma and Devine-Wright, 2014). The algae-derived fuels industry could create high- and low-skilled jobs (Adenle et al., 2013) and the "employment rates of bioenergy … are higher compared to fossil fuel supplies" (Ramachandran, 2012, p. 455). However, potential skills shortages, perhaps exacerbated by restrictive immigration policies, have also been noted (Department for Business, Energy & Industrial Strategy, 2018).

Related to these economic issues, additional political and legal questions may be pertinent. However, these are not widely discussed in the academic literature. The regulation of seaweed-based industries in Europe differs by country: in southern Europe, the state regulates the use of foreshore coastal areas and, in general, public authorities decide on how space is used (Netalgae, 2012). In northern Europe, maritime areas can fall under the responsibility of the state, the Crown Estate (in the case of the UK) or local landowners (Netalgae, 2012). This may lead to conflicts (Roberts and Upham, 2012). To set up a seaweed farm in the UK, a lease is required to use the seabed and a marine licence is needed from the national regulator (Wood et al., 2017). It is suggested that clarity about these procedures (in particular the assessment for marine licensees), especially for macroalgae, is needed for supply-chain stakeholders (Wood et al., 2017).

With regard to seaweed, in Asia positive social impacts of cultivating this feedstock have been noted, such as social equality through female employment and, because of increasing incomes, greater community cohesion and participation in leisure activities (Troell et al., 2006; Roesijadi et al., 2010; Hurtado, 2013; Kronen, 2013). However, no research has yet focused on the societal impacts in the UK. Public acceptance is important for the successful transition to renewable sources (Bidwell, 2013; Perlaviciute et al., 2018). Indeed, more public engagement in bioeconomy concepts is needed (Department for Business, Energy & Industrial Strategy, 2018). Although general opinion surveys often show support for renewable energy, this does not always translate to local acceptance: forceful local resistance has affected the development of wind, biomass and solar technologies (Ladenburg and Sanja Lutzeyer, 2011; Ramachandran, 2012; Bidwell, 2013).

This public opposition was based on negative perceptions of emissions, smells, visual impact, and traffic congestion in addition to concerns about the impact on property value and health (Firestone et al., 2012; Jensen et al., 2018; Perlaviciute et al., 2018), marine life and recreational activities (Firestone and Kempton, 2007). Place theory, in particular place attachment, has often been used to understand people's reactions to renewable-energy developments (Sulu et al., 2003; Devine-Wright, 2011b; 2012; Perlaviciute et al., 2018). The fit between perceptions of what the technology and the place represent (Devine-Wright, 2011a) is a key indicator of public acceptance. In studies of marine infrastructure, the ocean is often perceived as a special place where built structures contrast negatively with nature and are seen to urbanise rural areas (Devine-Wright and Howes, 2010; Devine-Wright, 2012; Wiersma and Devine-Wright, 2014). Longer-term residents often have stronger attachments to a place (Devine-Wright, 2012) and frequent beach users are also less supportive of marine developments (Wiersma and Devine-Wright, 2014). These attachments to place can form at local, national and global levels (Devine-Wright and Batel, 2017) and the stronger the attachment, the stronger the preference for offshore developments (Wiersma and Devine-Wright, 2014). Place attachment issues are accentuated if an individual lives close to the development site (Bidwell, 2013), is unfamiliar with the technology, which is likely in the case of macroalgae biofuels (Haggett, 2011; Firestone et al., 2012) and feels powerless to influence the development in their neighbourhood (Ramachandran, 2012). Relationships with developers are also important predictors of acceptance (Gifford and Nilsson, 2014). In particular, acceptance may be affected by distributional justice (the allocation of benefits and costs, especially in communities that are affected), procedural justice (the perceived fairness and transparency of decision-making) and trust in the development organisation, especially during the planning stage (Devine-Wright, 2011b, 2012; Hall et al., 2013). However, it is not clear if these issues would play a part in acceptance of developments related to producing seaweed-derived fuels.

Doubts about the environmental and social sustainability of using feedstock for bioenergy may also increase resistance from local residents and NGOs (Ramachandran, 2012). This opposition may occur when social acceptance is ignored in favour of technology (Burton et al., 2009). To overcome resistance, trust must be built through transparent, two-way communication and knowledge transfer in the early planning stages (Ramachandran, 2012). Therefore, the current focus on the technological aspects of macroalgal biofuel development risks this type of opposition, because the potential social impacts have largely been ignored. This paper seeks to fill that gap.

Not all perceptions are negative, and renewable technologies do not always result in public opposition. Perceived social benefits include job creation, energy security and economic development through employment, which may lead individuals to support developments (Ramachandran, 2012; Wiersma and Devine-Wright, 2014; McGrath et al., 2016). In terms of job creation, areas of north-west Scotland have been identified as suitable for macroalgae production, partly due to an existing skills base in the area (Milledge et al., 2015b).

Overall, little empirical research goes beyond technological development in the context of seaweed biofuels. Given the uncertainty over potential production and processes (aquaculture and supply-chain elements) for macroalgae biofuels, we know very little about commercial stakeholders and public perceptions and it is hard to predict whether social concerns and potential opposition would materialise. The key message is that any development in this area must be preceded by a proactive understanding of the potential for these issues, especially as public acceptability is often addressed too late and varies by context and project (Perlaviciute et al., 2018). Hence, this work examines the perceptions of a range of commercial stakeholders and the public within the macroalgal supply chain. It focuses on supply chains producing biofuels via gasification and goes beyond the current focus on technology. By taking this proactive approach, this examination provides detailed information that can be used to develop relevant and meaningful policy and pre-empt resistance from residents, consumers and the general public.

3. Methodology

This empirical study examined stakeholder perceptions associated with the macroalgae biofuel supply chain. It was divided into two parts: (1) key industry and policy stakeholders; and (2) the wider public. We outline the methods used for each part below. By including these audiences, we responded to accusations that energy-infrastructure research fails to consider actors' roles, expectations and interactions at macro, meso and micro levels (Devine-Wright et al., 2017). Both parts take an exploratory qualitative approach intended to provide depth, insight, and understanding (Malhotra et al., 2017 to this under researched area.

3.1. Industry and policy stakeholders

In the first part of the study we completed 19 semi-structured interviews with key informants. Semi-structured interviews allowed us to capture in-depth insights while giving stakeholders the freedom to elaborate on important topics (Horton et al., 2004). Because they can capture significant amounts of data in a single meeting, they reduce the need for follow-up research, which can be problematic when targeting high-level experts (Horton et al., 2004). A key aspect of this approach was to identify appropriate stakeholders. In line with Savage et al. (1991), Gold (2011) and Chanthawong and Dhakal (2016), we were concerned with stakeholders who had an interest in the action taking place (in this case, developing a biofuel supply chain) and the practical ability to influence it. We conducted an extensive search that considered Mitchell et al.'s (1997) stakeholder attributes of power (utilitarian and regulatory), legitimacy (level of interest) and urgency (those more prevalent to supply-chain development). This resulted in identifying nine groups of stakeholders as 'influential' or potentially 'influenced by' the development (see Table 1). These groupings allowed us to identify stakeholders in detail and invite them for interviews. Although it became obvious that the Crown Estate was an important stakeholder in the UK, we were unable to gain access for an interview. The reason given was that they were not open to all types of end-product generation and did not support gasification/drop-in diesel – the focus of this work. Table 1 details each stakeholder interviewed.

The interviews questions focused on drivers and challenges (what drives development, relevant incentives and policies, challenges of developing macroalgae biofuels), industry networks and communication (communication with government, within the biofuel sector and cooperation/collaboration between different parties), and macroalgae trials (challenges and support).

Table 1
Industry and policy stakeholders interviewed.

Stakeholder group	Respondent	Description
Government/regulators/ environment agencies	A	Policy expert
	B	Fisherman's association
Beach or land owners/offshore wind	C	Oyster farmer/seabed owner
	D	Major offshore wind generator
Seaweed industry/fishing industry	E	Aquaculture
	F	Seaweed wild harvest
	G	Fin-fish aquaculture
	H	Seaweed cultivation and harvest
Silage experts	I	Silage construction
Biofuel producers	J	Major EU biofuel producer
Fuel distributors/forecourts	K	Aviation biofuel distribution
	L	UK international airport
End users	M	British airline
	N	UK international airport
Consultancy and academia	O	Seaweed expert (food)
	P	Seaweed expert (academia)
	Q	Algae academic
	R	Algae academic
Venture capital	S	British private equity

3.2. The wider public

The second part of the study explored the perceptions of the wider public and the potential for public acceptance, which is key to the success of renewable technologies (Perlaviciute et al., 2018). Members of the public are considered to be non-experts; they are unlikely to be able to answer specific questions about the impact of a technology without being given at least some basic information. Therefore, we used focus groups to investigate these issues. Focus groups are an effective means to explore concerns, experiences and opinions about a certain topic (Barbour and Kitzinger, 1999; Bryman, 2001) and collect data through group interaction (Morgan, 1996) and spontaneous responses. They can provide possible solutions to problems raised (Duggleby, 2005; Onwuegbuzie et al., 2009) while acknowledging disagreements (Perlaviciute et al., 2018). Furthermore, they can capture a wide variety of views and allow respondents to ask questions about the issues (Barbour and Kitzinger, 1999). They have been used to capture attitudes towards similar projects, such as road-based bio-derived fuels (Jenson et al., 2018), low-carbon energy and carbon-capture technology (Upham and Roberts, 2011). Each focus group had three parts: (1) respondents' general perceptions of renewable technologies, specifically biofuels; (2) a short presentation of the biofuel/macroalgal biofuels process (developed in collaboration with the wider project team of scientists and social scientists); and (3) a final open discussion in reaction to the presentation. We were aware that an open discussion followed by a presentation of the key processes and issues might cause stronger, potentially negative reactions from the respondents. This is in line with a study by Sűtterlin and Siegrist (2017), who found that when discussing renewable technologies (which did not include biofuels), a more specific, concrete approach diminishes potential acceptance in comparison with a more abstract approach. However, this strategy was appropriate because, as Sűtterlin and Siegrist (2017) note, informed decision-making is possible only when positive *and* negative aspects are tackled. In addition, this design responded to the need for research on unfamiliar technologies and hypothetical developments (Wiersma and Devine-Wright, 2014).

We held focus groups in four locations where seaweed cultivation and production could take place. We selected these locations based on the following criteria: (1) proximity to the coast, where the need for economic development is highlighted by the UK government's Coastal Communities Fund (CCF); (2) a history of fishing and aquaculture

Table 2
Focus groups-locations and attributes.

Location	Location (attributes)
Shetland Islands	Coastal community (macroalgae harvest/cultivation experience)
Scottish mainland coastal town – Oban	Coastal community (local fishing/aquaculture economy)
Southern coastal town – Whitstable	Coastal community (no local fishing/aquaculture economy)
Inland city – York	Inland community (in an area with biotechnology development)

within the local economy; and/or (3) involvement with macroalgae cultivation and harvesting. One focus group took place inland, where a bioeconomy cluster is already in place. The groups were designed to capture a broad range of UK public perceptions while investigating any variances between UK locations. This responded to comments that similar energy projects may be evaluated differently depending on the unique characteristics of the community (Perlaviciute et al., 2018), and that evaluations of changes to places are diverse (Devine-Wright and Howes, 2010). In addition, rural or coastal communities may see large-scale energy infrastructure as unwanted industrialisation, while it may overburden communities in locations that are already developed (Perlaviciute et al., 2018). Table 2 details the locations.

We recruited the focus-group participants through leaflet drops in the local area and advertising in local newspapers. We had planned to hold two focus groups in each location, but recruitment was problematic in one area; therefore, seven focus groups took place with 33 participants in total.

Using a two-part methodology, this concurrent mixed-methods study (Farquhar et al., 2011) attempts to combine "evidence from a variety of sources that do not share the same weaknesses" (Craig et al., 2008, p. 2). This comprehensive approach provides a diversity of viewpoints (Johnson and Onwuegbuzie, 2004; Harrison and Reilly, 2011) and responds to comments that little energy-infrastructure research has used mixed methods (Wiersma and Devine-Wright, 2014). For both methods, the data analysis was driven by an etic approach (guided by previous literature and a PESTEL[2] framework) and an emic approach (the situated knowledge of the participants) (Reinecke et al., 2016). This enabled us to determine key themes in the data and remain open to factors specific to seaweed-derived fuels.

4. Results and discussion

Several different issues were identified by the stakeholders and the public participants. We examined the importance of each issue by considering the number of appearances in the transcripts and the length of time for which it was discussed. Levels of knowledge about various issues differed significantly among stakeholder groups, and even the commercial seaweed experts lacked knowledge of seaweed biofuel-production techniques and the potential technological constraints. This supports James' (2010) finding that although technical studies and commercial interests exist, demonstration projects are lacking and there are large knowledge gaps about the prospects of seaweed biofuels.

The following sections mirror the PESTEL framework. This type of strategic planning analysis framework is vital in emerging industries and has been used to assess several energy sectors, including liquid biofuels and bio-coal (Walsh, 2005; Talamini et al., 2013; Wiersma and Devine-Wright, 2014; Gegg and Wells, 2017). We begin with the technological issues, which are presented in the same order as the background section, and end with the social issues.

4.1. Technological issues

All the stakeholders discussed the technological issues that they felt were pertinent, but their focus depended on their expertise. Stakeholders with seaweed experience focused on cultivation and harvesting, whereas those experienced in policy, biofuels and venture capital discussed the wider constraints of gasification. Regarding cultivation and harvesting, there was a split between perceptions of the readiness of the technology required. Respondent H was confident that the technology was ready for large-scale seeding and mechanised harvesting, and that all issues have been solved:

> … we have solved all of those! We are now working with the textiles industry to grow seaweed on materials … Technically there is no issue.

However, the majority of the stakeholders mentioned technological issues that remained, which supports previous research (Kraan, 2013; Dave et al., 2013; Msuya, 2013). They highlighted the following concerns: the physical structures required for large-scale cultivation, particularly in deep waters; cost-effective methodologies and economics of harvesting (due to high European Union (EU) labour costs); and high depreciation costs of seaweed-cultivation machinery. They did not discuss the current ban on mechanised harvesting (Roberts and Upham, 2012). Respondent B also noted the weather challenges of upscaling:

> The storms are absolutely unbelievable.

However, locations with less potential for weather damage could be chosen (Roberts and Upham, 2012). Overall, most stakeholders highlighted that technological issues remain due to the lack of demonstration facilities.

While we did not expect the general public to be technological experts in the field of seaweed-derived biofuels, technological issues were discussed in the focus groups. Respondents were sceptical about the strength of the equipment and whether an appropriate seaweed volume could be produced, which mirrored the technological concerns of the stakeholders. This scepticism led respondents to question whether it would be worth the effort to develop macroalgae biofuels rather than use more established renewable technologies (which they were familiar with) or encourage behaviour change to reduce demand. This scepticism was not restricted to algal biofuels, but covered broader biofuel technology:

> I think it's stupid. Biofuels are for cars and they are over 100 years old, and we are still using it, normally there is nothing that we use for that long … It is old fashioned? It is now stuck in this system. And now biofuels are prolonging it!

Given the doubt about the technological aspects, respondents were at best confused – "so it is rather theoretical isn't it … it's confusing!" – and at worst felt that further development was not worth the effort. Scepticism about new technologies has also been noted in consumer assessments of domestic microgeneration (Watson et al., 2006).

4.2. Environmental issues

Perhaps surprisingly, environmental issues were not extensively discussed by the stakeholders. Although they mentioned the uncertainty resulting from a lack of demonstration projects (especially on seaweed, aquaculture and fishing), they focused on the potential benefits.

Conservation issues were raised by one respondent (C), but this was

[2] PESTEL – Political, Environmental, Social, Technological, Economic, Legal.

related to potential opposition by the Inshore Fisheries Conservation Authority rather than MSACs (Roberts and Upham, 2012). Stakeholders mentioned the environmental benefits from reducing emissions, but focused on the benefits from cultivation. Algae's ability as a nutrient filter in aquaculture featured prominently in the interviews, which supports previous findings (Tsagkamilis et al., 2010). One stakeholder said:

> Positive for us would be taking nutrients from the water. Not sure about the downsides, to be honest. Anything to help take out nutrients is really good for us!

Although stakeholders considered the general environmental impact to be positive, they acknowledged that large-scale testing and demonstration projects are needed urgently to assess environmental problems ("we need to demonstrate the technology" – Respondent J) and noted that without this, the industry was in danger of stagnating. This mirrors comments from the Department for Business, Energy & Industrial Strategy (2018). The algae expert gave an example of a proposed joint tidal and seaweed project that failed:

> … someone wanted to put tidal barriers into the Wash and integrate macroalgae and other stuff, and it was an SSI and had high bird populations etc. I think nobody really could give them an accurate estimate of the environmental impact … good or bad and I think that that was the main issue. With no data, it was very difficult for them to make a decision regarding investments.

Unlike the stakeholders, the focus-group respondents discussed environmental issues extensively and were extremely concerned about potential negative impacts on marine life. In Oban, these included concerns about local wildlife: the respondents stated that seals were already being affected by the aquaculture industry. A York respondent summarised these issues:

> … what chemicals are you going to introduce to the environment to maximise growth or minimise pests … what does it do to the other creatures that are there? Have many studies been made about the flora and fauna that are native and the migration patterns and what happens?

Respondents were also concerned about pollution from lost equipment and from plastic:

> … the oceans are filling up with plastic and it's getting worse and worse. This will add to that problem.

Finally, many of the environmental concerns were related to the potential scale of cultivation and harvesting, with more concerns about large-scale farms (e.g. several hundred hectares) than smaller scale farms.

Overall, the responses from the stakeholders largely supported previous research, but the perceptions and concerns among the general public have been highlighted here for the first time.

4.3. Economic issues

Several significant economic challenges to developing a macroalgae supply chain were identified by the stakeholders. Cost uncertainty and the challenges of predicting costs were frequently cited as issues caused by the lack of working examples, especially for gasification technologies and large-scale seaweed cultivation. James (2010) notes that the highest area of cost would be associated with the technical challenges of cultivation and harvest, and the stakeholders agreed: "The biggest cost is probably the cultivation" (Respondent P). However, some respondents suggested that the technological challenges have been overcome and that reasonable cost estimates should be available soon. Respondent H noted:

> Technically there is no issue. It's purely financial at the moment.

Gasification costs were also considered to be uncertain, particularly when accounting for the capital costs of the production facilities. Furthermore, because seaweed can also be used to produce high-value items such as food, animal feed and chemicals (with high-value returns), the respondents questioned whether low- or zero-value feedstocks (e.g. solid waste) would be better suited to biofuels and provide a better economic return for producers. These points were noted by Adap + (2013) and align with the "cascading use of biomass" principle of realising one or more material uses before using the residual biomass for other outputs such as energy (Keegan et al., 2013). However, this may lead to competition for a biomass resource (Department for Business, Energy & Industrial Strategy, 2018). Several stakeholders suggested that using waste residue from manufacturing high-value seaweed products might be the best option and make biofuels from seaweed cost-effective. Indeed, they suggested that the economic viability of a gasification facility would be unsustainable if the raw material had any cost. Respondent H noted:

> For us the economic driver is the chemicals that you can get out of the seaweed. That's what drives us. Let's put it this way – if large-scale cultivation would really take off in the next 10 years, which I think it will … then you will have a product which is left over which could be used for biofuels.

Stakeholders also discussed the lack of private investment due to its high-risk nature, in alignment with prior research (Wells et al., 2013). Respondent S noted:

> I'm being quite harsh but if you look at private-equity houses of a business typical investment then you can always argue that the future is an educated guess, but this sort of thing has no reference points in the past … so it will have a very high-risk premium. So it is very difficult for investors to even contemplate …

Respondent S then went on to highlight that those who were likely to invest in seaweed biofuel technology would already be highly knowledgeable about the industry and would probably be involved in the seaweed industry or the aquaculture industry. Without concrete demonstrations of the whole process, private-equity firms would be unlikely to invest in seaweed biofuels within the next 10 years, so demonstration projects cannot rely on these firms for support.

As in other technologies, scaling up brings economic considerations. Stakeholders were confident that seaweed cultivation could provide large volumes of biomass in the UK: "Of course [we can produce that much] – yes we can, but give us the space and the licence to do it!" (Respondent H). Supporting the literature (Chanthawong and Dhakal, 2016), the stakeholders felt that Scotland was a promising region. One respondent said:

> In theory there is adequate water in Scotland [for mass seaweed cultivation for biofuels], in other parts of the UK there is too much coastal activity and there is too much risk from excessive weather, etc.

However, stakeholders also noted a lack of interest from the biofuel industry:

> the biofuel industry often say, if you have a new feedstock, we need over 100,000 tonnes on a yearly basis to run a proper biorefinery – but we [the seaweed cultivators] have to stand with our hands in the air and say we can only produce 40 tonnes at the moment.

Partnerships with aquaculture and potential to generate high profits were mentioned by stakeholders in the seaweed and fishing industry. As noted in the environmental section, nutrient-cleaning benefits the aquaculture industry and seaweed could provide additional revenue. Respondent G's company had previously attempted (but failed) to produce seaweed with fin fish to increase the sustainability of the product:

> We wanted to look at a seaweed site and to market the seaweed for

food. Mainly the drivers were environmental and marketing as well, selling the seaweed alongside the product. They were trying to make a difference to the environment and asked for a premium for the product. Mainly from the nitrogen uptake. I think that was a key thing – being able to sell the product at a slight premium.

Many focus-group participants were sceptical about the potential profitability of the industry: biofuels and more broadly. One respondent spoke of his disdain for renewable energy projects:

> … Google were investing in a technology to make a renewable form of energy that would be cheaper than coal … However, after four years the project was canned, it failed. Big fail, not little fail. Failed! Impossible, it can't be cheaper, people are going to continue using coal … All this is stuff is great for creating jobs, great, but the stuff you get from the end of it is … crap.

Participants in coastal locations also discussed job creation, which may be expected due to the lower employment rates in these communities (Depledge et al., 2017). In Shetland, however, participants did not feel that job creation would be useful: there is already almost full employment, and the seasonal nature of the jobs created by farming would not be attractive. In the mainland coastal towns there were concerns about the seasonal nature of jobs, workers being brought in to fill posts, the availability of the necessary skills and housing new workers. One respondent commented:

> … seasonal workers as quite disruptive, they generate short-term needs, that means people don't want to invest to meet those needs, like accommodation etc., this is an expensive area to live. We don't have large amounts of short-term reasonably priced accommodation to put temporary workers in.

Overall, the focus-group respondents did not perceive the same economic benefits that aided the acceptability of other types of renewable development (Wiersma and Devine-Wright, 2014).

4.4. Political and legal issues

These issues were discussed alongside the economic issues, so they were mentioned briefly in the previous section. Policy and aquaculture legislation were the two main issues for the stakeholders.

Many stakeholders felt that the policy framework was inadequate in the UK. They suggested that without strong policy support from government, investment would not take place because of the significant cost of developing biofuels:

> … if you're going to produce aviation biofuels without any form of policy support, it has to be cost competitive. The carbon price is totally not there to support aviation biofuels. There has been very little moving on integrating aviation into biofuel policy.

Policy support was considered to be particularly lacking for seaweed, with the lack of stability discouraging investment and pushing seaweed towards high-value products rather than biofuels (Wells et al., 2013). However, the stakeholders also acknowledged that this was an issue not just for seaweed or even biofuels, but for the wider renewables landscape:

> I think the whole renewable policy framework for renewables in in disarray at the moment. I think it has been a political football, and so the whole thing is largely uniformed and certainly not clear.

Regarding competition for seaweed from high-value products, the food industry was seen much more positively. A respondent from the industry mentioned that the Scottish Association for Marine Science (SAMS) is a major driver for UK seaweed cultivation. Respondent P stated that SAMS is working with the seaweed sector on government interests and Respondent O stated:

> … [with SAMS] we are headed in the right direction. We had a visit from ministerial and government legislators. So, at government ministerial level there is interest but that has yet to materialise into strategic impact assessments and strategic direction.

Furthermore, Respondent O spoke positively about work being done by the UK government and the seaweed industry to develop the seaweed food industry in the UK:

> … we have just started the Scottish Seaweed Association, to bring together various stakeholders together with government and it is very much in its infancy … Certainly, in terms of long-term food policy macroalgae has been identified by the UK government.

Other stakeholders also felt that policy direction in the UK did not suit the development of gasification/drop-in diesel biofuels. A policy stakeholder who chose not to take part in the interviews commented, by e-mail, on a preference for biomethane rather than synthetic diesel mainly to reduce particulates.

Stakeholders made some positive comments about the relatively progressive licensing framework for seaweed in the UK. This was complemented by positive perceptions of the Crown Estate and its active licensing for UK seaweed cultivation:

> We have a pretty progressive framework that already allows seaweed cultivation in the UK. You need policy and regularity processes in place before you can put the stuff at sea. … In the UK we already have it. And in Scotland we have a draft plan for the cultivation of seaweed at the government level.

While the Crown Estate is active in licensing seaweed cultivation, it is not open to all end-product generation (in particular, gasification/drop-in diesel). When questioned further, the respondents made comments that were less positive. Respondent O noted:

> … legislation is challenging – if you look at current legislation you can only grow in certain areas with a certain distance from the other aquaculture sites because of fear of viral transmission and things. These things need to be adjusted [for large-scale cultivation].

The stakeholders discussed whether challenges in aquaculture legislation stem from a lack of knowledge and whether existing legislation may need to be relaxed, supporting previous research (Wood et al., 2017). For example, rules about distances between aquaculture sites exist to reduce the spread of disease, but this may not apply to seaweed. Respondents gave examples of other countries where the rules have been relaxed. For example:

> … now Canada have already done this where you can grow seaweed within 10 m of a salmon farm, so they can take up the nutrient there. Which could be beneficial. It also grows faster. So, these little things need to be solved.

The stakeholders felt that larger demonstration projects would not happen without relaxing certain rules, increasing knowledge and introducing seaweed-specific legislation. As summarised by Respondent R:

> … the licences fall under aquaculture, so people don't really know what to do with it. I would say that if there was a specific driver or incentives, it would maybe accelerate change, but as it is, people that have to navigate this patchwork of regulations …

In the focus groups, the respondents felt that renewable energy in the UK was inadequate and they would support government or tax incentives to boost renewables. However, they did not feel that there was enough information to make an informed choice about seaweed biofuels. While they valued having a mix of energy sources, they felt that if one was not economically viable or a good long-term plan, it should not join the mix. One respondent noted:

> Well, it's about the [energy] mix isn't it. And you have to do the sums. Having a pragmatic approach and also looking at what's

happening and what legacy you're going to leave.

Discussions about policy often turned to the benefits of behaviour change versus investment in renewables. Indeed, apart from the Shetland focus group, behaviour change was key. In the inland focus group, one respondent noted:

> A lot more can be done very easily … one of the discussions I have with lots of people is that we could easily, right here now … tomorrow! … we could reduce our fuel consumption on the roads by a third by restricting the speed limit to 55. The fuel consumption rises exponentially with speed, so the fuel saving by changing from 55 to 80 is phenomenal and you could do that tomorrow morning by creating a speed limit and enforcing it. You reduce the fuel consumption down by a third!

This was supported by a respondent in the Oban focus group, who noted:

> I just did a driver fuel-efficiency course and I'm what I thought was an efficient driver and even I gained 10% … everyone who drives should do the course … we could achieve the same savings [as using seaweed biofuels].

Overall, the respondents felt that more needs to be done in the UK to provide renewables, which may include seaweed biofuels. Behaviour change was highly valued as a way to tackle climate change and energy-security issues, and respondents noted this should be considered with all options, especially if new technologies (such as seaweed biofuel) are untested.

4.5. Social issues

Marine-user conflicts were highlighted by several stakeholders, in particular in the context of near-shore cultivation. Respondent F explained:

> Yeah, it's a coastal zone management problem … if you overlay onto all other activities which are already going on in the coastal zone – growing macroalgae for biofuels … you'll have people [other marine users] reaching for their revolvers.

Although stakeholders discussed offshore sites as a potential solution, they suggested that these sites lack the nutrients required for optimum growth.

Because of the potential benefits of nutrient uptake, aquaculture companies in Shetland were less concerned about marine-user conflicts and felt that there was room for seaweed cultivation:

> From our point of view, I don't think there would be conflict of interest at all, but saying that, if they were going to go close to one of the sites that we would like to expand into, that could be an issue I suppose … There are areas you could easily put seaweed.

Stakeholders were concerned about conflict with fishing in inshore waters. They felt that conflicts could be prevented with careful planning but further knowledge was needed:

> I think the initial reaction would be negative [from fishermen and trawlers]. They would say there is enough development already. The area they can fish in already is quite circumscribed. And the threat really is that it could become more circumscribed because the government already have plans to do things with wind turbines and things like that … But then again, there are large areas of sea which you can't fish in because they are closed areas and there are lots of areas which are unsuitable for fishing because of the sea floor …. .

In the focus groups, the main concern was the potential visual impacts of large-scale cultivation, which supports previous work on renewable-energy infrastructure (Wiersma and Devine-Wright, 2014). The level of concern varied by geographical region and scale of development. Small-scale production was received fairly positively, but large-scale production caused a much more negative reaction. Respondents in coastal communities (except Shetland) were very concerned about the visual impact, supporting research on wind turbines (Firestone et al., 2012). One respondent said:

> I think for most people that live in places like this, I can't speak for most people, but I think that that would be visually unacceptable for most people, it's got to be far enough out to not be intrusive.

Respondents in these communities were worried that the expansion could get out of control, especially alongside other aquaculture:

> … we moved up here because we love the area [western Scotland] and were glad to get out of the rat race, but it seems like it might follow us. It's not really the visual impact so much because they don't look that bad, but it's never controlled.

However, in the York and Shetland groups there was much less concern about visual impact. In York, this may be because most residents are not regularly close to the sea; previous work suggests that those who use the coast frequently are less likely to support marine developments (Wiersma and Devine-Wright, 2014). In the Shetland group, the lack of concern appeared to relate to their often daily interactions with aquaculture, the fishing industry and similar structures. This supports work on wind turbines, which found that familiarity and proximity are key drivers for acceptance (Haggett, 2011; Bidwell, 2013). Drawing on place theory, because these communities are familiar with marine infrastructure, there is a positive symbolic fit between the place and the development; it fits the character of the area, as seen in studies on some tidal projects (Devine-Wright, 2011a, 2011b, 2012).

Other concerns about visual impact included the size and location of biofuel plant facilities and the location of silage depots. Respondents also mentioned that the smell of seaweed in summer could be a big issue for seaside towns. One respondent said:

> … it's the inland processing that worries me, it doesn't look particularly attractive. But as everybody said, you also have the road issues and do you want lorryloads of raw seaweed coming through the town, and trust me if you live here in the summer, the seaweed absolutely stinks, it is very unpleasant.

Interestingly, there was very little concern overall about ensiling the seaweed in depots or silage materials. The subject of silage was generally well received by the respondents, possibly because they had already seen silage depots dedicated to land-based farming. Drawing on place theory, there is a natural fit between these new developments and current land uses. Furthermore, in Shetland the impact of the on-land infrastructure was seen as positive. The prospect of regular work in silage, biofuel processing or logistics outweighed any negatives.

Respondents also drew attention to potential impacts on local infrastructure; in particular, disruption on public roads. One respondent with planning experience explained that a dramatic increase in haulage could be a problem:

> I don't think this would even get though planning in Kent … It would almost certainly be turned down straight away.

This supports the work of Roberts and Upham (2012) and is potentially similar to work on shale gas, which highlights impacts such as increased congestion, deterioration of roads, threats to drivers posed by increased volume, and maintenance costs (Anderson and Theodori, 2009; Kargbo et al., 2010). In some places this has led to regulation, via fees, for heavy trucks (Rahm et al., 2015).

Distributional justice, procedural justice and trust, which were deemed important in previous work (Hall et al., 2013), were not important factors for the participants. This may be because the developments were hypothetical, not actual.

5. Conclusions and policy implications

The discussion highlights several important aspects for stakeholders and the general public with regard to developing macroalgal biofuels. These support and extend earlier work on macroalgal biofuels, biofuels and renewable technologies more broadly. From a technological perspective, while the processes needed are feasible, particularly with experience gained from the aquaculture industry, scaling up is still required to be certain of its potential and develop a sustainable harvesting policy (Roberts and Upham, 2012). From an environmental perspective, stakeholders saw nutrient-filtering as a benefit, but the general public were concerned about sea waste, rubbish and impacts on wildlife. From an economic perspective, there was concern about cost uncertainty (related to technological aspects) and competition with high-value products for seaweed. It looks likely that for now, seaweed will be sold into the growing high-value markets for food, pharmaceuticals and animal feed. If this market is developed on a large scale, there may be scope to use waste residues for biofuels. The general public were positive about local employment and wider energy-security benefits, which supports the suggestion that individuals are more likely to support a project when they see societal benefits (Perlaviciute et al., 2018). However, they did not see particularly strong benefits, which may affect future acceptance. Overall, stakeholders perceived the regulatory framework for seaweed farming and producing macroalgal biofuels as relatively open, but they felt that policy support, which would be key to successful development, was inadequate. The public supported renewables in general, but they felt that more information was required to justify government support. Work on offshore wind in France suggests that these developments are more readily accepted when accompanied by a coherent environmental policy (Wiersma and Devine-Wright, 2014); therefore, the interplay between policy and public acceptance should not be ignored. Many of the public respondents mentioned behaviour change as potentially more important, highlighting a policy link with the Behavioural Insights Team (www.behaviouralinsights.co.uk). Finally, from a social perspective, both groups highlighted potential marine-user conflicts. For the public, these depended on location and familiarity, as is the case for offshore wind (Haggett, 2011; Firestone et al., 2012). Applying place theory, in particular the fit between the development and the place, the findings supported the prior literature (Devine-Wright, 2011b). This suggests that widespread demonstrations (such as those seen for hydraulic fracturing) would be unlikely, but local opposition is possible and should be tackled proactively (Perlaviciute et al., 2018).

While this work broadly supports stakeholder issues noted by previous research, the key contribution here is understanding social opposition, resistance and potential support. These issues are vital for future development and moving through the stages of the FSRL (Steiner et al., 2012). Firstly, the foci differed between the stakeholders and the public, and even between different stakeholders. These differences should be considered in order to enable mutually beneficial two-way communication and knowledge transfer between those involved (Ramachandran, 2012). Furthermore, involving NGOs and the public through relationship-focused management at an early stage considerably increases societal acceptance (Gold, 2011). This must involve the highest level of public engagement: a two-way exchange of information that may transform opinions on both sides (Devine-Wright, 2011b). Secondly, given the mixed responses to macroalgae as a biofuel among the public (and, in some cases, stakeholders), policy-makers need to question whether the public will react positively to uncertain and (in their eyes) marginal gains from the further development of potentially peripheral offerings. The energy mix, biofuels as part of a diverse portfolio of renewable energy sources (Koh and Ghazoul, 2008) and energy security may be more important to the public. Participants in this study were more likely to support established renewable technologies and were more in favour of behaviour-change interventions overall. However, given that large-scale road and air transport remains dependent on high-energy liquid hydrocarbon fuels (Zhao, 2017), if government policy supports any bio-derived fuel (regardless of source material) it must highlight this reliance, which cannot be met through electrification and the technologies that focus-group respondents appeared to support. This current reliance, and therefore the mix of technologies needed, is a key message that must be communicated clearly alongside the government's plan to shift most new cars and vans to zero emissions by 2040 (Defra/DfT, 2017). Thirdly, this public and stakeholder support was uncertain largely because the relevant technologies have not yet been scaled up enough to provide a deep understanding of the technological, cost and visual implications.

The only way to provide a clear view of the potential for macroalgal-derived fuels, and to allow appropriate development, is to scale up and provide demonstration projects with policy support. Given the level of uncertainty, this is very unlikely to be funded by private investors, who would need longer-term consistent and transparent policy commitments to be sure of returns (Lah, 2017; Department for Business, Energy & Industrial Strategy, 2018). Therefore, government investment is needed: directly, through universities or via other funding methods. These types of capital grants (with repayment) can complement subsidies or other supporting policies (Leach et al., 2011). Further investment in the UK Future Fuels for Flight and Freight Competition, launched in 2017, may begin to fill this gap, but is unlikely to provide enough funding for capital infrastructure. Only stable long-term policy, which is transparent and consistent and stays in place for a significant period of time to allow stability and sustainable technical development will result in investment (Wells et al., 2013; Chanthawong and Dhakal, 2016); political uncertainty increases perceptions of risk in a project (Leach et al., 2011). Any subsidies for this technology, versus alternative technologies, need to be defined and committed to. Investment in large-scale cultivation and harvesting would also benefit the wider aquaculture industries and increase potential demand for high-value products such as food; however, as noted by Chanthawong and Dhakal (2016), any policy should try to balance biofuel feedstock use in the food and energy industries. This type of symbiotic relationship, through co-location or efficient feedstock use, might attract private investment if marine policy is developed to further support this alongside existing aquaculture. Czyrnek-Delêtre et al. (2017) note benefits of co-location with salmon farming while Langlois et al. (2012) note the environmental benefits of co-locating with offshore wind. Any policy should “focus on the areas where it can have the most impact in convincing investors to put their own capital at risk” (Leach et al., 2011, p. 4015), and subsidies or public funds should be used to encourage private R&D investment (Jamasb and Pollitt, 2015). Balanced policies that combine measures that result in larger synergistic effects are likely to have the greatest effect overall (Lah, 2017). Policy could also incentivise links between aquaculture and biofuels by encouraging cooperation and coordination in the supply chain (Gold, 2011). Finally, if policy supports the development of aquaculture and demonstration facilities, the benefits and reasoning must be communicated clearly to the public early in the planning stage to avoid resistance (Ramachandran, 2012).

5.1. Limitations

One limitation of this work is that key stakeholders may not have been included. While we made every attempt to include all relevant stakeholders, the full supply chain is complex and a vital opinion may have been missed. The Crown Estate's refusal to take part meant that an important voice was not considered. Although the Crown Estate is not in favour of drop-in diesel, this study has provided perceptions of seaweed farming, ensilage, gasification and drop-in diesel that are useful for the supply chain for this process and for organisations producing non-biofuel seaweed products (e.g. cosmetics) and biofuels using other feedstocks. An international perspective would also be useful, given that aviation fuels are a global commodity and any new fuel may need approval from multiple governments. In addition, although the focus groups were representative, a wider selection of participants might have led to different issues being raised and some key issues might have been missed. Because the participants had little knowledge of seaweed-derived fuels, the issues raised may have been influenced by the methodology; therefore, future work should seek to collaborate these findings.

5.2. Future research

From a stakeholder perspective, the supply chain will continue to evolve as technology and processes develop, so future work must involve any new stakeholders and include those whom it was not possible to include here. From a public perspective, the next logical step is to use a more representative sample through a large-scale survey or similar to build on and test our key findings (allowing for triangulation and instrument development (Harrison and Reilly, 2011)), examine how widely these concerns are felt, and identify whether this differs by, for example, socio-demographics and geographical location, drawing further on fit and place theory. Previous research has noted that many surveys of this type receive non-substantive responses (Edwards, 2018); therefore, surveys must be designed carefully to truly understand support for and opposition to these types of technologies. Public support is constantly evolving; therefore, longitudinal research should take the work beyond the identification stage (where people first know about the technology) to examine public perceptions at the interpretation, evaluation and coping stages as developments grow (Devine-Wright, 2011b). Furthermore, researchers should present these findings to relevant government and policy stakeholders (such as representatives from Defra, the Department for Business, Energy & Industrial Strategy and the Department for Transport) and examine how the findings could focus further policy development.

5.3. Final conclusions

The UK bioeconomy strategy (2018) highlights the importance of the bioeconomy and biofuels in developing sustainable, economically viable alternatives to hydrocarbon-based fuels. Macroalgae has the potential to play a role in this, but it is often ignored by academic research and government policy. While technological issues are progressively being overcome, this paper illustrates that scaling up and a broader understanding of wider societal issues are important for further development and commercialisation. As with other technologies, stable, consistent and transparent long-term government policy is key; however, specific policies on seaweed-derived fuels are also required, given potential competition with other products and marine uses. Furthermore, a proactive approach to informing and communicating with the general public is imperative to the success of this technology, given lack of public knowledge in this area and the desire for a balanced and efficient fuel mix.

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