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Prospects for the use of macro-algae for fuel in Ireland and the UK: An overview of marine management issues

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abstract

Competing demand for land is driving biofuel and bioenergy research in various directions including macro-algae (seaweed). This paper reviews the main issues for the marine environment of cultivating and harvesting UK and Irish seaweed for biofuels/bioenergy, informed by stakeholder interviews. These showed stakeholders were sceptical of an offshore cultivation industry developing but generally considered inshore cultivation possible, while noting various practical obstacles and conditions. Views on expansion of seaweed harvesting were more divided, with research scientists being relatively cautious.

1. Introduction

The large-scale increase in demand for biofuel and bioenergy has resulted in the emergence of a wide variety of environmental and socio economic concerns. The greenhouse gas saving associated with many biofuel systems could be negated by the indirect carbon release through land-use change associated with brining grassland or forest into cultivation [1–3]. More specifically, the growth of terrestrial crops for biomass requires the use of significant amounts of land and water and can have implications for both biodiversity, food production and landscape [4,5]. Furthermore, if biofuel production continues to grow at current rates it is likely to present an enormous challenge for global governance [6]. Consequently the search is on for more sustainable alternatives. One option is the utilisation of marine biomass. However, research and development for a marine bioenergy and biofuel industry is still in its infancy. Furthermore, the marine environment represents numerous challenges in terms of technology, working practices and governance. Moreover, while a number of studies have explored the technical and environmental aspects of macro-algae for bioenergy [7,4], there is very little work on the potential public acceptance and governance challenges associated with the development of a marine biomass industry with fuel as an intended end-use.

Given these challenges, this paper reviews the prospects for developing a marine biomass industry in the UK and Ireland, informed by stakeholder interviews. It identifies a number of key barriers related to the governance and use of marine biomass, which would need to be overcome should the sector be considered potentially commercially viable. The methods used are literature review and semi-structured interviews with stakeholders and researchers in Southern Ireland, carried out in May 2010. The interviewees came from a range of backgrounds: industries already utilising seaweed resources, academia and government agencies. The interviewees were selected to inform issue scoping, not to provide a fully representative set of opinion sources. In the following sections, we introduce the main issues relevant to the prospects for a marine biofuels/bioenergy sector in Ireland and the UK.

2. Sourcing marine biomass

There are essentially two ways of obtaining marine macro-algae: harvesting natural stocks or cultivation. There are a number of mechanical options available for harvesting naturally occurring stocks of seaweed; however, serious concerns exist regarding environmental damage. Consequently in the UK and

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Ireland, mechanical harvesting has been outlawed and all current harvesting is done in a traditional manner by hand. In terms of cultivation, a range of techniques are available (see below). However, at present seaweed is not being commercially cultivated in either the UK or Ireland. Nevertheless, seaweed cultivation has a long history globally and is currently produced in large volumes across Asia and America.

2.1. Harvesting natural stocks of seaweed

At present the kelp harvesting industry around the British Isles is relatively small despite there being significant numbers of kelp beds around the west coast of Ireland and Scotland [8]. The kelp species naturally occurring around the UK are also themselves relatively small (up to 3 m in length), with the main species including: Laminaria digitata (Oarweed; Tangle), Laminaria hyperborea (Curvie), Laminaria ochroleuca (Bachelot de la Pylaie) and Laminaria saccharina (Sugarwrack) [9].

The main benefits of harvesting, relative to cultivation, are that the costs are much lower. Furthermore harvesting has been proven to be a successful method across Europe for other algae industries. In fact several of the stakeholder interviewees were of the opinion that algae cultivation in Western Europe is unnecessary due to the level of natural availability. A representative from a seaweed processing company commented that there is potential to obtain much more than their current annual harvest of 32 kt wet (8 kt dry) on the Galway coastline, taking a 4 year rotation into consideration to minimise the ecological impacts. This individual was also of the view that the algae market is currently saturated, such that harvest for fuel would not impact current consumers. However, concerns were raised by representatives of conservation bodies regarding the scale of harvesting that would be required for biomass production for fuel.

2.2. Cultivating Seaweed

Of approximately 200 species of seaweeds used worldwide, about 10 are intensively cultivated [7]. The kelp Laminaria japonica is currently the most important, with 4.2 million tonnes cultivated mainly in China [8]. World production of seaweeds was some 8 million tonnes in 2003 [7,10]. Outside Asia, the USA, Chile, Canada and some European countries have been among those attempting to establish large-scale seaweed cultivation[7,11–13]. Below we review some of the main management issues associated with cultivation.

3. Attributes of the marine environment

The differences between marine and terrestrial ecosystems have been reviewed by a number of authors [14,15–17]. These reviews have all been conducted within the context of conservation rather than the development of biofuels. However, many of the principles still apply. Table 1 takes Jones's (2001) summary of the ecological and management differences between terrestrial and marine environments and then adapts this, with a view to identifying implications for the development of marine bioenergy.

4. Cultivation challenges

As discussed above, if marine biomass is to make a serious contribution to fuel supply, artificial cultivation will be essential. Cultivation is predominately affected by four factors: economic feasibility; practical considerations (i.e., whether it is physically possible to cultivate seaweed in a locality); environmental impact; and governance and regulation. The extent to which these factors impact upon cultivation is in turn influenced by factors such as the species of seaweed selected, the method of cultivation, the selected location and the wider economic factors to which all renewable energy technologies are subject, such as expectations of fossil oil prices and changes in regulation.

Four approaches to seaweed cultivation are currently the subject of significant research in terms of their feasibility within the British and Irish contexts: inshore cultivation; inshore cultivation integrated with other aquaculture activities; offshore cultivation and offshore cultivation attached to wind farms. In the following sections the advantages and disadvantages of each are assessed.

4.1. Inshore cultivation

At present, inshore cultivation represents the most feasible and cost effective approach to producing marine biomass. This is due to a range of technical and economic factors, such as use of relatively sheltered sites to protect the crop from storm damage and strong currents, ease of access for monitoring and harvesting and low transport costs. Sporelings could in principle be grown on an industrial scale and sold as a ready to deploy product, reducing the cost associated with small scale production. In short, the activity is technically feasible, should a viable return on the investment be judged likely.

However, inshore cultivation is far from risk free. Even when careful consideration has been given to site selection, the weather and sea conditions can present a considerable problem; pilot projects in Ireland have suffered several occasions of tides and currents washing the long lines away [21]. Furthermore, even with the minimal transportation costs associated with inshore cultivation, there is concern that it will not prove economically viable unless the biomass production, processing and use are on a small, localised scale. The scale of production is a major issue with inshore cultivation as the available shoreline is limited and much of it is protected by legislation aimed at conserving the marine environment whilst in other areas a new use may cause conflict with existing stakeholders.

Despite these challenges it seems that, at least in the first instance, any attempt to upscale seaweed cultivation for marine biomass will focus on developing inshore production. As Kelly et al. [4] comments, all modern day commercial production and harvesting methods, including the vast tonnages produced in China, are grown inshore and on long line systems. This was supported by all the experts interviewed for this research and is summarised by one of the research scientists:

> Importantly, without successful demonstration of the use of inshore cultivation for biofuel production, it is unlikely that there is chance of the adoption of offshore techniques. There is a lack of data on trials of large scale cultivation for biomass leading to a lot of uncertainty and a lack of enthusiasm to proceed with projects. If techniques do move offshore with the encouragement of successful inshore cultivation, these inshore sites need not become obsolete as there are plenty of alternative uses for the macro-algae.

4.2. Integrated aquaculture

As outlined above inshore cultivation currently appears to be the most feasible approach for seaweed cultivation. That said, ensuring the economic viability of the crop and finding appropriate sites which do not conflict with other stakeholders still represents a significant challenge. One possible way to mitigate against at least some of these problems may be to combine seaweed cultivation with other forms of aquaculture. This

Table 1
Ecological and management differences between terrestrial and marine environments.

Difference between marine and terrestrial ecosystems	Implications for marine biofuel development
Ecological difference	
Scale – Marine ecosystems tend to be much larger, with less well defined boundaries.	It may be difficult to wholly contain the production of seaweed in a designated area. This could potentially lead to wider ecosystem change, such as that arising from invasive species, population spikes (e.g., grazers) and chemical control measures.
Connectivity – Areas that are spatially separated are more likely to be functionally connected in marine ecosystems.	The connectivity makes predicting any negative impacts of seaweed cultivation significantly harder. There are numerous examples of how an intervention in the marine environment can have an unpredictable impact on distant ecosystems – e.g., the indirect linkage of Alaskan over-fishing to kelp nursery loss and further fish stock depletion via a causality chain linking seals, sea lions, killer whales, sea otters and sea urchins [18].
Variability – Biological communities in the marine environment tend to exhibit particular variability or discontinuities due to a combination of biotic, abiotic and anthropogenic factors, the interaction between which are increased by the connectivity of the marine environment [19].	The effect of introducing an alien species is difficult to predict and consequently to manage the impact of. Furthermore, even cultivation of naturally occurring species may alter the natural biotic balance of an ecosystem with unpredictable consequences for the wider ecosystem.
Management differences	
Naturalness – Marine ecosystems are generally natural in management terms, in that they are rarely the result of positive human intervention. In contrast, some terrestrial habitats considered to be of high conservation value, e.g., moors, lowland heaths and meadows, are semi natural in that positive human intervention is necessary to preserve them in their modified state [20].	The introduction of seaweed cultivation is unlikely to have a positive impact on inshore ecosystems. However, if combined with other forms of aquaculture, it may mitigate against some of the negative effects of fish farming.
Limited scientific knowledge base – Our understanding of the structure and function of marine ecosystems is poor compared to that of terrestrial systems.	The limited scientific knowledge possessed about both the cultivation and harvesting of marine biomass coupled with poor understanding of marine ecosystems makes decision making regarding the sustainable development of marine biomass problematic. Consequently, it is likely that in countries with well-developed environmental legislation, the precautionary principle will be applied when creating a legislative framework. The application of the precautionary principle has already led to the banning of mechanical harvesting of seaweed in the UK and Ireland. Without reliable data on the potential impact of cultivation on natural ecosystems it is likely that legislation surrounding the cultivation of seaweed will be equally cautious.
The multiple use of coastal seas – On land different activities tend to occur in dedicated areas, interactions between which can be managed with relative ease; conflicts are generally based on competition between different users, e.g. agriculture and conservation. Disputes can often be resolved at a local or regional level. In contrast, inshore seas are characterised by a growing industry and diversity of multiple users within the same area, with different societal sectors perceiving such ecosystems to be valuable in different ways, often leading to conflict.	At first glance the marine environment may appear to be immense. However, the majority of users, e.g., commercial fisheries, fish farms, gravel extractors, oil and gas industries, recreational users, renewable energy developers, are all competing for space in the relatively limited coastal seas area. Consequently finding space to grow a commercially viable amount of seaweed for biomass is likely to be challenging and could potentially create further conflict between marine stakeholders.
The Alien nature of marine ecosystems – For humans to undertake any kind of activity in the marine environment highly specialist and often expensive equipment is required. Add to this the challenges posed by unpredictable weather and sea conditions, working in the marine environment can become logistically very difficult.	The specialist equipment required to set up, maintain and monitor marine biomass production means cost will be significantly higher than for land based developments. Furthermore, the unpredictable nature of the marine environment means that there are significant risks. Making marine biomass financially viable may limit cultivation to sheltered inlets only.

approach not only offers the opportunity improve the economic feasibility of cultivation and provide a possible location, it also potentially offers a range of other benefits to the local environment and aquaculture industry.

Existing fish farm sites are likely to have been chosen taking into account the lower risk of weather damage and with water conditions that would be mutually beneficial for the algae and fish. Integrated seaweed cultivation with fish farming also offers the possibility of using the seaweed as a form of bioremediation against the nutrient run off from the fish farm. In a cited example from Chile, a study using rope cultures of Gracilaria chilensis showed that macroalgae cultivated within 10 m a fish farm had a growth rate 40% higher than growth 150 m to 1 km away, and monitoring of the waters around the farm also showed little impact from the runoff [21]. The majority of experts in Ireland believed that this was by far the most feasible approach, especially due to the bioremediation effects of the algae, the possibility of using some of the seaweed to feed back to the fish and the possibility of additional financial return for existing farmers.

However, despite these potential benefits, interviewees were still cautious. In particular, concerns were raised about economic viability. All agreed that there is still a great deal of uncertainty regarding the cost of integrating macro-algae into existing aquaculture sites and whether the outlay would justify the financial return. Concerns were also raised about the scale of production that would be possible. The large amount of algae required for bioenergy is likely to outsize the area available around the fish farms as the fishers would need to maintain access to the fish pens. It is unlikely a single fish farmer could produce enough seaweed for a viable bioenergy project. Consequently a co-ordinated effort would be required by a number of separate local fish farmers.

4.3. Offshore cultivation

The primary advantage of offshore cultivation is that there is far less competition for space; although consideration still has to be given to ensuring navigation channels are not disrupted. Chynoweth [22] summarises the results from a number of tests offshore of North America, regarding a variety of methods for offshore cultivation. These included free-floating cultivation systems (dynamically positioned by ships) and systems anchored to the seabed or buoys. The problems identified were in many respects similar to the challenges identified with inshore production, but were further aggravated by the lack of shelter and even more extreme weather conditions experienced offshore. A typical problem was that anchors were lost, causing the line system to get tangled. Circular ring structures (15 m diameter) were also tested, and found to be well-suited for the cultivation of Macrocystis (kelp) [7]. For floating seaweed species such as Sargassum a number of tests have been carried out (with limited success) of floating cultivation surrounded by a structure intended to keep the seaweed confined. This could potentially lead to significant cost-savings compared to line-based systems [7].

One of the challenges is providing fertilisation for the cultivated macro algae, and artificial upwelling of nutrients was demonstrated to work with two 0.2 ha grid structures in California [21]. However, the research scientists interviewed were not convinced that this could be recreated cost effectively on a larger scale. Maintenance of sites would be a lot more difficult as transport costs, greenhouse gas emissions and poor working conditions would have to be factored in. As with inshore cultivation, before any firm conclusions can be drawn, large scale pilot operations are required to assess the impacts, yield and cost effectiveness.

Aside from the above, there has been relatively little research into offshore cultivation and there was little support for the concept from the experts interviewed, primarily due to the technical challenges. In short, all of the additional considerations highlighted in Table 1 related to operating in the marine environment are magnified when working offshore. In particular the limited scientific knowledge base is even smaller, making predicting the potential impact of cultivation significantly less reliable. This was highlighted many times during the interviews, with one of the research scientists observing: 'I'm not convinced the technology is there to go offshore, very, very little work has been done'.

4.4. Offshore wind farm cultivation

In recent years several projects have referred to the potential of developing aquaculture facilities in conjunction with offshore wind farms. Using wind turbines as structures on which to base seaweed cultivation, potentially offers significant benefits over the development of new, purpose-built structures [11–13,22]. The experts interviewed also indicated that this approach was worthy of further investigation.

Notably, maintenance costs may be reduced with integration of wind farm and offshore cultivation, as it may be possible to schedule routine maintenance of cultivation infrastructure alongside the maintenance of the wind farm. One of the government representatives interviewed also noted that wind farm locations are also already well monitored and surveyed:

> ... what people have proposed is basically backpacking off the existing offshore wind farm infrastructure, furthermore, it may be one of the ways to get around the social acceptance of the offshore aquaculture.

However, the experts also identified a number of challenges that would need to be overcome:

- The need for access to the wind farm may lead to a reduction in crop yields as supply channels would need to be kept open around the turbines (Government Official). At the very least, ensuring access while at the same time using wind turbine installations as mounting points for lines will require careful zoning.
- Wind farm companies may not be willing to invest in marine biomass or allow others to use their infrastructure (Government Official).

In addition, a report from Sustainable Energy Ireland (SEI) notes that at present it is not known whether the levels of salinity, turbidity and other conditions surrounding wind farms would be able to support productive algae production so further research is required [21].

5. Environmental impacts

The magnitude of the environmental impacts of macro-algae cultivation or harvest will largely depend on the chosen methods, the size of the affected area and the demographics of the seaweed population. In addition, the carbon emissions from transporting the algae to the processing plant, oven drying the algae for processing, and maintenance of the crop and associated equipment all need to be considered. Clearly, the greater the distance between the cultivation and processing sites the higher the carbon emissions will be. Nonetheless, scoping life cycle analysis does indicate that use of macro-algae for the production of biogas for power and heat via anaerobic digestion can lead to substantial greenhouse gas reductions in the order of 78–91%[5]. Another, factor which needs to be taken into consideration is the disposal of post processing residues. As the SEI report points out, landfill disposal would not be sustainable [20]. That said, it may be possible to recover nutrients from the residues to fertilise cultivated algae, creating a 'closed loop' nutrient life cycle and reducing the need for waste disposal [21].

In terms of the environmental impacts of the specific cultivation and harvesting methods, only very limited work has been done, consequently, as pointed out by several of the interviewees, it is essential that a precautionary approach is adopted regardless of the method used.

5.1. Cultivation

A number of general concerns regarding the cultivation of seaweed have been identified. Of particular importance is the selection of species for cultivation: in the absence of understanding the likely broader impacts of macro algae production a precautionary approach would be to only cultivate indigenous species to minimise the risk of disrupting local ecosystems. Using indigenous species is not the only factor which needs to be considered and will not guarantee that no disruption will occur. For instance, consideration needs to be given to the size of aquaculture developments. Two of the research scientists pointed out if the area covered is too large it may have an impact on the hydrodynamics of the area, increasing the risk of monocultures spreading pests and disease. In addition, if the amount of algae in the ecosystem is increased, there will be a higher chance of eutrophication as the algae decomposes.

It is also worth noting that many of these potential environmental impacts may be mitigated if cultivation occurs in conjunction with fish farms and other types of aquaculture. There was a consensus amongst the interviewees that this technique represents the most promising way of developing the technology in the near future, due to the bioremediation of nutrient run off from the fish farms by the algae. Moreover, the nutrients remediated by the algae would lead to increased yield of algae. One of the research scientists went even further, suggesting that the cultivation of seaweed around fish farms would actually be far more environmentally beneficial than if cultivation did not occur at all. Furthermore, it looks increasingly likely that in the future fish farm developments will be required to demonstrate a nutrient remediation strategy before licences are granted – this is already the case in Denmark.

5.2. Harvesting

At present the impact of the harvesting of wild stocks of seaweed on the West coast of Ireland is likely to be minimal, as hand cutting methods are used rather than dredging technologies. However, the representatives from industry currently exploiting seaweed resources all agreed that if harvested seaweed is to be used for biofuel production, it would not be economically viable to rely solely on hand harvesting. There is some debate regarding the environmental impact of mechanical harvesting: the technique is currently banned in the UK and Ireland but is used in other parts of Europe such as France and Norway. In both France and Norway seaweed harvesting is heavily regulated with only a limited number of licences granted each year. In Norway, the legislation goes further requiring areas to be left fallow for six years between harvests [23].

There was a consensus amongst the interviewees that mechanical harvesting would have a greater impact than hand harvesting, but that the impacts would not be as damaging as occurs through the dredging used in other aquaculture industries, such as scallop fishing, as dredging would not be used and the rocky sea floor where algae is harvested would not be destroyed. Interviewees also agreed that the evidence from Europe suggests that mechanical harvesting could in principle be undertaken sustainably, providing it is properly regulated. That said, they also made it very clear, that despite the positive evidence from Europe, extensive trials and monitoring would be required locally before a sustainable harvesting policy could be developed.

6. Governance challenges

There are a significant number of technical, economic and practical challenges associated with the development of a marine biofuels industry. However, there was a consensus amongst the interviewed stakeholders that, with more research and additional funding, the majority of these could be overcome. They were far more pessimistic about the situation in relation to the governance challenges that are currently hampering both the cultivation and harvest of seaweed. All the experts agreed that a significant shift in legislation and attitudes towards algae cultivation is required if there is to be any chance of a biofuel industry based on marine biomass within the next 10–15 years. Two central problems were perceived as preventing the further development of the seaweed industry in Ireland and the UK: legislative restrictions imposed from Europe and a lack of knowledge and awareness amongst policy makers.

At present it is extremely difficult to obtain a licence for any type of marine aquaculture in the Ireland or the UK, due to concerns about the environmental impact and the cost of conducting a full environmental impact assessment. Despite algae cultivation and (to a lesser extent) harvest being relatively benign compared to the other types of aquaculture, it is currently governed under the same legislation as other, potentially more damaging types of aquaculture, such as fish farming. There was a consensus amongst the experts that legislation should be adapted to include a separate classification for seaweed cultivation, making it easier to obtain a licence; however, at present this seems unlikely.

All the experts agreed that the blanket ban on the use of all mechanical harvesting technologies was a major barrier to the expansion of the seaweed industry and the development of a sustainable and economically viable marine biofuels industry. This was highlighted by the frequently quoted example of a local cosmetics company who imported huge quantities of Lithothamnium from Iceland, despite its local abundance.

The European Habitats directive which initiated the designation of Marine Special Areas of Conservation (MSACs) represents the biggest governance challenge to both the inshore cultivation and harvest of seaweed. MSACs dominate the coast of Ireland and provide essential protection to marine and intertidal ecosystems. However, the legislation also makes gaining permission for new activities and developments (regardless of their environmental impact) extremely difficult to obtain. Any plan/project which may affect the integrity of the MSAC has to be thoroughly assessed through a comprehensive survey approved by the statutory conservation agency. If the impacts are found to be significant, the plan/project can only go ahead if there are no alternatives or if there are imperative reasons of overriding public interest (these can include social and economic consideration) and an appropriate compensatory habitat has been created. In recent years a number of attempts have been made to gain permission for small scale seaweed cultivation trials, but these have been denied and described as ‘development by stealth’. That said, two of the experts did suggest that gaining permission for cultivation trials might be significantly easier if they were integrated with existing aquaculture developments. It is also worth noting that the vast majority of governance challenges predominately affect inshore waters: most of the protected areas around both the Irish and British coastline occur between 0 and 12 nautical miles from the shore. Consequently, from a purely legal perspective, if not a practical one, it may be preferable to cultivate seaweed further offshore.

The experts also noted that they thought the lack of knowledge and awareness surrounding the potential of seaweed in general and more specifically marine biomass meant that policy makers were nervous of the issue and hence unwilling to engage in the debate. Five of the experts explicitly stated that they recognised that they need to put more effort into communicating with policymakers and into ensuring that policymakers had the best and most up-to-date information with which to inform their decision making. The generally pessimistic views of the governance challenges associated with the development of marine biomass were summed up by one of the experts:

> ‘‘I believe that aquaculture is too intrusive in the marine space, visually, from the point of navigation, from a point of fishing, tourism. It’s too intrusive to ever be allowed to be developed to extent at which it would be commercially viable, especially for biomass issues because you need a big volume y mechanical extraction will never be authorised in Ireland.’’(Industry representative)

7. Social and public perception challenges

There is a sizeable body of literature highlighting the role of public perceptions in the context of low carbon energy technologies and a developing literature specific to public perceptions of marine energy technologies [24–27]. Ironically it is, at least in part, concern about public opposition that has led to the growing interest in the development of marine based technologies, which are by their very nature removed from centres of population. However, the marine-focussed studies indicate that public perception issues can still be important, particularly in relation to the impact of new developments on seascapes, navigation and marine environmental quality [24,25,27–29].

To date very little has been written specifically about the social/public perceptions challenges associated with expanding the seaweed industry for the development of marine biofuel or bioenergy. However, all the experts interviewed for this study have extensive experience working in the communities which are likely to be impacted by any expansion and were able to offer an insight into some of the issues which may arise. Furthermore, the existing literature on other marine low carbon energy also provides an insight into possible areas of concern.

It was noted on numerous occasions that if significant levels of public opposition were to occur in response to the further development of the seaweed industry, this was likely to predominately affect developments within inshore waters which would be visible from the land and could potentially impact other marine users.

In terms of visual impact, the experts all agreed that the impact of cultivation on seascapes would be very similar to the mussel farms that already exist in the waters around Scotland and Ireland. Furthermore, a number of the experts commented that 'smart farm' technology could be employed which would significantly reduce the number of buoys visible from shore. Evidence from studies of public perceptions of energy technologies in the marine environment indicate that this might be important, as concerns have previously been raised regarding the use of lighting and buoy markers used to delineate exclusion zones around installations. These may disturb place attachments if visible from the shore [24].

Possibly harder to mitigate against are the impacts on navigation, one of the most controversial issues arising from the consultation process on the Cornish Wave Hub (a seabed-based electrical interconnector) in Southwest England was the potential impact on navigation in the area, for which there are numerous influential maritime stakeholders including the Cornish Fish Producers Organisation and the Chamber of Shipping and Trinity House (the General Lighthouse Authority) [25]. Furthermore, other studies have demonstrated that closing off areas for offshore wind farms has caused significant conflict with the fishing industry. In particular compensation appears to be a particularly difficult issue to solve as fishers and offshore wind farm developers often had contrasting views on the form and level of appropriate compensation, as well as on the consultation process through which this was achieved – resulting at times in fierce distrust and conflict [30]. Although it is not anticipated that seaweed cultivation would create as much disruption as the installation of wind farms, the experts interviewed anticipated that at least some conflict with other maritime stakeholders should be expected.

Despite these perception challenges, the development of a marine biomass industry does potentially offer a number of benefits for coastal communities, notably job creation and business opportunities. This would likely prove welcome, providing the other conflicts referred to above can be managed, as rural coastal communities have typically suffered economic problems as a result of declining fishing industries. Indeed a number of the stakeholders commented that the potential to create jobs and develop new seaweed-based industries has the support of many MPs in the Irish parliament, who have expressed frustration at the bureaucratic nature of the application process for algae cultivation and harvest.

While one of the research scientists pointed out that many of the new jobs would only be seasonal, other experts suggested this may not necessarily be a problem, as many people in rural coastal communities still rely on the traditional Longshore economy and change jobs with the seasons in any case. Similarly, working in an expanded seaweed industry would likely attract people who are already engaged in traditional occupations such as peat cutting, fishing and reed cutting. Becoming economically involved with seaweed production may also be a welcome extra source of income for fish farmers and could be relatively simple to set up if pre-cultured lines could be supplied ready for use. However, it would also be necessary to consider the cost and time needed for maintenance, along with the inconvenience of having restricted access to the fish pens.

On balance, there was a consensus amongst the experts that the 'positive' community benefits which could arise from the development of a marine biomass industry would outweigh the potentially negative public perception challenges. That said, it was also noted that many members of the fishing and algae harvesting community are traditionalists and may be very wary of new technological applications for their environment. Consequentially, open communication between the developer and the local community from an early stage would be essential if new developments were to be approved without having to overcome local opposition.

8. Concluding comments

There are considerable practical obstacles to the use of marine biomass for biofuels and bioenergy. As production moves further from the shore, the technical challenges are amplified, though legislative compliance problems may decrease. Above all, the relative availability and price of alternative fuel options, and the policy frameworks that shape these, will remain strongly influential on the prospects for a sector that the UK and Ireland has yet to commercialise. This paper has scoped the main practical policy issues, informed by a range of opinion, as a complement to a growing literature on the technical aspects of macro-algae cultivation and processing for fuel. Of the options considered, integrating long-line seaweed cultivation with fish aquaculture for subsequent anaerobic digestion may be the most environmentally benign. By contrast, mechanical harvesting remains contentious, with academic researchers cautious and views divided.

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