Bioenergy from Macroalgae: Some Costs and Benefits

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A significant drawback of many bioenergy sources is that energy crops displace alternative land use, such as for food. Responding to this criticism seaweed has been suggested as a source of next generation bioenergy. It is harvested and cultivated on a commercial scale in several countries in Europe (Norway, France), Asia (China, Japan) and South-America (Chile), but in most coastal areas it is relatively underexploited and therefore offers an appealing prospect: at least in principle.

Significant resources will not be devoted to the development and application of this potential energy source unless rigorous appraisal has suggested there may be positive social net benefits from its implementation. In this paper we seek to contribute to such appraisal by conducting a Cost Benefit Analysis (CBA). This is not complicated in principle, given that detailed information on how to conduct cost benefit analyses is widely available in textbooks. However, in practice, this raises some challenges. In particular, as the production sector does not exist any analysis is bound to be somewhat speculative as a result. Seaweed is harvested and cultivated for various uses around the World and various technologies are used to extract energy from biomass. However, these functions have (to the best of the authors' knowledge) yet to be combined. Recent surveys bring together a digest of publicly available knowledge on the subject (Bruford et al 2009, Kelly & Dworjanyn 2008, Lewis et al 2011). Hermannsson & Swales (2013a) summarise the potential energy capacity for the sector in Scotland and conduct an investment appraisal, while Hermannsson & Swales (2013b) estimate the local employment impact for a potential marine bioenergy plant in the Western Isles and its capacity to save carbon emissions. We shall draw on these and other sources to address what are the social costs and benefits associated with a hypothetical production of electricity from macroalage in the Western Isles.

In practice, a new sector producing bioenergy from seaweed could emerge in a number of incarnations, depending on how the seaweed is sourced and what technology is used to convert it into energy. Here we assume that the feedstock is obtained from wild harvesting and draw on the wide range of information on the potential of such an operation provided in Kelly & Dworjanyn (2008). Furthermore, we assume that anaerobic digestion will be used to convert the seaweed into biogas and subsequently electricity. This draws on the findings of Lewis et al (2011) who conclude this processing technology is closest to commercial viability at the current state of technology.

The Western Isles, or Eileen Siar in Gaelic, is a council area in the Hebrides of the west coast of Scotland. In 2011 the community counted just over 26 thousand inhabitants residing on 14 islands. Due to a convergence of technical, natural and knowledge capabilities the community in the isles is uniquely situated to pioneer the use of seaweed for production of bioenergy. The islands are situated in waters that produce large quantities of seaweed (macroalgae) that is suitable as marine biomass for energy production. There is already an anaerobic digestion facility in operation in the islands that is used to dispose of household waste and produces both heat and bioenergy as its outputs. Furthermore, there is a wide range of know-how in existing marine-focussed sectors, such as fisheries and aquaculture, that can be drawn on in the development of an algae harvesting sector.

Of the seaweed habitats around the coast of Scotland approximately 1,000km^2 provide sufficient densities to be commercially harvestable. Approximately a fifth of these are around the Western Isles. Based on sustainable harvesting, seaweed could power more than 2,000 homes in the islands or just over a fifth of the homes in the community. The economic, social and environmental benefits of this are potentially significant.

Cost Benefit Analysis

Cost Benefit Analysis (CBA) is a policy appraisal tool frequently used for decision making, particularly on public policy issues. To this end public bodies maintain manuals on CBA and other appraisal tools, such as the UK Treasury's Green Book (with various supplements such as on GHG emissions and climate change) and the European Commission (Florio et al, 2008). CBA has its theoretical foundations in welfare economics and has been an active research field for several decades. CBA is the subject of several textbooks, for instance Layard & Glaister (1994). Hanley & Spash (1993) focusses on the application of CBA to environmental issues and provides a historical overview of the subject. CBA has been applied to a number of renewable energy cases (for an overview see Allan et al (2013)). A useful example to build on for this study is Moran & Sherrington (2007), which conducts a CBA analysis of a proposal for a large wind farm in Scotland's Clyde Valley.

The mechanics of Cost Benefit Analysis resemble those of simple investment appraisal (see Hermannsson & Swales (2013b)) in that it involves projecting a future stream of net-flows and discounting this to a base year value. This can then be used for decision making by first of all making sure that net benefits are greater than zero and furthermore for rival projects comparing net benefits to the identically calculated outcomes for other potential projects. Although sharing the same essential mechanics investment appraisal and CBA diverge in their scope. Whereas financial evaluation establishes a net present value based entirely on projected cash flows, CBA seeks to establish a net project value by summing a discounted series of projected net benefits. That is to say, the market value of benefits and costs are used when available, but for non-pecuniary items a range of methods are used to estimate monetary equivalent values for comparison on equal footing. In short, where monetary estimates are available for all relevant costs and benefits the Net Project Value (NPV) can be calculated as:

$$NPV = \sum_{t=1}^{N} \frac{B_t - C_t}{(1+r)^t}$$

Where B_t and C_t are the monetary value of benefits and costs at time t, respectively, N is the number of periods and r is the discount rate.

Scenario + Capacity

Hermannsson & Swales (2013a) estimate the energy potential and review the financial viability of using wild harvested seaweed as input for anaerobic digestion for energy production in the UK. Hermannsson & Swales (2013b) build on this analysis to explore the economic and emissions impact of establishing a harvesting operation for AD in the Western Islands. In this section we draw on these studies to outline a simple scenario for a cost benefit analysis of a hypothetical project where seaweed would be harvested as feedstock for anaerobic digestion in the Western Isles of Scotland.

1.1 Energy from marine biomass in the Western Isles

Macroalgae, or seaweed as it is more commonly known, is harvested wild or cultivated for various uses around the World. Around the British Isles seaweed has been put to various uses at different times, depending on availability and price of substitutes. Following the Second World War, resource scarcities stimulated comprehensive survey work of the extent and nature of seaweed forests around the coasts of Great Britain (Walker 1947ab, 1954ab). Recently, this interest has been revived as seaweed is seen as a potentially bountiful source of biomass for energy production. This has sparked research activity, which is summarised in several recent publications. Kelly & Dworanjin (2008) review evidence on the extent of harvestable macroalgae off the UK coasts and explore the potential for using it as a feedstock for producing bioagas via anaerobic digestion. Bruton et al (2009) examine the potential of marine algae as a source of biofuel in Ireland and Lewis et al (2011) review and compare options for the commercial utilisation of macroalgae in the UK. Hermannsson and Swales (2013a) draw on available evidence to estimate the energy potential from sustainable harvesting of wild seaweed in UK waters and examine the feasibility of harvesting seaweed off the Western Isles for local bioenergy production.

An anaerobic digester is a facility where organic matter (e.g. household waste, farm waste, and bio crops) is decomposed to form biogas (a mixture of methane, CO2 and other gases) that can be used for electricity generation, heating or input into further processing. The Western Isles council has already invested in an AD facility for refuse disposal as landfill options are severely limited by the isles' geography. With this investment already in place the Western Isles are ideally placed to pilot the anaerobic digestion of seaweed on a commercial scale.

Surveying available evidence Kelly & Dworjanyn (2008) conclude that in UK waters there are approximately 1,000km^2 of habitat where seaweed can be found in sufficient densities to be harvestable. If we focus exclusively on the Western Isles, the macro algae estimated to be harvestable there is approximately 18% of the total in UK waters (Kelly & Dworjanyn, 2008, Table 4.1, p. 48) or 180km^2.

Given available information we can estimate the potential sustainable harvest of seaweed around the Western Isles. We have 180 km^2 of seaweed forests in harvestable densities. Each plot can be harvested on average every 5th year[ii] so that every year we can expect to harvest from 36km^2 of water. As every m^2 will yield 3.7 kg, each km^2 will yield 3,700 tonnes (3.7kg x 1,000m^2 /1000). Hence for 36km^2 we can expect an annual harvest of about 133,200 tonnes[iii].

Hermannsson & Swales (2012) draw on information from Kelly & Dworjanyn (2008, Table 5.3, p. 73) to deduce the energy yield per tonne of seaweed. If the seaweed is anaerobically digested to produce biogas, which in turn is used to generate electricity each wet tonne of seaweed can be used to produce 64.26 kWh of electricity

Based on our previous estimates of potential wild harvest our annual energy yield could therefore equal 133, 200t × 64.26 kWh/t = 8,559,432 kWh/yr. To put this into context OFGEM reports that an average home consumes 3,300kWh of electricity per year and therefore the Western Isles seaweed harvest could potentially support the electricity consumption of 2,594 homes. According to the General Registrar for Scotland there were 12,208 households in the Western Isles in 2011. Therefore, seaweed could potentially provide electricity for 21.3% of households in the isles. This locally produced energy could be used to substitute imports of energy to the islands or exported to the UK grid. In either case, it is a significant boost to the local economy.

1.2 Assumptions

To carry out the cost benefit analysis a scenario is defined based on a set of basic assumptions:

- We assume anaerobic digestion (AD) will be used to produce electricity and heat in a combined facility in the Western Isles
- The feedstock will be obtained from wild harvesting
- We assume this will require no new investment due to the presence of an existing AD-facility (with available spare capacity) and use of existing capital in the fisheries sector for harvesting.
- We apply a mid-range of estimates for market price of inputted seaweed (£200). See Hermannsson & Swales (2013a). This represents the cost of harvesting the seaweed.
- We assume a 3.5% discount rate following the Green Book.
- We assume no operating cost of AD facility at the margin, as existing costs are covered by current refuse disposal operation.
- Furthermore, operating costs occur only in harvesting sector and we assume these are fully covered by the input price of £200 per dry tonne (or £20 per wet tonne).

Estimating the costs and benefits

A range of potential private and social benefits of the project are identified below along with their likely sign in Table 1 below. We shall discuss each of these in turn.

Table 3 Private and social impacts identified for Cost Benefit Analysis

Private impacts	Social impacts
Market income (+)	Subsidy (-)
Subsidy (+)	Avoided emissions (+)
Investment (-)	Ecological impacts (-)
Operating costs (-)	Local employment (+)
	Green credentials (+)

The private impacts include the earnings of the project from selling energy in the market and the FIT and RHI subsidies received for providing green energy. The negative private impacts include the required initial outlays (assumed to be zero) and the operating costs over the project's lifetime. On the social impact side we deduct the subsidies provided, in order to avoid double counting and instead add back an estimate for the value of avoided GHG emissions. For this estimate we follow the approach of Moran & Sherrington (2007), by applying estimates commissioned by HM treasury (Clarkson & Deys, 2002) for the cost of climate change attributable to each tonne of CO_2 equivalent GHG emissions. A GDP deflator is used to convert these to 2012 prices. This figure is subject to significant uncertainty and hence a range of estimates is used. These estimates increase by approximately £1 in each subsequent year to reflect increasing damage costs over time. The inflation adjusted base year values are reported in Table 2 below.

Table 4 Damage cost of carbon per tonne of carbon (C) and carbon dioxide (CO2) in 2002 and 2012 £ prices (own calculations based on Clarkson & Deys, 2002; Moram & Sherrington,2007).

	2002		2012	
	C	CO_2	C	CO_2
Low	35	9.5	45	12.1
Medium	70	19.1	89	24.3
High	140	38.1	178	48.5

1.3 Private and social net benefits

Our starting point for estimating the social net benefits of the project is the private investment appraisal conducted by Hermannsson & Swales (2013a, Table 2). The details of this scenario are reported in Table 3 below. As we noted earlier this scenario builds on the favourable (but plausible in this case) assumption that there is an AD facility in place and hence there are no investment or running costs incurred at the margin. However, the AD facility pays a market price to the harvesting sector, which drives its annual operating costs. As we can see, based on these assumptions the operation is close to breaking even and would require an additional subsidy of just under £15,000 per annum to sustain itself.

Moving beyond the potential of bioenergy from macroalgae as a standalone commercial venture we want to add to this calculation the present value of the costs and benefits of various non-pecuniary items, which are realised indirectly as a result of the enterprise.

As summarised in Table 1 there are a number of channels for which social impacts can occur, some positive and other negative. Here we assess the viability of the project when correcting for the double counting of subsidies and estimating a value for carbon saving. The results of this analysis as presented in Table 4 below. As we can see from this simple analysis, the project is not likely to provide a positive net social benefit and therefore should not be undertaken based on this criteria. However, there are a number of additional issues that need to be taken into account.

Table 5 Investment appraisal for the anaerobic digestion of harvested seaweed.

	Market input price, no investment or operating cost
AD Input	
Macro algae (kt (wet)/a)	25
Food waste (kt/a)	0
Expenditures	
Seaweed price (GBP dry tonne)	£200
Annual fixed operating costs	£0
Seaweed input cost	£500,000
Total expenditures	£500,000
Income	
Electricity (GBP)	£350,406
Heat (GBP)	£109,936
Fertiliser (GBP)	£25,000
Total income	£485,342
Annual free cash flow	-£14,658
Other assumptions	
WACC	3.5%
Project duration (n)	30
Investment (GBP)	£0
Estimated project outcome	
NPV (GBP)	-£269,591

Table 6 Net Project Benefit of AD based bioenergy from macroalgae based on a range of values for the social prices of avoided Greenhouse Gas Emissions (£).

		Low	**Medium**	**High**
Private impacts				
Market income	+	3,363,741	3,363,741	3,363,741
Subsidy	+	5,562,691	5,562,691	5,562,691
Investment	-	0	0	0
Operating costs	-	-9,196,023	-9,196,023	-9,196,023
Net private impacts		**-269,591**	**-269,591**	**-269,591**
Social Impact				
Subsidy	-	-5,562,691	-5,562,691	-5,562,691
Avoided emissions	+	1,958,158	2,882,183	4,730,232
Net project benefit		**-3,874,124**	**-2,950,099**	**-1,102,050**

First of all we have not taken into account ecological impacts, which are beyond the scope of this study to analyse. Although it is difficult to make a judgement a priori, ecological impacts could be significant and could feed back into other livelihoods on the islands, such as collection of drift cast seaweeds. In any case harvesting is unlikely to proceed without first undergoing a thorough environmental impact assessment. Conversely, if a significant share of the community's energy needs were met by locally produced bioenergy this could enhance a perception of the Western Isles' environmental credentials. Although somewhat speculative, the possibility cannot be excluded that local export sectors could use that to their advantage, such as in marketing differentiation.

1.4 Employment impacts

An appealing aspect of this project, especially from the point of view of the local economy is its potential economic development impacts. These are analysed in Hermannsson & Swales (2013a). Although analysing a larger project, if their results are scaled down to conform to the assumptions underlying this analysis, the project could provide additional employment of 19 FTEs or 0.2% of total employment on the islands. Of course there are caveats that would need to be delved into further, such as potential employment crowding out. It would be useful to incorporate this development impact into the CBA. Scotland's island communities have struggled with depopulation like other peripheral communities for a long time. Maintaining these communities is therefore likely to have a positive value in the objective function of Scottish and UK governments. Furthermore, there is pressure on fisheries policies to come up with replacement jobs to meet fleet downsizing and therefore it is not inconceivable that such a project would be seen in favourable light at the EU-level. However, there are no widely accepted guidelines as how to value avoided depopulation in a CBA context and beyond the scope of this project to conduct research specifically on that methodological issue.

In the UK, however, there is a tradition of evaluating regional development assistance in terms of exchequer cost per job (see Swales 1992, 2005 for details). A simple approach would be to calculate this as the present value of the additional annual subsidy needed for the project to be viable as a standalone commercial entity and divide through with the number of FTE jobs attributed to the project. This would amount to £269,591/19=£14,189. A one off payment of approximately £14,000 per FTE job is likely to be considered a relatively low cost per job. Recently the National Audit Office calculated that the average cost per job for the English Regional Growth Fund amounted to £33,000[iv]

Conclusions

This paper carries out a simple Cost Benefit Analysis for a potential new bioenergy production where wild seaweed is harvested and used as feedstock for anaerobic digestion, producing both heat and electricity. We formulate our scenario based on the assumption that this would take place in the Scottish Western Isles, which are a favourable location for such a development. In particular the existence of an AD facility in the isles permits us to assume that such a project could be undertaken without having to incur additional investment or additional fixed operating costs. However, we assume that the project has to bear a full market cost for its inputted feedstock.

Under these assumptions the project is not economically viable as a standalone commercial venture, but it is also not far from breaking even. Allowing for social benefits through avoided Greenhouse Gas Emissions the project becomes less viable. That is to say, our estimates of the social value of avoided emissions are lower than the subsidies available to the operation (which are counted as part of the commercial analysis). However, the project drives significant local employment impacts and compares very favourably with other regional development initiatives in terms of costs per job.

In brief, our analysis suggests harvesting macroalgae for energy production is neither commercially feasible nor a cost effective way of avoiding greenhouse gas emissions. However, it could be a very cost effective way of diversifying and expanding the economy of peripheral region, with the side benefit of reducing GHG emissions.

These results should be regarded as tentative, and providing a justification for scrutinising such projects further, rather than a justification for implementing them, which would be premature. Various simplifying assumptions had to be adopted. Furthermore, there are potentially significant costs and benefits that this study was unable to quantify.

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[ii] For harvesting procedures Kelly & Dworanjyn (2008. p. 49) refer to Norway where algae are harvested for industrial use. As a rule of thumb a given patch can be harvested every 5th year, although this varies given the bio productivity of the waters.

[iii] See Kelly & Dworanjin (2008, p. 45).

[iv] For details see: http://www.bbc.co.uk/news/uk-politics-18024447