A Sustainability Analysis of UK Bioethanol Production from Farmed Seaweed

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Abstract

Growing environmentalism and energy demand in the UK has caused increasing interest in seaweed aquaculture, driven by research into algal biofuel technologies. Seaweed is a 3rd generation biofuel production whose cultivation does not compete with food crops for land and freshwater. Two types of seaweed, *L.digitata and G.amansii* were evaluated with the LCA to assess their suitability to replace 5% of the UK's fuel demand with seaweed-derived bioethanol. Our research model shows that using *G.amansii* biofuel reduces CO_2 and SO_2 release by 75% and 64% compared to *L.digitata*. Release of greenhouse gases was 0.930, 0.233 and 0.602 CO_2-eq/kg Eth for brown, red seaweed and lignocellulosic feedstock respectively, lower than first-generation biofuels above 1 CO_2-eq/kg Eth. However, fermentation requires nutrient input in form of nitrates and phosphates, which contributes significantly to eutrophication. Development of seaweed aquaculture was also limited by restricted information on operational costs, biomass yields and unspecified regulatory context. Facility cost is expected to be £138.47 million with operational costs of £139.305 million, significantly contributed by energy input from distillation making up 43% of operating costs alone. This produces bioethanol at £0.417/kg considering utilities only. A 5% blend results in additional £0.082 per kg of fuel. However, 1063 km^2 of sea and the construction of a new large processing plant in Port Glasgow would be necessary.

Introduction and Goals

- In recent years, climate change has become a hot-button issue, therein the search for renewable sustainable alternative fuels. First-generation biofuels required large landmass, competing with farm crops
- Third generation feedstock like macroalgae such as seaweed are a promising feedstock for bioethanol production since they do not compete for arable land or require fertilisers which cause eutrophication
- **This study aims to evaluate the technoeconomic and environmental feasibility of employing seaweed as part of the UK's bioethanol production strategy to meet 5% of road fuel demand (597485 tonnes).**

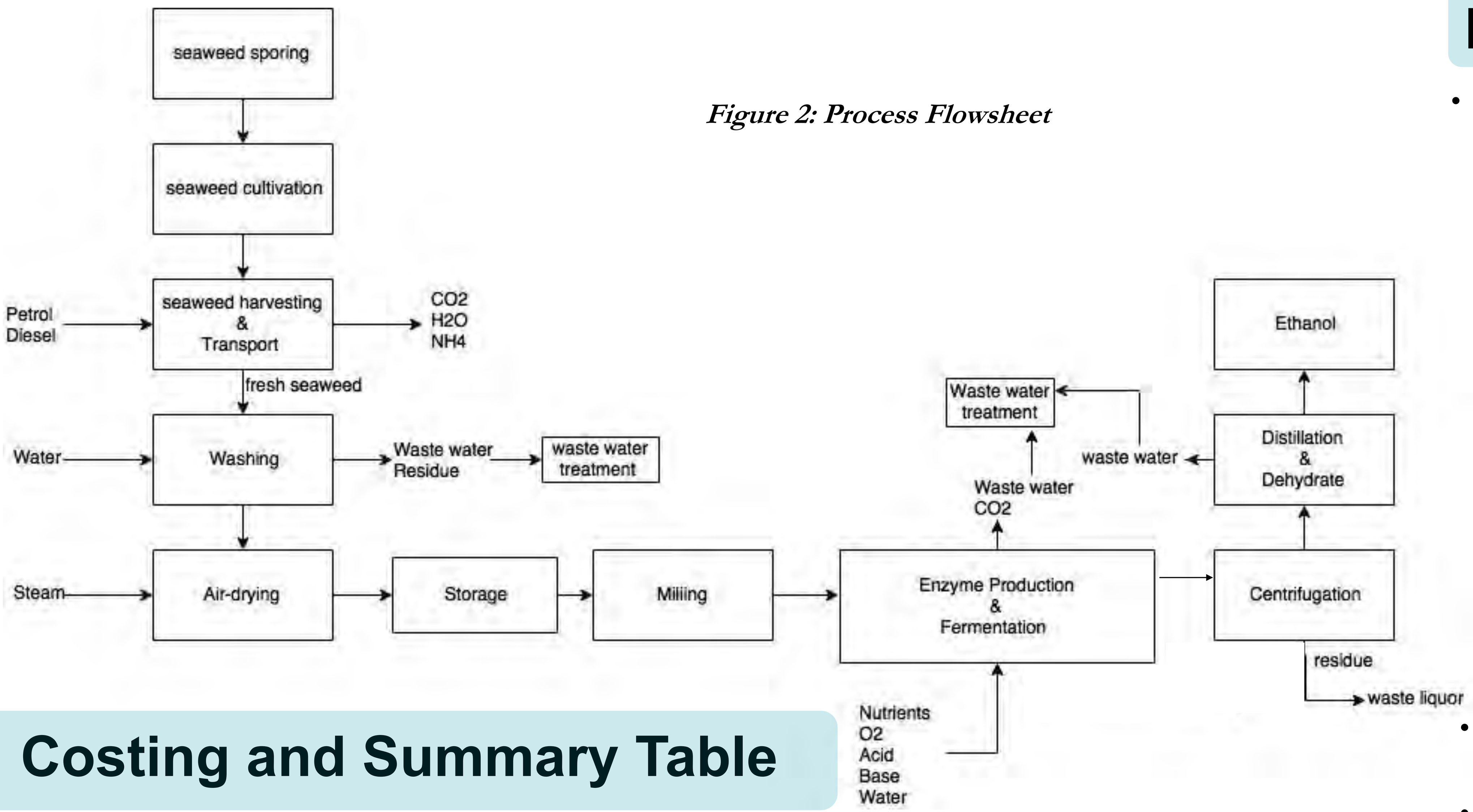

Figure 2: Process Flowsheet

Costing and Summary Table

Category	Value	Notes
Details of plant location	Port Glasgow	883,600 square meters total
Storage space required	800 square meters	
Total litres of ethanol that can be produced with current feedstock availability	757.37 million litres	Yearly
Yield of ethanol per tonne for biomass	0.281 tonnes	Assuming dry biomass (15% wet biomass)
Cost of ethanol per kg	£0.417/kg	
If blended at 5% with petrol, additional price per litre of fuel	£0.082/L	

Table 1: Key Findings Summary Table

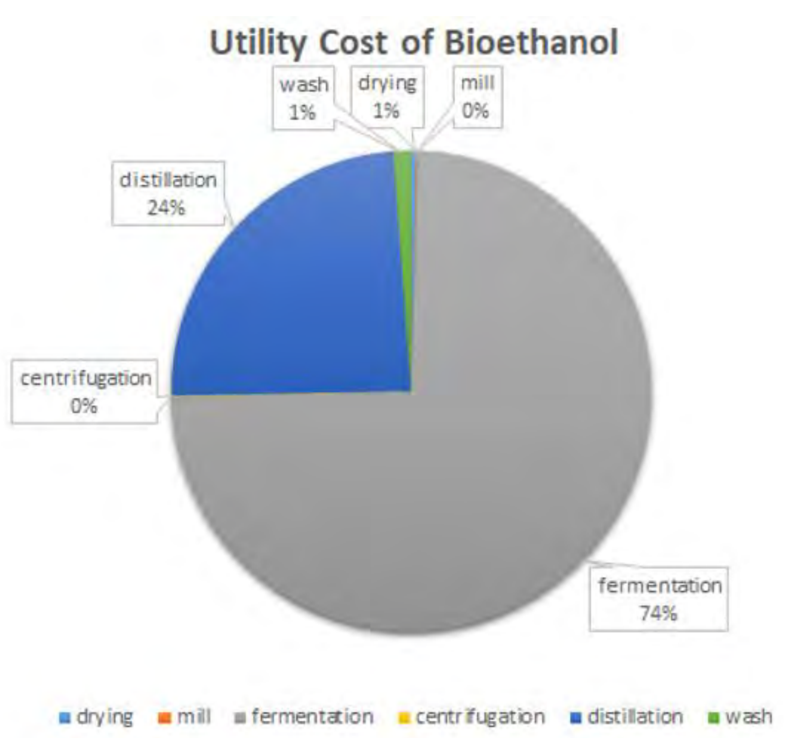

Figure 3: Costing Breakdown

Assumptions and Limitations:

- Not all peripheral components were included
- Extremely huge equipment used in the manufacture need to be customized and energy consumption is estimated from small-scale equipment.
- Existing studies analyse hypothetical scenarios based on experimental data extrapolated from laboratory results due to lack of large-scale operational data, therefore in reality these figures might change.

Scope and Methodology

- Scope of this study was the **cradle-to-gate** technoeconomic and environmental assessment of bioethanol production from chosen longline seaweed feedstock via Life Cycle Assessment (LCA) against other bio-derived fuels with a functional unit of **1 kg** of ethanol
- Our choices of cultivated brown seaweed species are ***Saccharina latissima*** (Sugar kelp) and ***Laminaria digitata*** (Oarweed) as they have a fast growth rate and are native to the western coast of Scotland
- Our factory will be located in **Port Glasgow** to conserve natural resources, for transport linkages and economies of scale
- Carbohydrate composition of seaweed (laminarin, cellulose, mannitol and alginate) **varies seasonally and yearly**, thus average carbohydrate composition between years was used for monthly predictions
- Harvest periods were selected by **optimal organism fermentation conditions** using carbohydrate composition

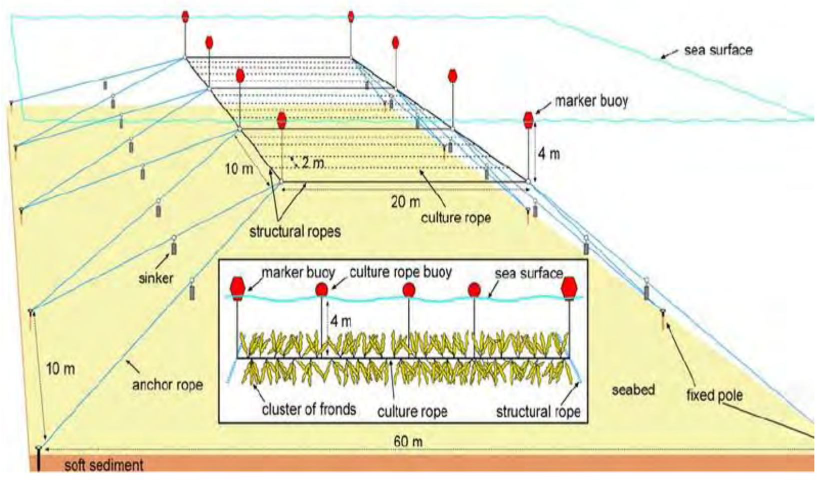

Figure 1: Longline Seaweed Cultivation Setup

- LCA analysis was carried out with SimaPro and compared with other biofuel types. A **second LCA analysis** was done with red seaweed species ***Gelidium amansii*** (Agar weed) to compare environmental impacts with different feedstock and fermentation methods
- Cost-analysis was also conducted to evaluate **economic feasibility** of bioethanol production, and increase in petrol prices if fuel is composed of 5% ethanol

Environmental Footprint and Analysis

- **Main assumption**: since feedstock data was unavailable from SimaPro, inventory data entered was based on equipment and material composition in cultivation and harvest of the seaweed, i.e. polypropylene ropes, boats made of wood and plastic fibres

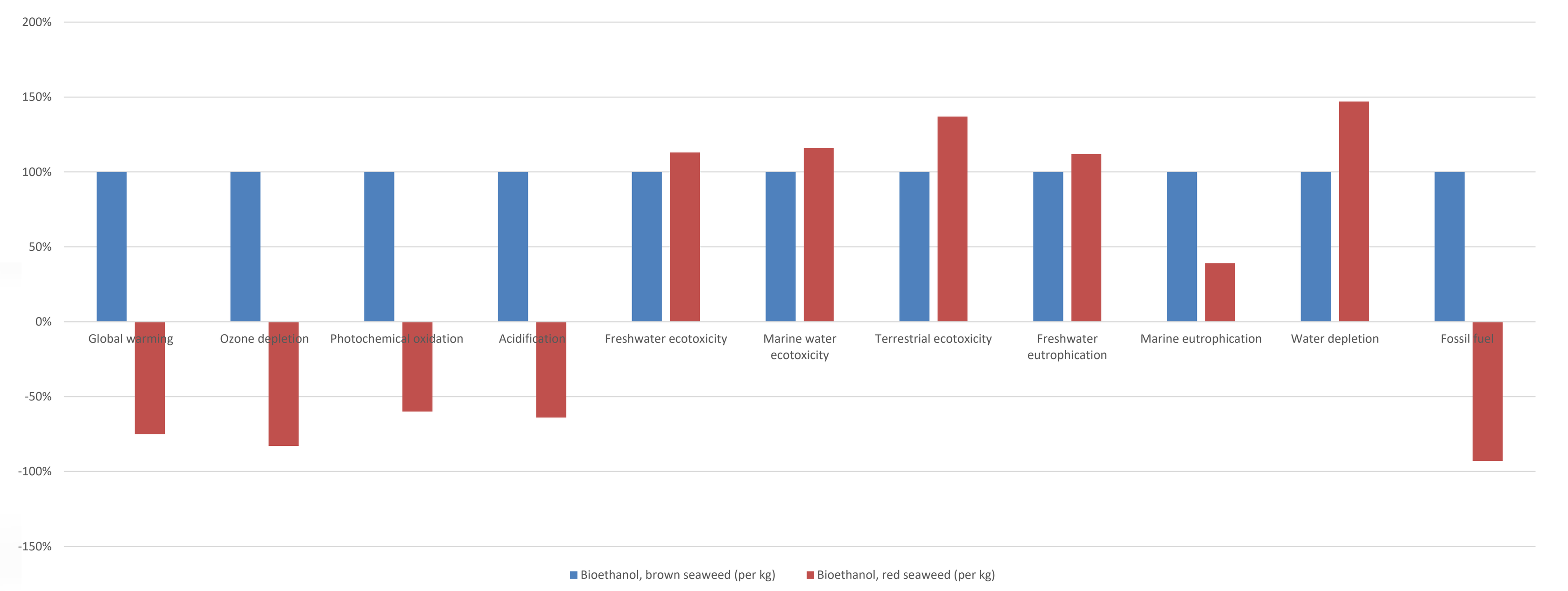

Figure 4: Comparison Between Environmental Impacts for Red and Brown Seaweed

- Significance is the resultant difference (%) of the impact categories with red seaweed compared to base case which uses brown seaweed.
- Alternative model of LCA using red seaweed as feedstock showed a further reduction of **64%** of kg of SO_2 released associated with acidification as well as **75%** reduction of CO2 released associated with global warming
- However, both process developments have high environmental impact for marine water ecotoxicity, terrestrial ecotoxicity and water depletion, possibly due to input of nitrates and phosphate as fermentation stock material or during cultivation.
- When selecting the best strain for cultivation, both brown and red seaweeds show benefits in different categories, therefore choices can be made based on nutrient availability and suitability of cultivation onsite

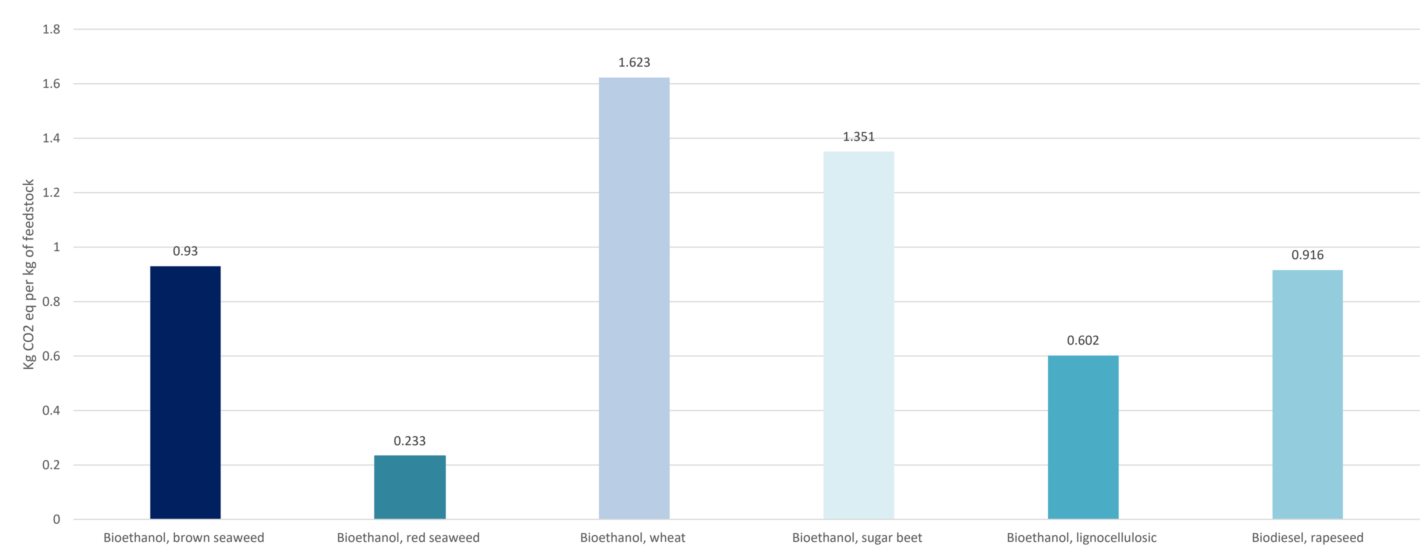

Figure 5: Greenhouse Gas Emissions Between First to Third Generation Feedstocks in the UK

Further Potential Improvements

- Different types of feedstock blends
- Heat integration for batch processes through pinch analysis
- Consider separate hydrolysis and fermentation (SHF) instead of Consolidated Bioprocessing (CBP)
- Compare impacts for different fuel types using engine fuel conversion efficiency

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