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II. Economic assessment for first generation green biorefinery (GBR): Scenarios for an Irish GBR blueprint☆

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ABSTRACT

Green biorefinery (GBR) is an alternative use of grassland biomass. GBR involves applying technology to chemically and physically fractionate (split) biomass such as grass and grass silage to produce marketable products. Three GBR system models were developed in a companion paper to determine, using scenario analysis, the most technically feasible scenario for the development of a blueprint Irish GBR system. The three GBR system models were a combination of feedstock system and biorefinery technology: Grass/silage – basic technology (GS), Silage – basic technology (S) and Silage – advanced technology (AT). The models were then assessed at different input volumes. The focus of this paper is on the development of the economic modelling component of the three GBR system models in order to identify which of the previously selected GBR scenarios is the most technically and economically viable to develop a blueprint for a first generation GBR. Six scenarios were assessed in this paper. The GS, S and AT GBR systems, at two input volume rates: medium volume and low volume. Additional scenario analyses were also carried out to investigate two possible production scenarios "No Prot" (fibre product only), and "Prot" (includes proteinaceous secondary product). Both the economic and technical scenario analyses of this paper and its companion paper suggest the most appropriate GBR systems for a first generation Irish blueprint are the combination of Silage feedstock – basic biorefinery technology (S), at the medium input volume and both "Prot" and "No Prot" systems.

1. Introduction

1.1. Alternative use of grassland biomass

Grasslands play an important role in global agriculture, covering about 69% of the world's agricultural area [1]. Interest in alternative uses of grasslands has been gaining momentum over the last decade or so, particularly in Europe [2]. Green biorefinery (GBR) is such an alternative use of grassland biomass. GBR involves applying technology to chemically and physically fractionate (split) biomass such as grass and grass silage [3] into two streams, press cake (the solid fibre fraction) and press juice (the liquid fraction). The press cake can be utilised for products such as insulation materials for building [4]. From the press juice the proteinaceous fraction (proteins, peptides, amino acids) can be extracted for applications such as animal feed or cosmetics. There is also great potential for extracting high value

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Nomenclature

a	annum
A	area supplying green biorefinery facility (ha)
AD	anaerobic digester
AT	advanced biorefinery technology scenario
Bipolar ED	bipolar membrane electrodialysis
BT	basic biorefinery technology scenario
CF	cash flow
CHP	combined heat and power plant
CP	proteinaceous fraction (e.g. proteins, peptides, amino acids, nitrate) of feedstock (kg t^{-1} DM)
CSO	Central Statistics Office (Ireland)
d	distance dependent part of transport costs (€ km^{-1} t^{-1} DM)
DM	dry matter
DM content	dry matter fraction (kg t^{-1} fresh matter)
FM	fresh matter
GBR	green biorefinery
GS	grass feedstock system – processing grass feedstock during summer (4 months) and silage for the rest of the year
h	hour
ha	hectares
HV	high volume input (or throughput) of feedstock processed by the green biorefinery (5 t DM h^{-1})
ir	interest rate (or discount rate) which reflects the risk associated with the investment (%)
IRR	the *ir* which results in an NPV = 0
K	potassium fertiliser (kg ha^{-1} a^{-1})
kWh	kilowatt hour
kW_e	kilowatts of electrical energy
L	distance independent part of transport costs for unloading (€ t^{-1} DM feedstock/€ t^{-1} slurry)
LV	low volume input (or throughput) of feedstock processed by the green biorefinery (0.2 t DM h^{-1})
LA	lactic acid fraction of silage feedstock
MJ	mega joules (1×10^6 J)
MV	medium volume input (or throughput) of feedstock processed by the green biorefinery (0.8 t DM h^{-1})
N	nitrogen fertiliser (kg ha^{-1} a^{-1})
$N{-}NH_4$	plant available nitrogen in waste slurries returned to fields supplying the green biorefinery facility (kg ha^{-1} a^{-1})
NDF	neutral detergent fibre fraction of feedstock (kg t^{-1} DM)
NO PROT	production scenario which produces fibre products alone as insulation material
NPV	net present value
min	minute (60 s)
ODM	organic dry matter = a term to group compounds such as water soluble components e.g. sugars, VFA (butyric acid, acetic acid, propionic acid), as well as the insoluble components fats, oils and smaller fibre fractions of the grass/silage feedstock (kg t^{-1} DM)
P	phosphorus fertiliser (kg ha^{-1} a^{-1})
PC	press cake – solid fraction of the refined grass or silage feedstock
Prot	production scenario which includes a secondary proteinaceous product as an animal feed
PJ	press juice – liquid fraction of the refined grass or silage feedstock
Q	feedstock quantity required for the 46 weeks of biorefinery operation (t DM a^{-1})
S	silage only system – processing silage feedstock for the 46 weeks of operation
t	tonne (1000 kg)
T	total transport costs (€)
TS	total solid content of the waste stream (%)
VDS	volatile dry solids (kg t^{-1} DM). It is the volatile solids expressed as a fraction of the stillage DM. It is the collective term for the organic matter in the sample (minus ash), that is readily used during anaerobic digestion
UF	ultra filtration membrane purification technology in AT scenarios
UASB	upwards flow anaerobic sludge blanket reactor
$W\ (mK)^{-1}$	watts per m K – indication of insulation properties
X	radius of the catchment area (km)
$\bar{X}$	average haul distance to the biorefinery facility (km)
Y	average grass yields of the catchment area (t DM ha^{-1} a^{-1})
τ	tortuosity factor, the relationship between the actual transport distance and the direct distance
η	electrical efficiency of the CHP unit (%)

biochemicals such as lactic acid, which can be used as a building block for plastic production (polylactic acid (PLA)). After extracting the desired fractions from the biomass the residual grass or silage slurries ('stillage') can then be fed into an anaerobic digester to produce biomethane gas, which is converted into electricity and heat [5].

1.2. *Key factors for developing a GBR blueprint for Irish grasslands*

A "Blueprint for an Irish GBR" has been proposed by O'Keeffe et al. [6], producing insulation materials from the grass fibre fraction and a proteinaceous product for animal feed from the grass juice fraction. Three GBR system models have been developed to generate scenarios to enable the selection of the most technically feasible Irish GBR scenario and are outlined in a companion paper [7]. The key factors identified for determining the most suitable GBR scenario were investigated. These include:

1) *Viable feedstock system – grass/silage (GS) or silage only (S)*: The GS system processed grass during the summer (4 months) and silage for the remainder of the year. The S system used silage only as the feedstock for the complete annual production [4,8].