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A bio-economic analysis of a sustainable agricultural transition using green biorefinery

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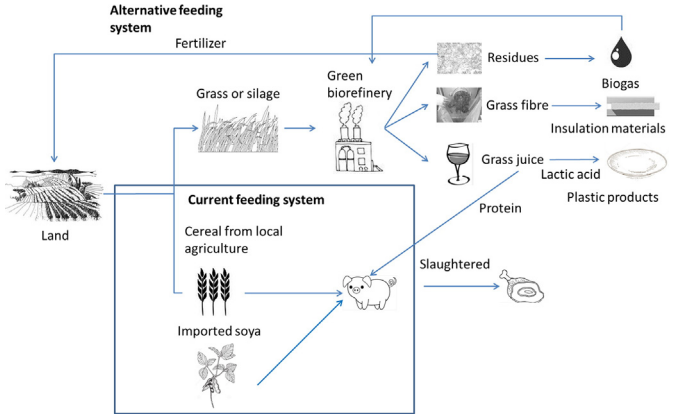
HIGHLIGHTS

- We explore potentials of grass protein from GBR to substitute cereals in pig feed.
- Life-cycle analysis is combined with cost-benefit analysis to analyze the effects.
- Using grass protein can be economically feasible for both pig farmers and GBR.
- Using grass protein in pig feed can reduce NO_3 emissions but increase N_2O emissions.
- We discuss the diseconomy of scale in GBR investment and possible policy support.

GRAPHICAL ABSTRACT



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ABSTRACT

Traditional pig production often relies on cereal-based feed, which has adverse environmental effects, e.g. nitrogen leaching and greenhouse gas (GHG) emissions. Alternative production systems are therefore sought to improve the sustainability of pig production. A promising alternative is to use proteinaceous feed from grass, produced in a green bio-refinery (GBR), to substitute part of the cereals in the feed. Cultivation of grass on arable land can reduce nitrogen leaching and pesticide application, and increase carbon storage. The GBR using grass as feedstock also produces valuable byproducts, e.g. fibre and biogas. In this study we combine a life-cycle analysis (LCA) and a cost-benefit analysis to compare the economic and environmental effects of producing the pig feed to produce 1 ton of pork using two feeding systems. We apply this approach to the intensive Danish pork production as a case study. The results show that compared with traditional cereal-based feeding system for producing a ton of pork, using proteinaceous concentrate from small-scale GBR will (1) decrease the average feed cost by 5.01%; (2) produce a profit of 96 € before tax in the GBR; and (3) decrease the nitrogen leaching (NO_3-N) by 28.2%. However, in most of the scenarios (except for G2), the nitrogen emissions into the air (N_2O-N) will also increase because of the increased N fertilizer application compared to a cereal-based system. In most of the scenarios (except for S1 and G1), the energy and land use will also be saved. However, some important factors, e.g. the soil characteristics, pressed juice fraction in fresh biomass and scale of GBR, could subvert the conclusion about energy and land use saving in the alternative feeding system.

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Nomenclature

AT	advanced technology
BT	basic technology
CBA	cost benefit analysis
DM	dry matter
FCR	feed conversion ratio
FM	fresh matter
GBR	green biorefinery
GHG	greenhouse gas
GS	grass/silage as feedstock
HV	high volume
LCA	life cycle analysis
LV	low volume
MJ	megajoules
MV	medium volume
N	nitrogen
P	phosphorus
PJ	press juice
PC	press cake
S	using only silage as feedstock
WOI	weaning-to-oestrus interval

1. Introduction

Agriculture occupies approximately 60% of the land in Denmark. More than 50% of the agricultural land is allocated to the production of cereal grain and 77% of the cereal area is used for animal feed. Despite the significant allocation of land to feed production, Denmark imports approximately 1.5 tonnes of soy meal every year. Soy meal is used in compound feed to increase the protein content. Apart from representing a financial cost, the import of soy meal also gives rise to environmental and social concerns in the producing countries (Aide and Grau, 2004; Fearnside, 2001). The high share of Danish agricultural land allocated to cereals also pose environmental concerns, including eutrophication of fresh- and marine waters (Velthof et al., 2005), acidifying pollutants (due to the ammonia emission), pesticide and energy use. Furthermore, the current feed composition is not optimal: firstly, up to 80% of phosphorus in cereals feed is in the form of phytic acid and difficult for monogastric animals, such as pigs, to digest, resulting in high-phosphorus content in the manure; secondly, pigs cannot utilize the essential amino acids in the cereal feed efficiently, resulting in an excess of nitrogen excretion in the manure (Dourmad and Jondreville, 2007).

A promising alternative is using the proteinaceous products separated from grass to substitute cereals and soya in pig feed (i.e. alternative feeding system, Fig. 1). Grass is an important source of protein. However, traditionally it is believed to be only suitable for feeding ruminant (e.g. cattle, sheep). Grass in the natural state cannot be digested well by pigs. However, with a green bio-refinery (GBR) plant the grass can be made into protein-rich press juice (PJ) and fibre-rich press cake (PC) (e.g. for production of insulation materials, gardening material or cattle feed). Proteinaceous concentrate made from juice can be comparable in quality to cereals and soya (Kamm et al., 2010), which reduces the domestic cereal production and import dependence of soya. The residues of the GBR can also be used to produce biogas and be fed back to land as fertilizer with reduced environmental effects.

The idea of adding the ingredient of grass into pig feed is not completely new. Patterson and Walker (1979) examined the use of effluent from grass silage in the pig feed. They found that if silage effluent was included in the pig diet at about 10% of the total dry matter, it could supply almost all the necessary minerals with the possible exception of copper. Numerous studies examined the possibility of adding grass and grass silage as roughage into pig feed (Carlson et al., 1999; Danielsen et al., 2000; Hansen et al., 2006; Lebret, 2008). However, the proportion of grass and silage (in their original state) applied in the pig feed is relatively low due to its low digestibility (e.g. of organic matter and energy (Lindberg and Andersson, 1998)). There are relatively few studies

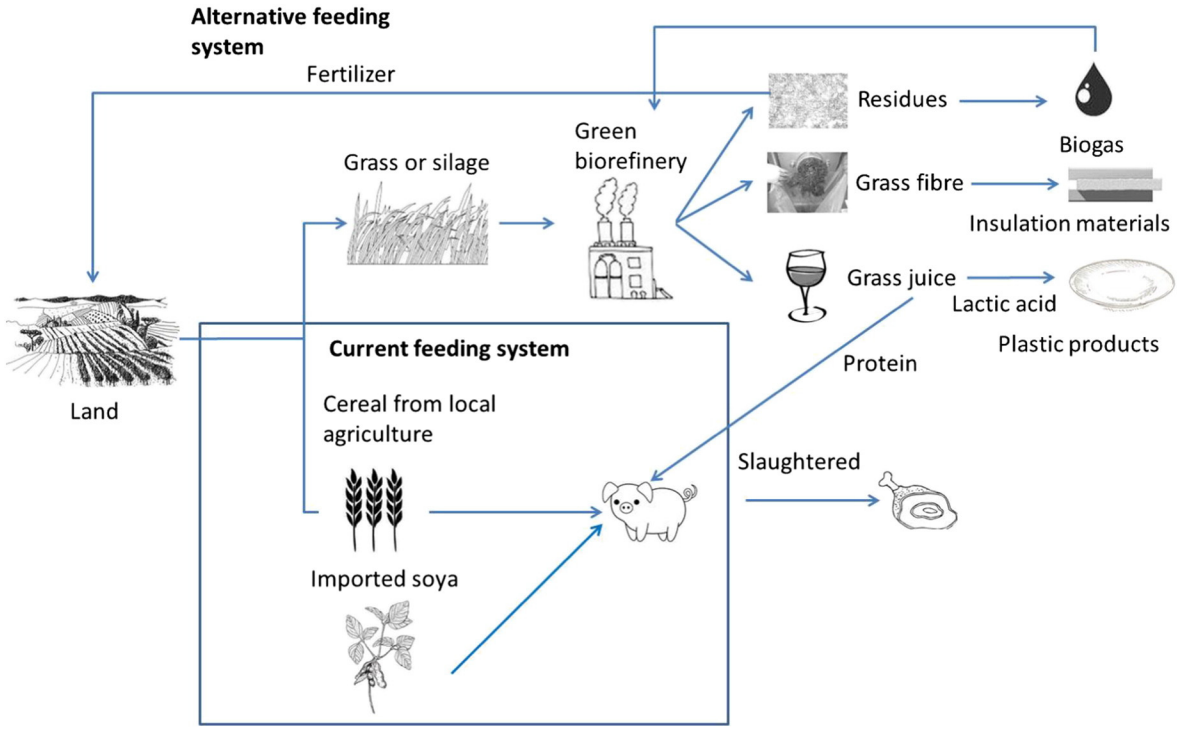

Fig. 1. Current and alternative pig feeding systems.
Note: Some pictures are from Sharma et al. (2012).