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BioHEAT: A policy decision support tool in Ireland's bioenergy and heat sectors

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HIGHLIGHTS

- Methodology for an integrated bioenergy and heat policy decision support tool.
- Techno-economic model with a novel representation of consumer decision making.
- Flexibility to model policy impacts on all 3 energy end use sectors.
- Method examines supply chain competition from a policy perspective.
- Results for three scenarios examined to demonstrate the model functionality.

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ABSTRACT

Bioenergy is likely to play a key role in decarbonising the energy system. The versatility of bioenergy as a transport, heat or electricity fuel is one of its key strengths but can add to the complexity of policy design. Polices aimed at stimulating bioenergy use in one end use sector should consider the impacts of use and uptake in the others.

This paper details a methodology for an integrated bioenergy and heat policy decision support tool that is being used to inform policy in Ireland. The previous literature has focused on individual supply chain optimisation, plant sizing and plant locations from an operator's perspective. The BioHEAT model is a techno-economic model that accounts for the co-dependencies between the end use sectors. It extends the approach to supply chain specification in the literature to incorporate a novel representation of consumer decision making in the heat sector and the flexibility to model various policy types in heat, electricity and transport sectors from a policy making perspective. Three scenarios are examined to demonstrate the functionality of the model, including the interaction between separate policies targeting the Heat and Power sectors. The results demonstrate how the model can be used to examine policy impacts against a range of metrics including the contribution to renewable energy and carbon reduction targets; cost to the exchequer and the marginal cost of carbon abated. The model has helped to inform the development of a renewable heat policy instrument in Ireland.

1. Introduction

Many countries are looking to bioenergy as a means to achieve climate and renewable energy goals [1]. The long term energy system models show that bioenergy has a key part to play in meeting the climate change mitigation goals outlined in the Paris agreement [2,3]. Biomass feedstocks are a versatile renewable energy source and can be used to produce renewable energy for heat, electricity and transport. Biomass can be converted into refined liquid, solid or gaseous fuels, and there are several production pathways possible for most feedstock types. Many countries already have polices in place to develop the use of bioenergy in all three end use sectors [1]. Further policy interventions will be required make long term decarbonisation goals a reality.

The versatility of bioenergy offers many options for policy makers but it also adds complexity and brings a significant risk of unintended consequences [4–7]. Policy makers should be aware of the impacts that policies, intended to stimulate the use of bioenergy through one particular pathway, can have on other bioenergy pathways as well as on non-energy markets for biomass feedstock. Policy initiatives that increase bioenergy production in one sector at the expense of bioenergy output in another are counterproductive. As part of a recent policy design initiative for renewable heat in Ireland, several of these

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challenges were apparent. A modelling solution was sought to address these issues. This required the development of a novel methodology that goes beyond those previously published in the literature. The purpose of this paper is to share the knowledge gained to inform similar efforts elsewhere. Bazilian et al. make the important point that while there are several models available to examine energy and other water, food and land use questions these are often focused on long term policy research orientated work rather than short term applied policy decision support tools [8].

BioHEAT is a techno-economic simulation model of bioenergy supply chains in Ireland. It follows previous approaches in incorporating a detailed representation of bioenergy supply. It goes beyond many of these by including cost effective allocation of limited bioenergy resources between the Power, Transport and Heat end use sectors. Bioenergy related demand for heat is typically treated as an external input in other approaches [9–13] and bioenergy related models that include a representations of consumer behaviour seem to be rare – our review did not find any examples. The simulation of consumer behaviour and decision making is a particularly novel approach and can have applications for heat sector modelling beyond renewable uptake.

Much of the research and modelling to inform bioenergy decisions is focused on specific aspects of the supply chain such as the most optimal way to use an individual resource or supply chain [13–27], where to locate a bioenergy producing plant and what size a plant should be [26,28–43], and factors influencing refining costs [44–46]. Others focus on what might be required from policy interventions in order to bring about uptake of a certain technology or feedstock [47–51].

Optimisation models for bioenergy supply chains are common. De Meyer et al., examined the use of optimisation methods in the design and management of the upstream supply chain [9]. They conclude that models are usually developed for specific cases that address a specific part of the supply chain at one point in the hierarchical decision level. Most models address the optimisation problem from the plant or bioenergy user's point of view. Mafakheri and Nasiri reviewed the modelling of biomass to energy supply chain operations [10]. They point to the limited research about certain aspects of biomass supply chains. One of the conclusions from the review was the lack of evidence about the extent of the impact of policy drivers and incentives on the design and management of biomass supply chains. Shabani et al., reviewed value chain optimisation of forest biomass for bioenergy production [11]. The optimisation models reviewed tended to deal with location specific or end use sector questions such as technology choice, plant size and location, storage location, product mix and environmental and social objectives. Cambero and Sowlati also reviewed the literature on forest biomass supply chain assessment and optimisation [12]. Many of these models reviewed considered energy demand as an exogenous constraint to be met in the optimisation and did not examine the cross cutting impact on other supply chains or bioenergy end uses.

Mitchell et al., developed a decision support tool, as part of a project under the International Energy Agency's Technology Collaboration on bioenergy, called the BioEnergy Assessment Model (BEAM) [52,53]. The BEAM model allowed a techno-economic assessment of biomass-to-energy policy schemes. The model has modules that characterise the economics of feedstock supply, pre-treatment and conversion into a final product. The case studies presented in these papers inputted demand for bioenergy products – electricity and ethanol – as exogenous factors and the model generates estimates of the costs of meeting those demands. Freppaz et al. is a well sited example of an optimisation approach [13]. The model seeks to minimise the costs related to plant, transportation, biomass harvesting costs and energy distribution. The constraints to be satisfied include a requirement to meet a proportion of the thermal energy demand in a given area. The model decides on the annual biomass use and plant size. The only policy variable included is a constraint to specify the minimum amount of energy that must come from renewable sources in a given area. Some models focus on optimising the supply chain to a refinery without consideration of the final energy use. [45,46]. The specification of biomass supply chains in BioHEAT has mirrored the predominate approaches outlined in literature to include recourse costs, transport costs, refining costs and conversion costs.

A few of the modelling methods have been applied to high level policy analysis. Kalt and Kranzl assessed the economic efficiency of bioenergy policy using a techno-economic model [48]. The cost of energy production for clusters of bioenergy technologies are compared with a reference system. The model does not estimate uptake in a detailed way but rather compares the costs of energy production and evaluates a mitigation cost based on this. This method helps with a broad assessment of policy but is not suitable for uptake assessments and does not tell policy makers anything on the cross cutting impacts of a policy implementation. Wahlund et al., take a similar approach, comparing the cost of replacing a reference fossil fuel in each of the heat electricity and transport sectors base on an evaluation of the supply chain costs [49]. Schmidt et al., looked at the cost effectiveness of various bioenergy related policy instruments in Austria in a similar way to support advanced bioenergy conversion technologies [50]. BioHEAT focuses on the policy maker perspective. Much of the literature either focuses on bioenergy from the perspective of an agent in the supply chain or on broad policy evaluations. Policy makers are concerned with understanding the impact a measure may have on uptake of specific types of technologies and how a policy in one sector may impact on policy objectives in another. The method outlined here is a useful addition to the literature in this regard.

The inclusion of energy demand, especially heat demand, has taken various high level approaches. Schmidt et al., developed a spatially explicitly optimisation model for domestic forest biomass production and use in Austria. The model used detailed data on forest supply chain costs and a representation of heat demand to examine the comparative cost of wood pellet heating compared to CHP and gasification technologies [33]. Heat demand is based on high level factors such as number of employees for commercial and industrial demand and average consumption values by age and type of house in the residential sector. Steubing et al., implemented an optimisation model to examine the best use of residual and waste biomass in the EU [47]. The model assesses the alternative uses of bioenergy between the heat transport and electricity generation options. Heat demand is based on aggregate energy balance data divided simply into heat for household use and heat for industrial use. Steubing in a separate paper looked at identifying the optimal plant sizes and locations for wood based SNG from an environmental and economic perspective [38]. Bentsen et al., developed an optimisation model to minimise the energy system emissions by allocating biomass resources to meet energy services [54]. They use supply cost curves of biomass as inputs and include supply chain emissions from biomass in the optimisation. Tan et al., developed a fuzzy optimisation model for biomass production and trade [55]. Within the model bioenergy demand in each region is an input specified by a lower limit and a tolerance level. The Global Biomass Optimisation Model (GLOBIOM) uses a partial economic equilibrium methodology to determine the land use change implications of bioenergy policy [5]. Demand for bioenergy resources are passed to the model and the prices for bioenergy feedstock, and thus the supply side response, are determined endogenously through the product balance constraint. The BioHEAT model estimates for heat demand are developed in a detailed way and the decision to move to a renewable heat technology is not solely influenced by the cost. The specification of building archetypes in BioHEAT allows a more representative analysis of the likely demands for bioenergy and other forms of renewable heat. Demand for bioenergy in the electricity and transport sectors is specified in a similar way to other models in the literature and in the case of electricity can also be limited by economic considerations.

The extensive barriers have heating related investments are well documented [56–59]. Heat consumers do not make choices solely on