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Managing the moisture content of wood biomass for the optimisation of Ireland's transport supply strategy to bioenergy markets and competing industries

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ABSTRACT

The aim of this study was to analyse the supply of wood biomass (short wood) to the three peat power plants in Ireland and the impacts on the competing wood-based panel industries. The methodology includes the development of a spatial decision support tool based on LP (Linear Programming). It uses drying curves to assess the moisture content, weight and energy content of biomass during a two year period planning. Harvesting, chipping, storage and transportation costs are calculated based on the biomass moisture content. The model optimally allocates woodchips and logs from thinnings and clearfells. Results show that the planned maximum 30% co-firing rate at the three peat power station could be met with the forecasted short wood availability from both the private and public sector. The costs of supply increased not only with higher demands, but also with tighter constraints on the MC demanded by power plants. Spatial distribution and operational factors such as efficiency in transportation and truck loading showed to be sensitive to changes in MC. The analysis shows the benefits of managing the MC when optimising supply chains in order to deliver biomass to energy plants in a cost-effective manner.

1. Introduction

Currently, Ireland imports 85% of its energy needs and it is highly dependent on fossil fuels with oil as the main fuel source (45.4%) followed by natural gas (30.4%), coal (11.2%) and peat (6.1%). This makes the country vulnerable to supply disruptions, price changes, and also contributing highly to greenhouse gas emissions [1]. The reduction in greenhouse gas emissions agreed to in the Kyoto Protocol in December 1997 binds several countries to mitigate climate change, with the European Union setting targets to increase the share of renewable energy sources. Ireland has a 16% target for renewable energy sources by 2020. This goal must be met through an increase of 10% in the transport sector, 12% in the heat sector and 40% in the electricity sector [2].

The Irish government has undertaken to reduce national CO_2 emissions through a range of measures like the National Renewable Energy Action Plan [2]. One of these measures is the conversion of peat fired power plants to co-fire with renewable biomass. It is planned that Ireland's three peat power generation plants to be co-firing with 30% biomass. Peat-based power plants are typically located in the proximity of peat sources to reduce the logistic cost, transmission losses due to transportation [3]. Bord Na Mona (BNM) is responsible for the mechanised harvesting of peat. BNM owns Edenderry peat power station (120 MWe), and sells peat to the remaining two power plants which are owned and operated by the Electric Ireland (which is the main electricity supplier in Ireland and also owns and controls the country's transmission grid). These plants are Lough Ree (100 MWe) and West Offaly (150 MWe), and the total annual electricity output from these three peat power plants is 370 MWe, which equates to 6% of Irelands total primary energy requirement (TPER). Greenhouse gas (GHG) emissions from energy production is one of the major contributors to anthropogenic climate change [4]. The burning of peat currently emits 2.8 Mt of CO_2/annum which is equivalent to 4.1% of Irelands GHG emissions [5].

At present Edenderry Power is co-firing biomass at 22%, displacing around 283,375 MWh from peat in 2011, and is on target for 2015 [6]. Achieving the 30% co-firing target implies the offsetting of

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0.9 Mt of peat with biomass, and will require an increased amount of biomass [7].

Biomass plays an important part not only on the global response to the challenges on energy security, but also greenhouse emissions, and climate change. Although it is not a complete solution, it can play an important role in partial substitution of fossil fuel in energy supply [8]. In Ireland, industrial biomass energy (with wood as the major source) accounted for 69% of all thermal renewable energy used in 2011, which corresponds to 2.9% of all thermal energy used in the country [9]. Forestry is the largest biomass resource with over 744,000 ha which equates to 10.6% of Ireland's land area, and further 17% expansion of forest cover is planned by 2030 [10]. Half of the estate's forests are less than 25 years old, with 53% of the forests being managed by Coillte (a commercial semi state company) and 47% managed by private owners [11].

The biomass potential is constrained by its characteristic low energy density (energy per volume), widely dispersed occurrence, and seasonality of supply. Biomass resources are also often distributed in remote locations [12]. These factors add complexities to the supply chain and can increase the cost of technology required to convert biomass into useful sources of energy (harvesting, collection, transport, communition and storage operations) [13]. The present costs of primary biomass fuels are also often higher than the cost of competing fossil fuels [14]. Compared to more traditional energy technologies like electricity and gas, however, fewer efforts have so far been apparent in techno-economic modelling and optimization of biomass supply chains [15].

Another constraint for the wood biomass industry is the competition on national and international markets for forest products. The use of wood biomass energy by commercial and domestic users has risen considerably in the last years. In 2012, 36% of the roundwood harvested in Ireland was used for energy generation [16]. This situation increases competing demands for small sized timber volume assortments which traditionally were used in the manufacture of wood panels and fencing materials [17]. In this scenario it is important that wood biomass resources are used as efficiently and cost effectively as possible, allowing forest owners and wood processors to reduce harvesting and transportation costs, optimally match wood to market needs, and capture more value [18].

Supply chain planning in the forest product sector encompasses a wide range of complex decisions at different planning levels, which usually are made and supported with the assistance of optimisation-based decision support tools [19]. Effective design, planning and management of forest biomass energy plants play a critical role in reducing the energy generation cost and making it a viable energy source [20]. Recent advances in computational tools have made it possible to build mathematical models for analysis and optimization of complex supply systems [21]. Many approaches have been used to simulate and optimise specific biomass supply chains, and to get a better understanding of the cost reductions that could result from the implementation of more efficient logistics operations while ensuring a reliable and sustainable supply of forest fuel [13].

Where to locate power plants and how to supply forest biomass to each plant is a problem that is commonly approached through location-allocation modelling, where the global objective is to minimize the total transport cost, typically expressed as the product of demand and distance [22]. Commonly, biomass production and transportation account for a significant part of the whole bioenergy costs. The key element is to obtain sufficient biomass quantities in order to satisfy the energy plant at the least cost [23].

Planning tools often used for tactical planning is Linear Programming (LP) [24]. LP is an optimal decision making tool in which the objective is a linear function and the constraints on the decision problem are linear equalities and inequalities. LP is a well suited method for solving allocation problems and has been widely used in determining forest biomass availability [23]. It can be used also to find a destination of flow from supply points to demand points. Eriksson and Bjoerheden [26] in Sweden presented one of the first studies on biomass allocation. Their study dealt with one power station and six areas supplying four biomass products (sawmill residues, logging residues, wood chips and tree sections). The aim was to satisfy the demand at the plant at minimum cost for a period of one year. With the use of linear programming (LP) they analysed different supply scenarios: chipping at roadside or at the plant, and transporting direct from to the plant or via terminals. They concluded that transportation costs constitute the most essential part of the total supply costs, and that contrary to practice the best scenario was to comminute (chipping) at the forests with direct haulage to heating plants instead of using terminals.

MILP (Mixed Integer Linear Programming) modelling was used by Ref. [27] with the aim of supplying from different forests and sawmills to various heating plants while minimising forwarding, chipping, storing and transportation costs. One of the decision variables included in the model was whether or not to acquire residues from forests and sawmills that were not owned by the supplying company. Monthly plans for forwarding, storage and chipping were also determined. Different scenarios were tested based on storage restrictions, increased demand, chipping capacity and including new terminals.

Another MILP model on the forest fuel supply network at a national scale in Austria was designed by Ref. [28]. The model includes decisions on transport modes (road, rail and ship), number of terminals and their spatial arrangement. Scenarios were formulated to study the impact of rising energy costs and route optimisation. Railway had a minor share in all scenarios because the initial transport is always done by truck and the total transport distances are relatively short within Austria. The impacts of rising energy costs on procurement sources, transport mix and procurement costs were evaluated. Their results show a 20% increase of energy costs resulting in a procurement cost increase of 7%, and an increasing share of domestic waterway transportation.

A study in Denmark presented a GIS-based method to determine the least costly strategies to allocate forest wood chips to energy plants in Denmark. The GIS used a cost-weighted distance to wood chip resources and the annual demand as decision parameters [29]. The model allocated each supply of wood chips to plants along the least-cost paths in terms of travel time, until the demand of each plant is met or the wood chip source is exhausted. Resource areas are mapped on a national scale and the cumulative and total costs of supply for each plant are calculated. The study suggested that allocation analysis with a network-based GIS is a suitable method to express the costs connected with matching local demand and supply, although allocation in the GIS system does not optimise overall least costs, which results in a non-optimal supply of plants which have less access to resources [29].

Combining GIS (geographic information systems) and Linear Programming has been studied by authors in Ref. [30] in order to optimise the supply through the use of terminals. In Austria wood energy constant supply is required through the year especially in winter when conditions often make mountainous regions inaccessible. The authors aimed to develop a regional fuel wood supply network that included the optimal use of terminals by testing a number of different scenarios based on demand, upgrading of energy plants and inclusion of harvesting residues. Together authors in Refs. [26] and [27] these authors have concluded that direct supply (without the use of intermediate terminals) is the most efficient and economical way to supply fuels to heating and power plants. Although the use of terminals can improve the quality of the