Potential availability of non-woody biomass feedstock for pellet production within the Republic of Ireland

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Abstract: The threat of increasing fuel prices and climate change necessitates the need for clean, renewable and independent energy sources. A GIS (Geographical Information Systems) model was developed using ArcGIS 9.2 to analyze the availability of non-woody biomass (wheat, oat, barley and rape straw, willow and miscanthus) for pellet production in Ireland. Utilization within the heating and electricity sector would displace currently used fossil fuels with cleaner, carbon neutral non-woody residues. The aim of the analysis was to determine the total hectares of biomass within Ireland and compute the potential non-woody biomass yield. The greatest potential source of biomass for pelleting is cereal straw. Within the Republic of Ireland the South-East, South-West and Mid-East of Ireland have the greatest biomass yield for pellet production and likely to be most economically viable. Non-woody biomass has a realistic potential to displace fossil fuels within the heating and electricity sector resulting in CO_2 mitigation.

Keywords: biomass pellet production, non-woody biomass, GIS analysis, renewable energy source, CO_2 mitigation

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1 Introduction

Biomass pellets are a clean and convenient fuel. Pellets are generally produced from sawdust[1]. Pelletising is a method of increasing the bulk density of biomass by mechanical pressure (compression) and heat[2]. Pellets are cylindrical in shape, of 6–10 mm diameter and 10–30 mm in length. Pellets are easily handled allowing cost-efficient transportation of an energy dense fuel (650 kg/m^3 bulk density) and automatic operation of boilers[1-3]. The facilitation of the use of local resources in pellet production makes a concrete contribution to environmental change and independency of energy supply[1]. In 2003 the EU's dependency on energy

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imports had exceeded 50%[4]. Biomass is a very effective solution in the reduction of CO_2 emissions giving that the emitted CO_2 during combustion originates from the CO_2 taken up by the biomass (closed carbon cycle), hence no increase in overall CO_2 emissions[3]. Pellets are a key technology for increasing biomass uses worldwide (80 million tons of pellets in the EU by 2020, corresponding to 33 million tonnes of oil equivalent (MTOE))[1,3].

In past years the European pellet market has shown dynamic growth in both production and demand. This is partially due to the increased use of pellets for residential heating as well as electricity generation[5]. While the potential of forest fuels for pelleting is estimated at 543 million m^3 solid (1100 Terra-Watt hours – TWh) within the 25 member countries of the European Union (EU 25), the actual available resources is about 140 million m^3 solid (280 TWh). The major contributing factor in the difference between potential and actual resources is as a result of realistic harvest potential, such as recovery rate and use of stumps[6]. If all of this available resources was to be utilized this potential would account for 2.1% of the final energy consumption within the EU 25, which in 2007 was 13100 Terra-Watt hours[7]. Currently less than 5% of this realized potential is utilized (2005)[6].

Although this unexploited resource exists within the EU, the shortage of woody raw materials for pellet production is a possibility[8]. As a result of excess demand on woody biomass and pellet supplies Sweden, Denmark and Southern Europe are looking to large volumes of agricultural residues as a future alternative for fuel pellet manufacturing[6,8]. Small agri-pellet productions already exist in Germany and Poland while larger markets exist in the Czech Republic and Denmark[9,10]. While straw presents the greatest potential for the production of alternative pellets, other material sources include energy crops and grasses[2,6,8-10]. Ever increasing technological advances in pellet production can achieve overall conversion losses for drying, milling and densification that are lower than 10%[3]. Many agricultural residues can be delivered at moisture content of less than 20% (straws and some energy crops) avoiding the need for drying of the material[8]. Agri-pellets do however present a very interesting alternative for co-firing with fossil fuels, both technically and economically[6,10].

All types of woody biomass, agricultural residues and energy crops are suitable raw materials for pellet production. Pellets from bark, agricultural residues (cereal straws) and energy crops are generally more appropriate for combustion in larger-scale systems[1,6], due to the emissions, deposits and corrosion resulting from higher content of such elements of nitrogen (N), sulphur (S), chlorine (Cl) and potassium (K) present in all or part of these materials. The emission of higher concentrations of Nitrogen Oxide (NO_x), Sulphur Oxide (SO_x) and Hydrochloric acid (HCl) are a result of these elements present in pellets made from such materials compared to wood pellets[8]. Hence the need for pellet standardization is important. Highest quality pellets are required for the domestic markets while large-scale co-firing units can handle lower quality pellets[3]. Pellet standards already exist within the European countries with developed markets such as Sweden (SS 18 71 20), Austria (ŐNORM M 7135), Germany (DIN 51731 and DIN plus), Norway and Switzerland[1,11]. Raw material composition significantly influences the quality of the pellets combustion, emissions and efficiency[11]. Currently wood pellets are classified under various physical and chemical properties within which they must meet stringent limits[11,12]. A new European standard (CEN TS) for solid biofuels is to be implemented, with the potential to streamline terminology and quality within the pelleting industry by considering both the pellet material and its properties[3,13,14].

Within the bioenergy sector pellets are globally significant as they are the first wood based fuel which can be transported over long distances and still remain profitable[15]. The world's leading pellet countries consist of Canada, USA, Sweden, Germany, Austria, Finland, Denmark, Italy, Poland and Russia[15]. The largest volumes of biofuels are traded between the Baltic States (Estonia, Latvia and Lithuania) to the Nordic countries (Sweden, Denmark and Finland)[13].

Biomass usage in Ireland is largely wood heating in homes and industry[16]. Overall in 2002 renewable energy contributed a mere 1.15% of the final energy consumption[17]. In 2007 renewable energy accounted for 1.56% of the final energy consumption for Ireland with biomass usage being 1.35% of the energy consumption. In 2002 approximately 26 tonnes of wood pellets were consumed in Ireland, all imported from Sweden, Austria, Spain and Canada[16]. Grant aid for pellet stoves and boilers from Sustainable Energy Ireland saw a large increase in wood pellet demand. Pellet production capacity is estimated at 72,500 tonnes in Ireland for 2008 – 2009[18,19]. In 2007, 21,000 tonnes of wood chip, 24,000 tonnes of pellets, 2,300 tonnes of briquettes and 42,000 tonnes of firewood was consumed in Ireland[20]. Further development of independent, renewable energy sources is essential in Ireland giving that in 2007 90% of our energy was imported[21]. The potential presented by non-woody biomass could form a key role if and when feedstock's currently used for pellet production (sawmill residues and forest thinnings) became less available. The use of energy crops like Miscanthus and willow or agricultural residues would be the next possible biomass feedstock resource[22,23].

Advances in computational tools have aided in facilitating the building of models to analyse and optimise biomass supply systems. Non-woody biomass and agricultural biomass supply logistics consists of multiple harvesting, storage, pre-processing and transportation operations[24-29]. Research conducted by Sokhansanj et al., 2006, developed the IBSAL model which simulates the flow of biomass from field to biorefinery. The model was developed using the simulation language EXTEND. Many other biomass models have been developed to simulate specific tasks or operations so as to optimise the operations output with minimal cost. Nilsson, 1999, decribed the development of a simulation model for baling and transporting wheat straw to district heating plants in Sweden.

Research conducted by Tatsiopoulos and Tolis, 2003, produced a model to evaluate the supply of cotton gin waste to combined heat and power (CHP) plants in Greece, while a model to simulate sugar cane harvest and mill delivery in South Africa was developed by Hansen et al., 2002. In utilising integer linear programming researchers developed a system for analysing biomass network models known as Bioloco[32,33]. Frombo et al., 2009, presented an environmental decision support system based on a Geographic Information System (GIS). The function of the non-linear mixed-integer model is optimal planning of forest biomass use for energy production. Research conducted by Rentizelas et al., 2009, examines the issue of storage on the logistics cost. In previous research by Nolan et al., 2009, both the storage of biomass and the associated costs of each step of the logistics chain was evaluated. The development of GIS based models and analyses allow non-spatial data and spatial data to be fused into one single tool[27]. A GIS model developed by Deverell et al., 2009, focused on analysing the potential feedstock availability around nine possible bioethanol plants in the Republic of Ireland. By developing a GIS availability analysis, it is the main focus of this research to determine the potential availability of non-woody biomass within the eight regions of the Republic of Ireland for the production of biomass fuel pellets. Each optimum location will then be analysed to determine if large scale pellet production within the regions of Ireland can be sustained using local biomass resources.

2 Material and methods

To determine the availability and quantity of non-woody biomass (cereal straws and energy crops – miscanthus and willow) grown in Ireland the total hectares of sown crops were obtained. Data in relation to the hectares of wheat, barley and oats planted in Ireland were obtained from the Central Statistics Office (Census of Ireland 2000)[20]. The Census of Agriculture was conducted in accordance with the Statistics Order, 2000 (S.I. No. 132 of 2000). The Department of Agriculture and Food provided data on the total hectares of rape seed oil (rape straw), miscanthus and willow planted (Energy crops grant 2007 applicants)[39]. All data received were divided into total hectares of each crop per district electoral division.

The data were used to build and develop a Geographic Information System (GIS) model which would calculate the total hectares of biomass. The GIS software used to develop the model was ERSI's ArcGIS 9.2®. Data entry in ArcGIS can be in text format converting to georeferenced spatial data. All spatial data are georeferenced with respect to the Transverse Mercator Projection and referred to as the Irish National Grid (true origin 8° W and 53°30' N with false origin 200 km W and 250 km S of the true origin).

2.1 Building the GIS model

Using ArcGIS 9.2 a shapefile of the island of Ireland was loaded into the software. Overlaid on this map was a shapefile of the District Electoral Divisions (DED's) of Ireland. The projected coordinate system for the model is the Irish National Grid (TM65_Irish_Grid – ArcGIS). District Electoral Divisions are a low-level territorial division in Ireland. Data received on crop hectares per DED were in numeric format. Fields titled for each crop type were added to the attribute table of the DED shapefile. The respective data were then added to the relevant fields. This information was sub-divided into the eight regions of Ireland: Border, Dublin, Mid-East (M_E), Midlands, Mid-West (M_W), South-East (S_E), South-West (S_W), and West. Ireland is divided into eight regions for NUTS statistical purposes. These are not related to the four traditional provinces but are based on the administrative counties. A shapefile for each region was created containing the DED's and crop data relevant to the region. The model was developed and analyzed. Table 1 lists the counties of Ireland by region.

Table 1 Counties of Ireland subdivided by region

Region	Counties
Border	Cavan, Donegal, Leitrim, Louth, Monaghan and Sligo
Dublin	City of Dublin and Counties of Dun Laoghaire - Rathdown, Fingal and South Dublin
Mid-East	Kildare, Meath and Wicklow
Midlands	Laois, Longford, Offaly and Westmeath
Mid-West	Clare, Limerick and North Tipperary
South-East	Carlow, Kilkenny, South Tipperary, Waterford and Wexford
South-West	Cork and Kerry
West	Galway, Mayo and Roscommon

2.2 Analyzing the model

The first analysis of the GIS model was to determine the mean density location for each crop within each region. This analysis was performed using the mean centre tool in ArcGIS. It is from these centre points that the pellet production facilities can be located. By locating the production facilities within the mean density location of these central crop densities the maximum available biomass yield can be identified with minimum transport distance.

Once these locations are identified buffer zones of 10 kilometer radii were established to a maximum radius of 100 kilometers about each of the points. Firstly the buffer tool identified the buffer radii (10–100 km), while the union overlay tool identified each District Electoral Division within each buffer radius. This analysis was conducted for each region and buffer radii. The objective was to determine the total number of hectares per buffer radius and region of Ireland.

Due to the result that several DED's were overlaid by more than one buffer radius the total number of hectares was duplicated in cases of overlap leading to incorrect biomass yields. To resolve this issue a new field titled "Recal_Area" was added to the attribute database of each of the buffer radius shapefiles. Using the "calculate geometry" command allows the area of any record in the database of a feature layer to be calculated. The modified area of any DED which falls between multiple buffer radii can be calculated for each of the given buffer radii. This allows the actual total hectares of biomass to be calculated without duplication for each buffer radius by region of Ireland.

As the mean centre location for the pelleting plant falls outside the boundaries of the border region a new location was determined considering only the crops with greatest biomass potential (Wheat, Oats, Barley and Winter Oil Seed Rape). The new plant location is denoted by the abbreviation "Border_Relocated". In considering the low biomass yields for the West, Mid-West and Midland regions of Ireland a new pellet plant location was to be established. This new location would be central to the three aforementioned regions and utilize the resources from all three areas. The location of the plant was determined as previously by identifying the mean density location of the biomass crops within the three regions. The new plant location is denoted by the abbreviation "Mid-Central-West".

2.3 Analytical data

The average annual crop yields for the given biomass were recorded (wheat, barley and oat cereal crops – central statistics office 2007[20] crop statistics, rape straw, willow and miscanthus – Teagasc Crops Research Centre[40]). In calculating the yield of straw biomass from cereal crops the biomass yield is a percentage of the grain yield. By combining this data with the results of the GIS model an annual biomass yield in tonnes can be calculated. This can be sub-divided by buffer radius and regions of Ireland.

3 Results

3.1 Building the GIS model

The model was developed using the DED shapefile as the data source overlaid on a shapefile outlining the country of Ireland. Further shapefiles were created as the analyses of the GIS model required (Regions of Ireland, Crop mean density locations, Optimum plant locations, Overlay buffer radii). Figure 1 is a graphic illustration of the shapefiles upon which the GIS model was developed sub-divided by the regions of Ireland.

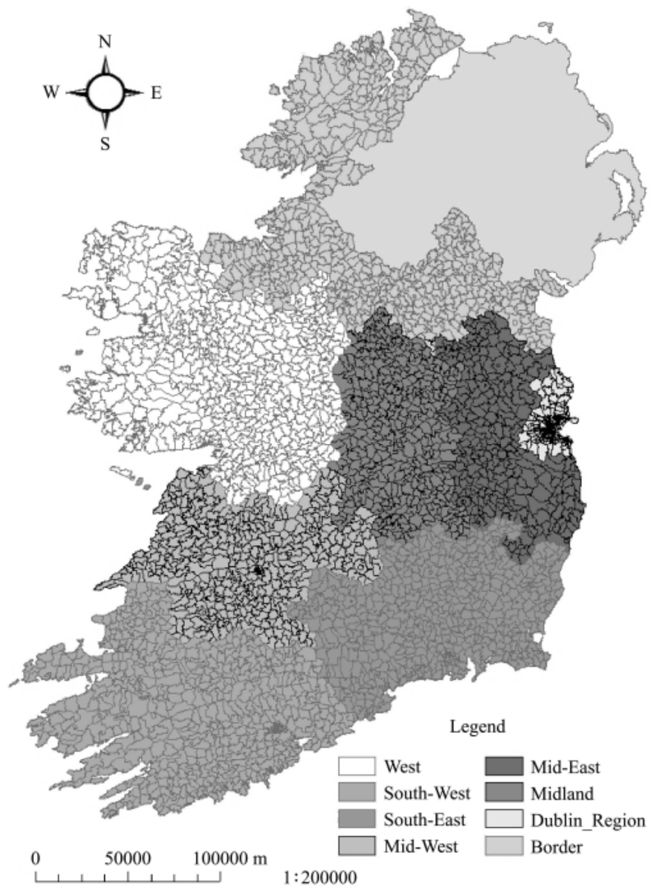

Figure 1 District Electoral Divisions (DED's) divided by region overlaid on shapefile of Ireland

3.2 Analyzing the GIS model

The first analysis of the model determined the mean density location of each biomass crop within each region. This allowed the optimum pellet production location to be determined. Figure 2 illustrates the optimum pellet plant location with respect to the central mean density locations of the biomass crops.

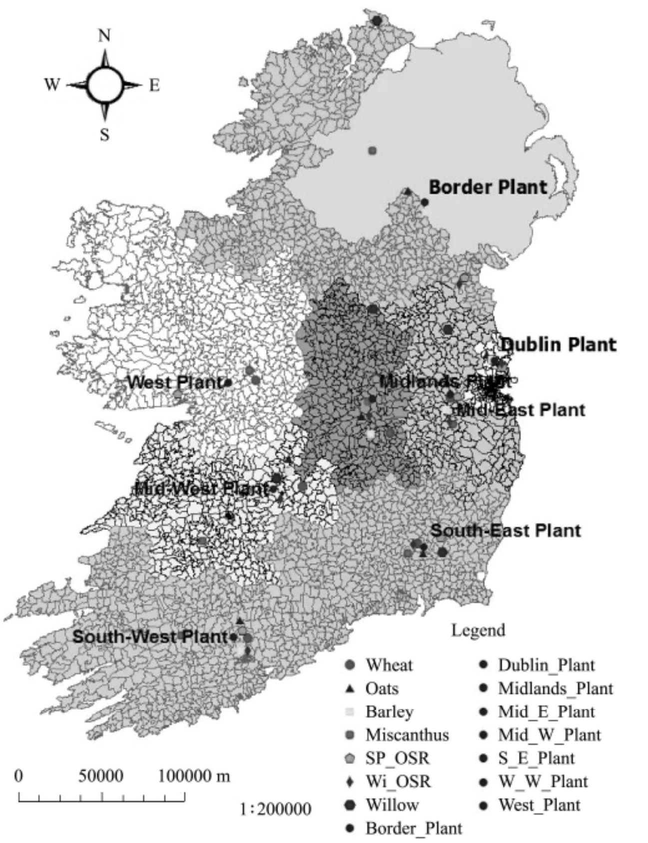

Figure 2 Crop mean densities with optimum plant location

Upon determining the optimum plant locations the 100 km buffer radii were applied to each point. Figure 3 illustrates the buffer radii applied to the South-East (S_E) region of Ireland. Given that many of the DED's were overlaid by several buffer radii the area of the modified DED's for a single buffer radius were to be calculated. By expressing the modified area as a percentage of the original area, the actual hectares of biomass within each buffer radius and region was calculated without duplication.

From this data the amount of biomass yield can be calculated for a given distance from the production plant. This analysis was conducted for each production facility within the regions of Ireland. Table 2 lists the total number of biomass hectares by region of Ireland. The majority of cereal crops are grown in the Mid-East, South-East and South-West regions due to soil suitability for these crops and drier land. The West and extreme North of the Border region are very mountainous and contain a high proportion of heavy poor draining soils or bog which is more suitable for grassland for cattle and sheep production. Parts of the Midland and Mid-West regions would be very similar with heavy poor draining soils and partial bog hence the lower hectares of cereal crops.

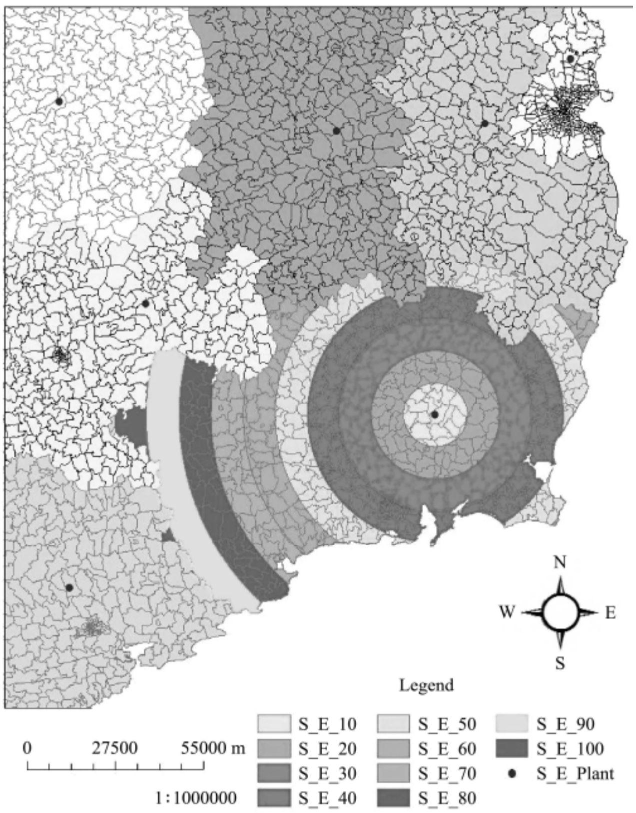

Figure 3 Buffer radii detail for the South-East region of Ireland sub-divided by buffer radius

Table 2 Average biomass yield per hectare

Crop	Yield/t • hm^{-2}	Moisture content/%	Source
Wheat cereal	9.2	20	CSO
Wheat straw	5.52		
Oats cereal	7	20	CSO
Oats straw	4.2		
Barley cereal	6.8	20	CSO
Barley straw	4.08		
Miscanthus	10	Dry matter	Teagasc
Rape straw	2.24	15	Teagasc
Willow	10	Dry matter	Teagasc

Note: Central Statistics Office (CSO); Teagasc Crops Research Centre.

Figure 4 gives a graphical representation of the total number of hectares of non-woody biomass grown within each region of Ireland in 2007 and also for the alternative plant locations.

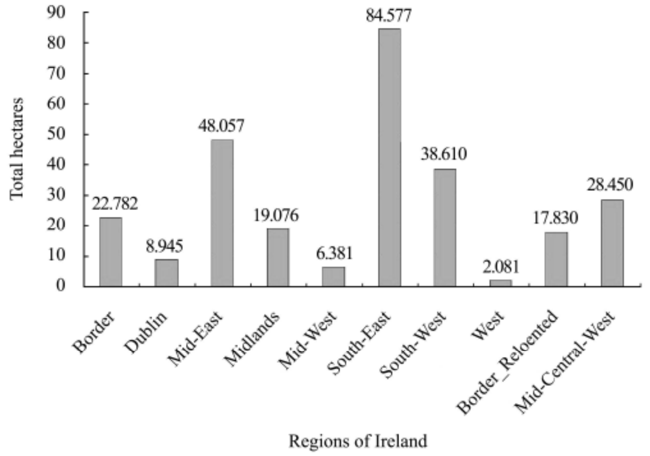

Figure 4 Total numbers of hectares of biomass

Figure 5 illustrates the alternative plant locations derived for the West, Mid-West and Midland regions (Mid-Central-West Plant) and for the Border region (Border_Relocated Plant). The figure also illustrates the associated mean density location of the non-woody biomass crops for the new alternative plant locations.

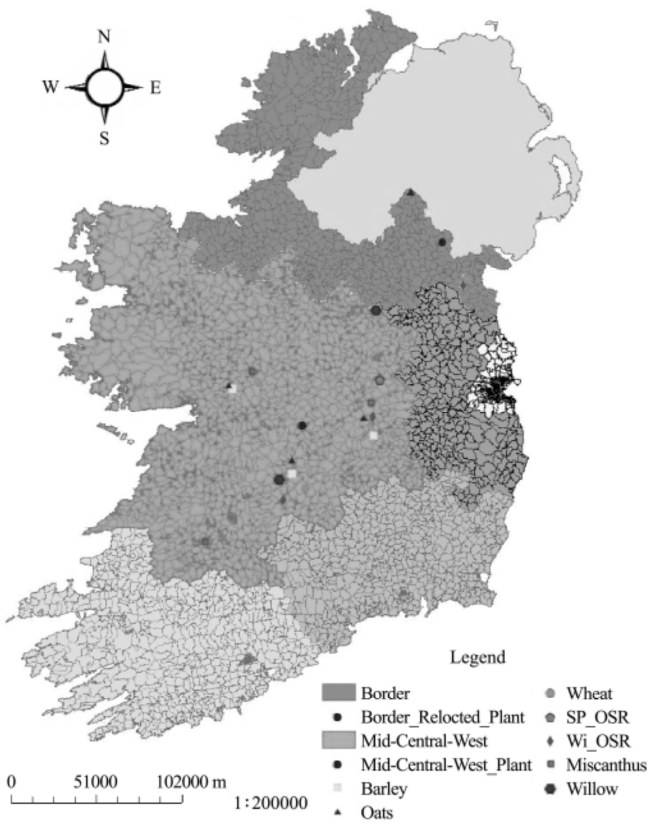

Figure 5 Mid-Central-West and Border_Relocated alternative pellet plant locations

3.3 Analytical data

By combining the total biomass hectares obtained from analyzing the model with the yield per hectare data for the given biomass an annual yield in tonnes of biomass was calculated. When calculating the straw yield for cereal crops the following calculation was considered (wheat, barley and oats):

Straw Yield (tonnes per hectare) = grain yield x straw to grain ratio (1)

For the purposes of this research the straw to grain ratio was assumed to be 0.6 tonnes of straw per tonne of grain. The average yield (t/ha) of each crop is listed in Table 2 while the biomass yield (tonnes) for each region of Ireland and for the alternative plant locations is recorded in Table 3.

Table 3 Non-woody biomass yield for by region of Ireland and alternative plant location sub-divided by buffer radius

Buffer radius/km	Total annual tonnes of biomass per region (,000)									
	Border	Dublin	Mid-E	Midlands	Mid-W	South-E	South-W	West	Border Relocated	Mid-Central-West
10	0.785	26.686	11.947	5.323	4.126	9.794	5.132	1.000	0.009	3.48
20	0.538	11.299	16.462	11.946	5.081	53.059	34.710	2.231	1.15	13.9
30	0.046	4.777	38.259	20.615	10.027	106.275	53.338	1.301	22.53	11.66
40	0.828	0.237	55.622	21.384	6.001	98.561	54.068	2.037	35.56	14.32
50	9.480	-	66.937	17.014	1.081	47.732	15.761	1.951	13.09	18.71
60	34.203	-	22.916	8.965	0.366	12.977	1.494	0.057	3.24	29.02
70	23.952	-	12.424	0.049	0.497	19.703	0.385	0.036	0	17.83
80	17.577	-	-	-	0.013	9.907	0.160	0.011	0	9.52
90	12.860	-	-	-	-	7.205	0.892	0.081	0.079	1.65
100	1.666	-	-	-	-	0.088	2.060	0.135	5.58	0.75
Total	101.934	42.999	224.567	85.296	27.191	365.301	168.000	8.841	81.25	120.82
% Cereal Straw	98.4	99.2	97.9	98.5	96.2	97.7	98.2	97.4	98.5	98.0
Total 0-50 km	11.677	42.999	189.23	76.282	26.315	315.420	163.009	8.520	72.343	62.061
Total 50-100 km	90.257	-	35.340	9.014	0.876	49.881	4.992	0.321	8.902	58.759

An average Lower Heating Value (LHV) of 14.5 GJ/t is assumed for the considered non-woody biomass at a moisture content of 15% (Teagasc Crops Research Centre[40]). The energy equivalent of the biomass yield for each region is presented in Table 4.

Table 4 Energy equivalent of non-woody biomass by region of Ireland

Region of Ireland	Biomass yield (,000 tonnes)	LHV @ 15% MC ($GJ \cdot t^{-1}$)	Energy equivalent (PetaJoules)
Border	101.934	14.5[1]	1.48
Dublin	42.999	14.5[2]	0.62
Mid-East	224.567	14.5[2]	3.26
Midlands	85.296	14.5[2]	1.24
Mid-West	27.191	14.5[2]	0.39
South-East	365.301	14.5[2]	5.30
South-West	168.000	14.5[2]	2.44
West	8.841	14.5[2]	0.13
Border_Relocated	81.25	14.5[2]	1.18
Mid-Central-West	120.82	14.5[2]	1.75

Source: [1]Teagasc Crops Research Centre; [2] Sustainable Energy Ireland – Energy Policy Statistical Support Unit.

In replacing existing used fossil fuels with non-woody biomass substantial CO_2 mitigation can be achieved. Table 5 presents the equivalent biomass quantity to replace some common fossil fuels used within the electricity and heating sector in Ireland and the equivalent CO_2 saving.

Table 5 Non-Woody biomass equivalent of fossil fuels and CO_2 savings

Fossil Fuel	LHV @ 15% MC ($GJ \cdot t^{-1}$)	Replacement Biomass Equivalent (tonnes)*	CO_2 Mitigation (t CO_2)
Residual Fuel Oil (Heavy Oil)	30.050	2.07	835,700[1]
Coal	23.665	1.63	1,040,400[2]
Liquefied Petroleum Gas (LPG)	40.08	2.76	700,700[2]
Milled Peat	6.618	0.46	1,272,000[2]

*Average non-woody biomass LHV @ 15% MC – 14.5 GJ/t; Source: [1] Teagasc Crops Research Centre; [2]Sustainable Energy Ireland – Energy Policy Statistical Support Unit.

4 Discussion

Cereal (wheat, barley and oaten) straw offers the greatest potential for pellet production from non-woody biomass in Ireland which is clearly evident from the results presented in Figure 4 and Table 3 (98% of total non-woody biomass considered). Alternative uses of straw are not considered within this research analysis (animal bedding and mushroom industry). However there is a decline in use of straw in animal bedding due to reduced stocking numbers and the increased use of slatted housing units. Also many contractors and tillage farmers are chopping at harvest and ploughing back the straw at sowing. Instead of chopping this straw and ploughing back at sowing this straw quantity could be utilized for pellet production hence not competing with straw utilized by other industries. In removing straw from arable land loss of nutrients to the soil is experienced. In many cases in Ireland straw chopping was never the practice hence no nutrients to the soil are lost. It is only with increasing price of artificial fertilizers that some arable farmers are considering chopping and plough back at sowing as a way of minimizing fertilizer costs. Chopping of straw has its own drawbacks in the consumption of extra diesel by the harvester during chopping while large volumes of residue can prove to be a problem in seedbed management at sowing time involving additional cultivation processes. In evaluating the advantages of straw chopping or removal one must examine each case specifically and will depend on the price available for straw over the cost of replacement fertilizers[40].

In considering the quantity of pellets produced from one tonne of non-woody biomass overall conversion losses are less than 10%[1]. One dry tonne of non-woody biomass produces approximately 1 tonne of pellets (less dust losses during the milling and pelleting processes). In general dust extraction and collection is employed feeding the collected material back into the pelleting process.

The regions with the greatest biomass yield are the South-East (365,000 tonnes, 5.3 PetaJoules of energy), Mid-East (224,500 tonnes, 3.26 PetaJoules of energy) and South-West (168,000 tonnes, 2.44 PetaJoules of energy) of Ireland (average calorific value of biomass considered – 14.5 GJ/t @ 15% moisture content) as is illustrated in Figure 2 and Table 3. The availability of biomass within a 50 kilometer radius of the optimum pellet plant location is greatest in the South-East, Mid-East and South-West regions also. Within the South-East region of Ireland 315,000 tonnes (86% of all resources or 4.6 PJ) of non-woody biomass is available within a 50 kilometer radius of the optimum plant location (Figure 3 and Table 4). In the Mid-East region 189,200 tonnes (84% of all resources or 2.7 PJ) of non-woody biomass is available with a 50 kilometer radius of the plant while in the South-West region 163,000 tonnes (97% of all resources or 2.4 PJ) are available with a 50 kilometer radius of the plant (Table 3 and Table 4). The greatest cost associated with pellet production is often the cost of the raw material. For production of pellets to be economically viable a year round supply of biomass with the least transport distance is important[22]. The South-East, Mid-East and South-West regions of Ireland meet this criterion most favorably. While the biomass yield for the Dublin region is considerably small (43,000 tonnes or 623.5 GJ) compared with the aforementioned regions, 88% of the non-woody biomass is available within a 20 kilometer radius of the plant location (Figure 4 and Table 3). Given the short transport distance and the population density within the Dublin region pellet production may be viable. If pellet production was not to be viable within the Dublin region the biomass resources may be utilized for pellet production within the Mid-East region due to the close proximity of both pellet plant locations (Figure 2).

The potential energy contribution of such non-woody biomass within the South-East, Mid-East and South-West regions would by 2% (11 PJ) of the total final energy consumption of Ireland for 2007, which was 550PJ (Table 4). In replacing fossil fuels with non-woody biomass substantial CO_2 mitigation can be achieved. By utilizing the total biomass available from these areas with the greatest biomass potential a maximum CO_2 saving of 1.27 million tonnes of CO_2 when using non-woody biomass to replace peat (Table 5). By replacing Liquefied Petroleum Gas (LPG) with the equivalent biomass quantity the CO_2 saving will be minimized (Table 5). The biomass potential for the South-East, South-West and Mid-West regions of Ireland could produce 3 Terra-watt hours of electricity.

The total non-woody biomass yield for the West of Ireland is 8,500 tonnes or 0.13 PJ, for the Mid-West 27,000 tonnes or 0.39 PJ, for the Midlands 85,300 tonnes or 1.24 PJ and for the Border region 90,257 tonnes or 1.48 PJ which is evident from the results in Table 3 and Table 4. Pellet production from non-woody biomass would not be viable within the West and Mid-West regions due to the low yield of biomass. For the Border region of Ireland only 13% of the total non-woody biomass yield is within a 50 kilometer radius of the plant location (Table 3). Long transportation distances will have a negative impact on raw material costs and the economic viability of pellet production. The overall non-woody biomass yield may also be insufficient to ensure viable production.

In reallocating the Border plant to the alternative position of Border_Relocated plant while considering only the non-woody biomass crops with greatest yield still has no bearing on the overall availability of biomass feedstock to the plant (Figure 5 and Table 3). The total non-woody biomass yield is calculated at 81,250 tonnes. Economic feasibility of such a plant would be questionable even though 72,300 tonnes (89% of all resources) of the material is within a 50 kilometer radius compared with only 13% of the biomass yield within a 50 kilometer radius for the previous plant location. The non-woody biomass yield for the Mid-Central-West plant is 120,800 tonnes (Figure 5 and Table 3). Within the new united Mid-Central-West region only 61,000 tonnes (51% of all resources) of non-woody biomass is available within a 50 kilometer radius of the optimum plant location. The large transport distance involved in obtaining the remaining 49% of the available resources may result in high feedstock costs. Hence pellet production within the region of Mid-Central-West may not be economically feasible.

For the pellet plant to be economically feasible and pellet production from non-woody biomass to be viable the costs of the biomass feedstock and pelleting related costs must not exceed the achievable price for non-woody biofuel pellets on the open market. In general for pellet production to be economically feasible a production capacity of 80,000 tonnes of pellets per annum is required. At this capacity a readily available cheap biomass feedstock is necessary.

5 Conclusions

Due to changes in EU policy and reduced animal stocking numbers, cereal straw offers the greatest potential as a source of non-woody biomass for pellet production in the Republic of Ireland.

Of the pellet production locations considered in this study, results indicate only three locations can meet its feedstock demands locally within a 100 km radius (approximately 80,000 to 100,000 tonnes of biomass). From a feedstock supply and transportation perspective these three locations likely to be viable for pellet production are the South-East, Mid-East and South-West regions of Ireland. Pellet production within the Dublin region is possible and likely to be economically viable due to the high population density and short transportation distances involved.

The overall energy equivalent of the non-woody biomass potential of the three likely modeled pellet production locations is 11 PJ or the equivalent to produce 3 Terra-watt hours of electricity. By replacing fossil fuels used within the household or industrial sectors with non-woody biomass pellets a maximum CO_2 emission saving of 1.27 million tonnes can be achieved. Further research into the effect of pellet production scale on the feasibility and economic viability of pellet production is necessary while also considering the results of this GIS analysis regarding feedstock availability.

[References]

[1] Egger C, Ohlinger C, Dell G. Wood pellets – tomorrow's fuel. In Renewable Energy World, September – October 2003.

[2] Mani S, Tabil L G, Sokhansanj S. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy, 2006; 30, 648－654.

[3] AEBIOM – European Biomass Association. A pellet road map for Europe – November 2008.

[4] Fagernas L, Johansson A, Wilen C, Sipil K, Makinen T, Helynen S, et al. Bioenergy in Europe – Opportunities and Barriers. VTT Research notes 2352.

[5] Rakos C. Recent developments in European pellet markets.

Presented at Pellets for Bioenergy: addressing the challenges, Utrecht, The Netherlands, May, 2007.

[6] Vesterinen P, Alakangas E. Efficient trading of biomass – Workshop Report. Available at: www.eubionet.net. Accessed on: 16th January 2009.

[7] Eurostat Energy Statistics Quantities – Final Energy Consumption (ten00095). Available at: epp.eurostat.ec. europa.eu. Accessed on: 19th March 2009.

[8] Pastre O. EUBIA – Pellets for Europe - Analysis of the technical obstacles related to the production and utilization of fuel pellets made from agricultural residues. ALTENER 2002-012-137-160.

[9] Junginger M, Hoeldrich A,Dahl J. et al. The Pellets@tlas Project – A comprehensive European pellet market overview. EIE//06/020.

[10] Production of big straw bales, straw, pellets, transport and storage for power plants and CHP plants - Fact sheet 12 – Denmark. Available at: www.eubionet.net. Accessed on: 16th January 2009.

[11] Fielder F. The state of the art of small-scale pellet-based heating systems and relevant regulations in Sweden, Austria and Germany. Renewable and Sustainable Energy Reviews, 2004; 8, 201－221.

[12] Hahn B. Existing guidelines and quality assurance for fuel pellets. www.umbera.at 2004, pp 1－20.

[13] Alakangas E, Hillring B, Nikolaisen L S. Trade of solid biofuels and fuel prices in Europe. Presented at the 12th European biomass conference, Amsterdam, The Netherlands, June, 2002.

[14] Technical Specification CEN/TS 14961: 2005 Solid biofuels – Fuel specifications and classes.

[15] Sikanen L, Mutanaen A. Pellet markets in Finland and Europe – An overview. Available at: www.pelletime.fi. Accessed on: 28th January 2009.

[16] Mc Carthy A. SWS Group. Efficient trading of biomass fuels and analysis of fuel supply chains and business models for market actors by networking. WP 1: Current situation and future trends in biomass fuel trade in Europe. Country report of Ireland. Available at: www.eubionet.net. Accessed on: 28th January 2009.

[17] Sustainable Energy Ireland. 2007 Energy Balance. Available at: www.sei.ie. Accessed on: 02nd February 2009.

[18] Pellets Map® 2008/09. In Bioenergy International, 2008, 35.

[19] D-Pellets, Knocktopher, Co. Kilkenny, Ireland. Personal communication.

[20] Central Statistics Office, Skehard Road, Cork, Ireland. Personal communication.

[21] Energy Policy Statistical Support Unit. Energy in Ireland 1990-2007. Sustainable Energy Ireland, 2008; 51－53.

[22] McKendry P. Energy production from biomass (part 1): overview of biomass. Resource Technology, 2002; 83, 37－46.

[23] Rice B, Finnan J. The outlook for biofuels. Engineers Journal, 2009; 63(4): 210－213.

[24] Sokhansanj S, Kumar A, Turhollow A F. Development and implementation of integrated biomass supply analysis and logistics model (IBSAL). Biomass and Bioenergy, 2006; 30, 838－847.

[25] Tatsiopoulos I P, Tolis A.J. Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods. Biomass and Bioenergy, 2003; 24(3): 199－214.

[26] Ravula P P,Grisso R D, Cundiff J S. Cotton logistics as a model for a biomass transportation system. Biomass and Bioenergy, 2008; 32, 314－325.

[27] Perpina C, Alfonso D, Perez-Navarro A, Penalvo E, Vargas C, Cardenas R. Methodology based on Geographic Information Systems for biomass logistics and transport optimisation. Renewable Energy, 2009; 34, 555－565.

[28] Tatsiopoulos I P, Tolis A J. Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods. Biomass and Bioenergy, 2003; 24(3): 199－214.

[29] Velazquez-Marti B, Annevelink E. GIS application to define biomass collection points as sources for linear programming of delivery networks. Transactions of the ASABE, 2009; 52(4): 1069－1078.

[30] Nilsson D. Analysis and simulation of systems for delivery of fuel straw to district heating plants. Doctoral thesis. Swedish University of Agricultural Sciences, Upsalla, Sweden, 1999.

[31] Hansen A C, Barnes A J, Lyne P W L. Simulation modelling of sugar cane harvest-to-mill delivery systems. Transactions of the ASAE, 2002, 45(3): 531－538.

[32] Annevelink E, DeMol R M. Biomass logistics. Proceedings 15th European Biomass Conference Workshop WS1.1 Florence, Italy, 2007: ETA-Florence Renewable Energies.

[33] Diekema W H, DeMol R M, Annevelink E, Elbersen H W. Combining goals in the logistics bioenergy chains. In Proceedings 14th European Biomass Conference, 495-498. Florence, Italy, 2005: ETA-Florence Renewable Energies.

[34] Frombo F, Minciardi R, Robba M, Sacile R. A decision support system for planning biomass-based energy production. Energy, 2009; 34, 362－369.

[35] Rentizelas A A, Tolis A J, Tatsiopoulos I P. Logistics issues of biomass: the storage problem and multi-biomass supply chain. Renewable and Sustainable Energy Reviews, 2009; 13, 887－894.

[36] Nolan A, Mc Donnell K, Mac Siurtain M, Carroll J P, Finnan J, Rice B. Conservation of miscanthus in bale form. Biosystems Engineering, 2009; 104, 345－352.

[37] Nolan A, Mc Donnell K, Devlin G J, Carroll J P, Finnan J. Economic analysis of manufacturing costs of pellet production in the Republic of Ireland using non-woody biomass.

[38] Deverell R, Mc Donnell K, Devlin G. Potential bioethanol feedstock availability around nine locations in the Republic of Ireland. Energies, 2009; 2, 120－133.

[39] Department of Agriculture, Fisheries and Food, Energy Crop Division, Government Buildings, Old Abbeyliex Road, Portlaoise, Co. Laois, Ireland. Personal communication.

[40] Teagasc Crops Research Centre, Oak Park, Carlow, Ireland. Personal communication.

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(By Wang Yingkuan)