THE POTENTIAL OF EUROPEAN BIOMASS RESOURCES AND RELATED COSTS IN THE EU-27 AND THE UKRAINE

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ABSTRACT: In this paper the European biomass resource potential is assessed, distinguishing between; dedicated bio-energy crops, forestry residues and agricultural residues. A scenario driven assessment was used to calculate available arable and pasture land for the EU-27 and the Ukraine for the years 2010, 2020 and 2030. A bio-energy crop productivity and cost model estimate the potential yields and production cost. Three scenarios have been used for the calculation, each with a different rationale of development path and speed. Results indicate that the bio-energy potentials are strongly feedstock dependant. The supply potentials for the EU-27 and Ukraine range from about 2 EJ in 2010 for oil crop based feedstocks to 17 EJ for the best performing ligno-cellulosic feedstocks in 2030. Both production levels as well as the relative abundance of available land for the production of Bioenergy crops favour Central and Eastern European countries (CEEC) and the Ukraine. Production cost levels are on average lower in the CEEC than the Western European Countries (WEC). The cost supply potenital indicates that European domestic supply is substantial under the assumptions made in this analysis.

Keywords: biomass resource potential, dedicated bio-energy crops, cost analysis

1 INTRODUCTION

Ambitious targets by the European Union are set to drastically reduce green house gas emissions. Population growth and increasing wealth are responsible for an increase of (fossil) energy use. Although, the direct coupling between energy use and economic growth is becoming less strong, radical measures are to be taken to substantially reduce primary energy use and GHG emissions while allowing the global economy to grow.

In the year 2000 11,7 EJ of transport fuels were used in the EU-25, increasing by some 38% over 30 years to 16,1 EJ in 2030 [1].

The European Union has set targets for the European transport sector to reduce GHG emissions while allowing mobility to increase. In the bio-fuel directive a first target is set to blend 5,75% of bio-based fuels with conventional fuels in 2010 to reduce transport related emissions. Recently the target for 2020 was announced at 10%. Reviewing the ambitious reduction targets on the one hand and the European transportation fuel volumes on the other, it may be clear that a major challenge lies ahead.

As for fossil resources, bio-based resources are scarce, the limiting factor being available land. To assess how possible demand volumes relate to what can be produced globally, but more relevant in Europe, several studies have been conducted.

A number of studies have focused on global biomass potentials, of which a review study by Dornburg et al. (2007) [2] provides a comprehensive overview (e.g. [3], [4] and [5]), we do not elaborate on these studies further because of the difference in scope with our assessment.

A more detailed overview of assessments of the European biomass resource potential is presented below. The European Environmental Agency has [6] estimated the European potential for a wide range of feedstocks. In these estimates the EEA applied criteria to prevent negative environmental impacts resulting from large scale biomass resource use. In this environmental friendly claim, biodiversity is considered to be a major aspect. The VIEWLS study [7] focused on the Central and Eastern European Countries (CEEC) and calculated the cost-supply potential according to five IPCC based scenarios. Ericsson et al. [8] assesses the physical biomass resource potential according to five scenarios over three time periods. Although an extensive number of studies have been carried out and a broad area is covered, a comprehensive coupling of detailed cost and supply, both top-down and bottom up, is lacking.

This study is carried out as part of the REFUEL[1] project. The objective of this paper is to evaluate the cost-supply potential of domestic European biomass resources. These include agricultural residues, forest residues and dedicated bio-energy plants. It does so for three scenarios with rationales complying with current policies (i.e. the Common Agricultural Policy) and possible future policy transition paths to reach (ambitious) bio-fuel targets. Three elements of this assessment provide key results. Firstly, detailed cost calculations provide a spatial cost overview of 13 bio-energy crops for 28 countries in Europe. Secondly, IIASA's Agro-ecological Zones (AEZ) modeling framework is used to provide a detailed spatial assessment of agro-economically attainable yields for 13 promising bioenergy crops. Thirdly, cost-supply curves have been estimated for EU-27 and the Ukraine including bandwidths in cost and supply potential. Results indicate the total potential of different biomass resources and related production costs. Results identify promising European regions based on the combination of the spatial supply potential and related production costs.

[1] The REFUEL project is designed to encourage a greater market penetration of bio-fuels. To help achieve this goal, a bio-fuels road map is developed that is consistent with EU bio-fuel policies and supported by stakeholders in the bio-fuels field. Starting early 2006, the project involves seven renowned partners and will run 24 months to completion. REFUEL is funded by the European Commission under the 'Intelligent Energy - Europe' programme.

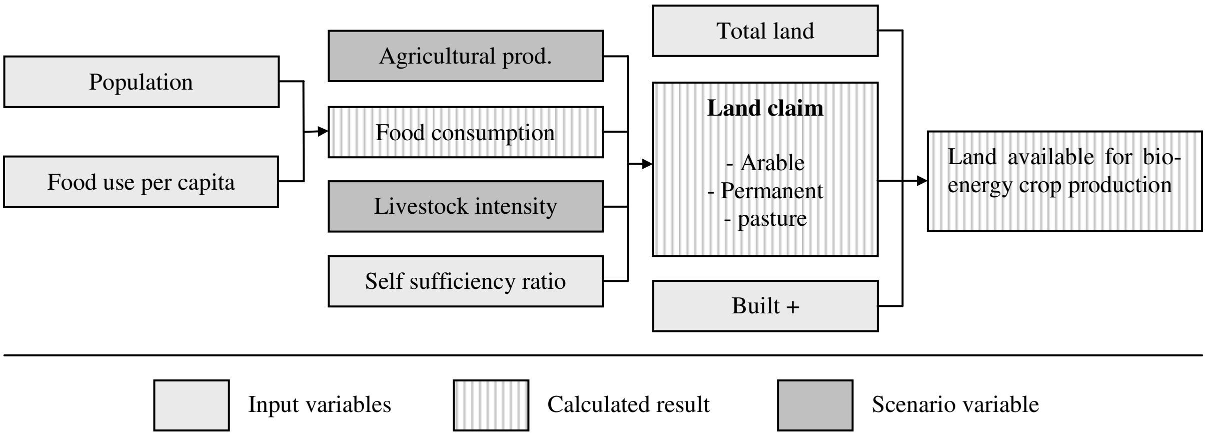

Figure 1: Modeling structure includes three types of variables, input variables (light grey), calculated results (striped) and (input) variables that are subject to scenario development (darker grey).

2 METHODOLOGY AND INPUT VARIABLES

2.1 Introduction

This chapter is divided in six paragraphs outlining the methodology applied. First (*2.2*), the potential of the available arable land and grassland in Europe is calculated by means of a (top-down) scenario analysis based primarily on country specific statistics. Second, the productivity of 13 bio-energy plants is determined by an bottom-up analysis using a detailed AEZ database of the included bio-energy crops (2.3). Thirdly, the results of the scenario analysis, i.e., the area potentially available for bio-energy plants, and the spatial AEZ bio-energy crop yield analysis are coupled; an overview of this part of the analysis can be found in Fischer et al. (2007) [9]. Section 2.4 describes a detailed bottom up economic analysis to estimate costs of bio-energy crop production. In addition country specific biomass availablility from forest and agricultural residuals as described in literature are included in the analysis (2.5 and 2.6).

2.2 Potential land area for bio-energy crop production

Figure 1 provides an overview of the variables included in the estimation of land available for bioenergy production. Details of the methodology are described in [9] of this conference proceedings.

The general approach comprises an estimation of future land area requirements for food and livestock sectors, with the remainder being available for bioenergy production while accounting for some agricultural land that will be converted to built-up and associated land areas.

Key factors driving changes in food and livestock sector land area requirements include a) demand (more specifically population growth and dietary changes); b) production intensity (crop yields and efficiency in livestock production); and c) Agricultural trade balance between Europe and the rest of the world.

Both cultivated land and pasture are considered as areas for growing biofuel feedstocks. The time frame is until 2030 and estimates are for individual countries.

An important assumption is that Europe will maintain its current (period 2000-02) level of self-sufficiency for food and feed crops as well as for livestock products. Thus the land becoming available for biofuel production is a result of future consumption and technological progress, e.g. through yield increases and improved feed conversion efficiencies. The resulting estimate can be interpreted as the land that becomes available without compromising food and feed production.

Agricultural productivity development

The production of food crops has over the last three decades shown a significant increase. The magnitude of this increase differs between the WEC and CEEC. In the WEC since the 1960's and 1970's, increasing fertilizer and pesticide use and improving farming practices, have led to large yield increases. While in some world regions yield increase is necessary to provide sufficient food, in Europe yield increases together with production incentives in the form of agricultural subsidies have led to overproduction in some sectors.

Future yields

The trend globally has been an increase in yields [11]. Causes underlying these increases are diverse. For projecting European yields, three scenarios are developed, see figure 2. Because of significant differences between the agricultural management system in the WEC and CEEC, we differentiate between these two regions when making yield scenario assumptions.

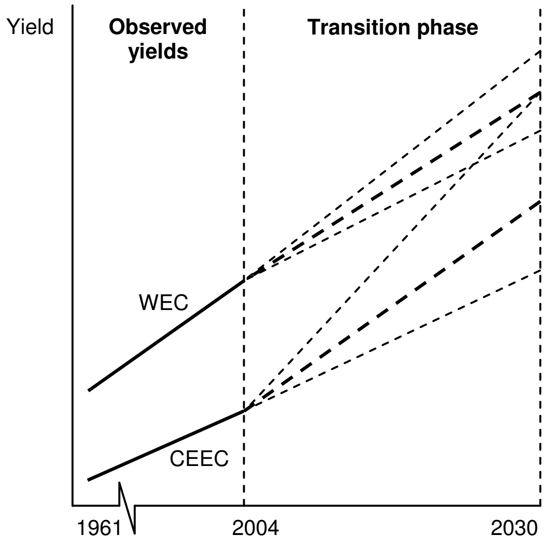

Figure 2: Three scenarios for agricultural productivity development in the Western European Countries (WEC) and the Central and Eastern European Countries (CEEC).

Baseline scenario

The baseline estimate for the WEC assumes that the historic trend, of observed yields, will be continued into the future. For the CEEC the baseline trend is estimated to increase faster than the historic trend extrapolation. The rationale is the assession of the CEEC to the European Union and the favarouble economic effect this may have on the economic situation in general and on the agricultural practice and related production intensity especially. It is assumed that the baseline CEEC yields will converge towards WEC 2005 yield levels.

Low estimate scenario

The lower estimate for the WEC is based on the assumption of an increase in the share of arable land under organic farming management. In a study by the FAO [12], it is estimated that organic farming leads to yield reduction of between 10% and 30% lower as compared to conventional intensive farming.

High estimate sceanrio

The high estimate scenario assumes higher yields compared to the baseline scenario due to an intensified production system. Therefore less land will be required for food and feed production and consequently additional land becomes potentially available for bioenergy production.

2.3 Biofuel feedstock potential

The biofuel feedstock potenital assessment is described in the conference proceeding by Fischer *et al.* [9] in chapter 2. The feedstock assessment provides a database with physical quantities per land unit and by land suitability class. Data is aggregated to NUTS 2 level. From the scenario projections outlined in the previous paragraph the total land available for bio-energy crop production is estimated on a country level. The combined data of the land availability and the potenital yield provide the total physical supply potential of the bio-energy crops. Within each crop group the best yielding feedstock type is selected to calculate the total potential yield in physical quantities for the EU-27 and the Ukraine. Using the (lower) heating values of the different feedstocks, a total energy supply potential is calculated.

2.4 Cost of the agricultural production of bio-energy crops

The calculation of the cost per unit of output of the agricultural production system requires quantification of physical inputs and of related unit costs of these inputs into the system. In figure 3 the cost factors are presented and their relations indicated. Total costs are composed of variable costs and fixed costs. The total costs, $Cost_{total}$, are calculated by adding the respective cost for capital goods (CC), land (CL), labour (CLab) and fertilizer (CF), all in € ha^{-1} yr^{-1}.

$$CT = CC + CL + CLab + CF$$

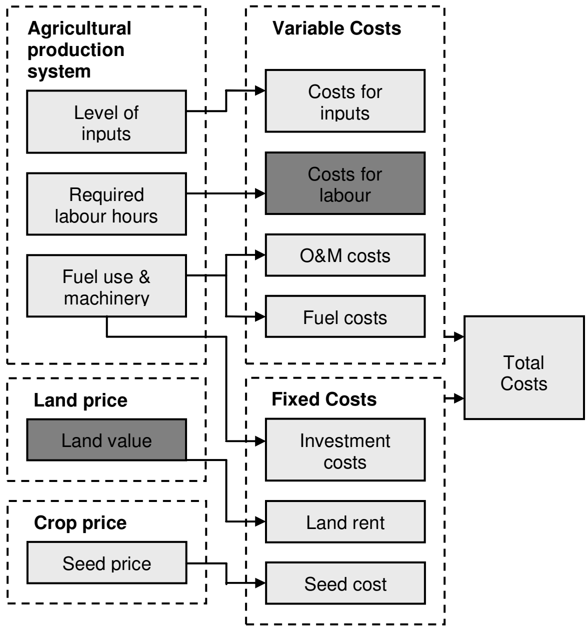

Figure 3: Schematic overview of cost factors in the agricultural production system. Indicated in light grey are input parameters that are assumed to be constant, indicated in darker grey are variables that are assumed to be subject to change as described in the scenario development (scheme derived from VIEWLS (2005) [7]).

2.4.1 Land costs

The Pan-european land surface is categorized in terms of suitability for growing bioenergy feedstocks. In total five suitability categories are distinguished (VS; very suitable, S; suitable, MS; moderately suitable, mS; marginally suitable and vmS; very marginally suitable).

The land of a specific suitability class i in a region is indicated by A_i (ha). Only the first three highest categories of suitability classes, i, are accounted for in the cost calculations. The land cost P is expressed in the cost per hectare per suitability class i indicated by P_i (in € ha^{-1} yr^{-1}). The remaining two lower suitability classes are assumed to have the price level of MS. The summation of the land prices and respected land areas is then divided by a region's total land, *A* (ha), to calculate average costs of land for each region.

$$CL = LCM \frac{\sum P_i \cdot A_i}{A}, \quad i = 1,3$$

With CL being the average land cost for a region (e.g. NUTS2, NUTS1), in € ha^{-1} yr^{-1}.

Development of land cost

In the base year the cost difference of land between the WEC and the CEEC is significant. Average land cost in the WEC is 214 € ha^{-1} compared to 24 € ha^{-1} in the CEEC. As presented in paragraph 2.1.3 the agricultural production in the CEEC is assumed, depending on the scenario, to achieve a substantially higher growth ratio than the WEC. A main reason of this higher agricultural production increase is the low baseline production and the rapidly improving economic situation in CEEC. Concurrently it is expected that the significant difference in land costs between WEC and CEEC will reduce over time. To account for this effect a time dependant multiplier is introduced in the projection of average land cost LCM in CEEC, as follows:

$$LCM = \left(\frac{CL_{WEC,0} - CL_{CEEC,0}}{T} \right) \cdot t + CL_{CEEC,0}, \quad t = 0,T$$

Table 1: Multiplier land costs in € ha^{-1} yr^{-1} and between brackets the average muliplier percentage per region per year. The average WEC land cost are assumed to stay constant at 210 € ha^{-1} yr^{-1}.

	2005	2010	2020	2030
CEEC – high	24 (100%)	61 (255%)	135 (564%)	210 (874%)
CEEC – baseline	24 (100%)	45 (186%)	86 (358%)	127 (530%)
CEEC – low	24 (100%)	24 (100%)	24 (100%)	24 (100%)

2.4.2 Fertilizer input costs

The costs of the fertilizer input are estimated using a nutrient balance method. Nutrients taken up by crops, including losses, must be replenished by fertilizers to maintain the soil nutrient balance. The average nutrient composition of crops is taken from the USDA nutrient report summary (2006) [13]. It is assumed that the nutrient composition of the harvested plant equals the nutrient uptake during its growth. This amount, corrected for certain additional nutrient sources, is to be applied to the field after harvest to account for the uptake. For instance, because of natural deposition of nitrogen the required nitrogen fertilizer that has to be applied is less than follows from the above gross calculations. A nitrogen uptake factor of 70% is applied to account for the amount of the deposition being actually sequestered by the soil. After the correction for the natural deposition and allowing for nutrient losses, the net input of compounds is determined. Three compounds are included being, Nitrogen (N), Phosphor (P) and Kalium (K).

$$CF = HC \left[P_N \cdot FF_N \left(\frac{CC_N - \alpha \cdot D_N}{\beta} \right) + P_K \cdot FF_K \cdot \left(\frac{CC_K}{\beta} \right) + P_P \cdot FF_P \cdot \left(\frac{CC_P}{\beta} \right) \right]$$

Where *HC* is weight of the harvested crop, in dry tons/ha. P_N, P_K and P_P represent the market prices of the fertilizers for respectively nitrogen (N), di-kalium-oxide (K_2O) and di-phosphor-pentoxide (P_2O_5) in €/100 kg (Eurostat, 2006). The crop composition, CC, indicates the quantity of the compound in the harvested crop in kg compound/ton harvested crop. The fertilizer factor, FF, is the ratio of fertilizer that has to be applied to compensate for the uptake of a certain compound. The fertilizer factors are for nitrogen 1 kg N/kg N, for Kalium 1,21 kg K_2O/kg K and for Phosphor 2,29 kg P_2O_5/kg P [13]. The country specific nitrogen deposition is denoted D_N in kg N/ha/yr. The uptake factor, α, indicates the fraction of the nitrogen deposition that is sequestered by the land. The general fertilizer use efficiency β used in the calculations is 0,45 [20], meaning that 45% of the nutrients in the soil is taken up by the plant.

2.4.3 Labour costs

Labour costs are determined by crop-wise input requirements and by the hourly labour cost (wage) with country-specific values. The labour inputs are derived from various references (e.g. [14] and [15]). The country specific labour costs for the agricultural sector are derived from LABORSTAT (2006) [16].

$$CL = LI_i \cdot (W_j \cdot LM_{j,t}),$$

Where LI_i is the crop i specific labour input in h ha^{-1} yr^{-1}, W_j is the country specific wage in the agricultural sector in € h^{-1}. The agricultural wage multiplier LM introduced in the scenario calculations is country specific and time dependant. The rationale and the values of the labour multiplier (LM) are explained below.

Because of changes in the economic situation due to the joining of the EU by the CEEC, wages will change. The wages are assumed to change in accordance with the overall agricultural production management system as proposed in the scenarios in the last paragraph. The average wage in the CEEC in 2005 is 3,73 €/h and 13,31 €/h for the WEC. Following the three scenarios we obtain percentages for the deviations of the wage from the 2005 level.

2.4.4 Capital costs

The capital costs comprise primarily expenses for machinery and maintenance. The actual expenses depend on the type of feedstock being produced and some regional differences may occur. Based on a literature review values for the capital expenses (CAPEX) are determined per crop in € ha^{-1} yr^{1}. Because of the rather limited number of suitable references, the overview is restricted to one or only a few case descriptions per crop. Regional differences in the cost are taken into account for labor, land and fertilizers. For the CAPEX however this may not be appropriate. Firstly, because the production of bio-energy crops will require massive new investments. From this perspective it is likely that the use and regional differences in existing capital goods (e.g. machinery) is of little importance. Second, it is assumed that the European market for state of the art agricultural machinery is open and therefore comparable, except for differences in tax regimes (e.g. VAT).

2.5 Forest felling residues

Country specific data on the forest residues are obtained from literature, Karjalaine [17] for the EU-25 and FAO [18] for the Ukraine, Romania, Bulgaria, Norway and Switzerland. Included in the overview are forest felling residues and the potentially sustainable harvetable amount of wood. This sustainable potential comprises the difference between the actual fellings and felling residues and the Net Annual Increment (NAI) an indicator for the yearly physical quantity of forest growth.

2.6 Agricultural residues

The agricultural residues data presented in the results of this paper are obtained from the VIEWLS database of which results and methodology are presented in the VIEWLS final report [19].

3. RESULTS

The results presented are all preliminary.

3.1 Available land for bio-energy crop production

The land potentially available for bio-energy production was calculated as explained in paragraph 2.2. For a detailed overview of results of available land for bio-energy plants see Fischer *et al.* [9].

3.2 Potential production from dedicated bio-energy plants

The results of the potential of dedicated biofuel feedstocks are based on (i) the available land, (ii) the yield potential of the specific plants, and (iii) the related production costs. On the basis of this information a cost-supply curve is plotted. This exercise is repeated for five feedstock groups, namely woody lignocelullosic plants, herbaceous lignocellulosic plants, oil crops, starch crops and sugar crops.

Figure 4 presents the cost-supply curves for woody lignocellulosic bio-energy plants. It indicates the annual supply potential and related cost for three time steps: 2010, 2020 and 2030. Assessed woody lignocellulosic bio-energy plants include poplar, willow and eucalyptus. Three shades of grey indicate the uncertainty areas stemming from the scenarios applied to the land availability and production costs.

Darkest grey is the uncertainty around the black curve for the margins in 2010, in medium grey the area for 2020 is indicated, and in the lightest grey the cost-supply range for 2030 is shown.

The supply potential for woody lignocellulosic bio-energy plants for the years 2010, 2020 and 2030 is estimated at; 6,0 EJ (5,8 – 7,6), 8,8 EJ (8,5 – 10,8) and 11,0 EJ (10,4 – 13,0), respectively. The cost ranges differ per year analysed due to variations in transition speed. In 2010 more than 80% of the supply potential is available at production costs between 1,0 and 3,0 € per GJ (at low heating value).

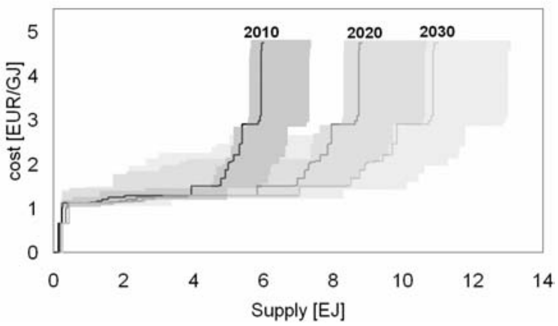

Figure 4: Cost-supply curve of woody lignocellulosic plants for the EU-27 and the Ukraine (with uncertainty ranges indicated in grey).

3.3 Summary: Total biofuel feedstock potentials

Three sources of biomass are presented, dedicated bio-energy plants, forest residues and cuttings and agricultural residues. Potenitals were estimated for different years and scenarios.

Figure 5 presents the total biomass resource potential in 2030 for the three sources of feedstocks. The countries are presented in descending order of the country specific potential. The total biomass potential amounts to 19,4 EJ (at low heating value), under the assumption of the best performing lignocellulosic crops for the high estimate scenario.

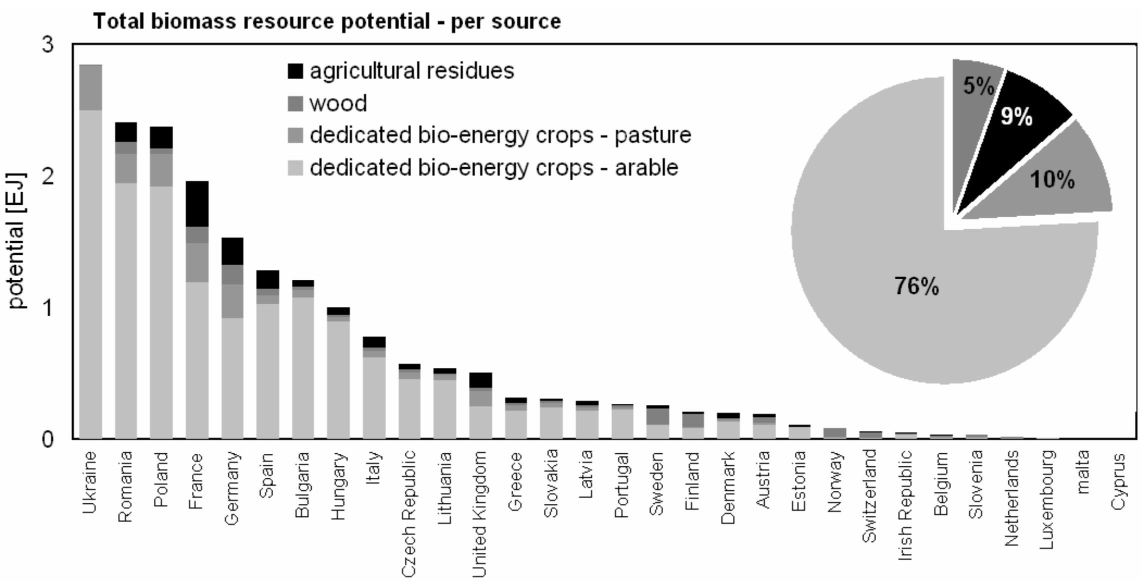

Figure 5: *prelimineary result* – total biomass potential in the EU27 and the Ukraine in 2030 based on the best performing bio-energy crop. This overview excludes agricultural residues for ther Ukraine.

3.4 Spatial distribution of biofuel feedstock potential.

The potential for growing bio-energy crops depends on available land and region-specific estimated yields. In figure 6 a sketch of land availability is presented. The map shows approximately 300 NUTS2 regions with the respective percentage of the land available for bio-energy feedstock production in 2030. This percentage indicates the share of land available for bioenergy as part of the total land of each administrative unit. The darker green colours indicate a higher availability of land for bio-energy crop production.

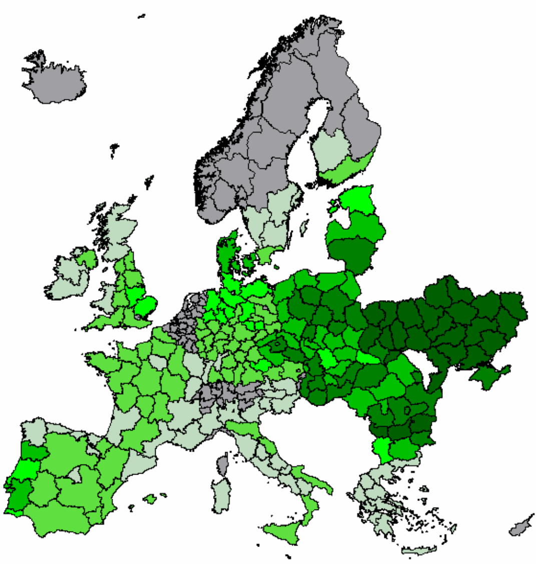

Figure 6: Land area potentially available for bio-energy crop production as a share of the total land in 2030.

4. CONCLUSION

From the preliminary results it can be concluded that there is a substantial biomass supply potential in the EU-27 and the Ukraine. Depending on the scenario assumptions, supply potentials and production costs differ significantly between regions and types of feedstocks. In general the CEEC have a larger supply potential at lower costs. Preliminary results indicate that the supply potential ranges from just over 2 EJ for oil crops in 2010 in the low scenario to over 17 EJ for the best performing dedicated biofuel feedstocks, mostly from lignocellulosic plants, under the high scenario assumptions in 2030.

Further work will be done on 'finetuning' of the results. This will include incorporating feedbacks from other work packages in the REFUEL project, to establish a final rationale and related input paramter values.

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