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Modelling of biomass resources suitable for fuel at regional level

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This paper deals mainly with modelling the amount of cutting residues and timber volumes as well as agricultural biomass suitable for fuel in Lithuania. Available methods to quantify forest cutting residues, oriented to getting summarized statistics from forestry data are analysed and the results are presented. Conventional cutting budget calculation methods are used to provide input data for the estimation of potential volumes of forest biomass suitable for fuel, such as small diameter trees from thinning cuttings, felling residuals and stumps from final felling.

Spatial modelling based on geographic information systems (GIS) is used to get the amounts of potential agricultural biomass suitable for fuel. Based on official statistics, trends in the yield of the main agricultural crops during the years 2000–2005 are discussed. Conventional yield parameters have been transformed into energetic values to cover the following product lines: heat production from straw (wheat, rye and barley), grain (wheat, rye and barley); bio-ethanol production from grain (winter wheat and rye), potatoes and sugar beet; and biodiesel production from rapeseed oil. Based on the information on soil and land use, potential yields of any crop have been modelled for all Lithuanian counties. The results presented in the paper in the form of a table and a map are expected to become the key parameter for constructing operational bioenergy development scenarios.

Key words: agriculture, bioenergy, biomass, cutting residues, geographic information systems, modelling

1. INTRODUCTION

The share of renewable energy sources in the primary energy balance of Lithuania in 2005 was 8.7% [1]. The strategic goal of the European Union for 2010 is 12%. Existing hydro-, wind and biomass combined heat and power (CHP) plants and installation of new ones will also add 7% (22% the EU goal) of electricity generation from renewable energy sources in 2010 [1]. The proposal for the Directive on the promotion of the use of energy from renewable sources sets a 20% share of renewable energy sources (RES) and a 10% binding minimum target for biofuel and transport overall in the EU by 2020. This figure for Lithuania is even higher and equals 23% [2].

Lithuania, with its agricultural and forest resources, has a huge potential for biomass energy production. Forests occupy 32.7% of the Lithuanian territory, which is less than in other Baltic countries; however, forestry plays an important role in the country's economy. Forests of the country are inventoried, their management is planned and the utilization is performed using well established concepts and practices. Nevertheless, the use of forest resources for fuel is far from the optimal and is based on quite outdated approaches [3].

The aim of this paper is to test some methods of modelling the biomass resources suitable for fuel to be introduced into operational spatial planning techniques at a regional level. To reach this aim, we summarize the existing statistical and geographic datasets in Lithuania suitable for regional land use planning, with a special emphasizes on bioenergy, namely basic geographic databases, including remotely sensed images, agro, forest, soil, other relevant databases; technical parameters of databases; accessibility of information, etc.

Later we use selected / developed methods to incorporate the above information into bioenergy-related models: technical parameters for modelling specific crops and solid fuel recovery methods; use of soil, meteorological and other data for modelling the bioenergy potential; methods for GIS applications in analysing and displaying biomass resources; the use of GIS in spatial planning; possible experiences from other projects, etc. [3].

General statistics on the acreages and yields of main agricultural crops, available from statistical bulletins and other similar sources, provides just a retrospective view of the resource availability. To visualise the future yield trends and changes in crop rotations, a statistical time series of at least 5 years are needed. Via extrapolations, conclusions about the yield development of crops are considered feasible [4]. However, most of agricultural biomass assessment models depend first of all on statistically verified yield data on each crop in a crop rotation system [5]. After the development of a biomass assessment model, its validation and adjustment are always required. This can be accomplished by comparing the modelled results with statistical data [6].

2. MODELLING METHODS

2. 1. Methods for biomass fuel resources available from forests

There are two potential sources of forest resource information in Lithuania: the conventional stand-wise forest inventory and the National Forest Inventory (NFI) using sampling methods. Detailed descriptions of the inventory systems and data collected are far behind the scope of this paper and can be found in numerous other sources [7–10]. Our focus was on two general uses of the information available:

- estimation of the biomass potential from Lithuanian forests to be used at the level of strategic planning;
- estimation of the biomass potential from Lithuanian forests to be used at the level of tactical or operational planning.

As a framework method of the estimation of forest biomass for strategic planning, the approach used in the Global Forest Resources Assessment 2005, conducted by Food and Agriculture Organization of the United Nations (FAO), has been selected [11]. Biomass is estimated for three groups: above-ground biomass, below-ground biomass and dead wood biomass. The biomass of separate tree species was estimated using the Basic Wood Density of Stem Wood [11]. The latter was estimated according to the tree species composition.

The total amount of biomass as calculated does not display the amount of biomass potentially available as biofuel for energetic purposes. Therefore, to improve the data at the strategic level, additional approach was used. We assumed three main parts of the total forest biomass as the potential for biofuel: small-diameter trees from thinning cuts, logging residues from all types of felling, and stumps from final felling. As a source material, we used characteristics of compartments from the stand-wise forest inventory and the average annual allowable cutting amount calculated on the base of a 10-year rotation period from the stand-wise inventory data.

It was assumed that all thinned wood in young stands (under 20 years) may be utilized as fuel. Logging residues are residues from all types of felling except thinning. Stumps may be available from final felling only. Stand volume was converted into biomass units, using the approach described above.

The estimated volumes of wood biomass can be considered as the theoretical wood waste potential. Various sources in Lithuania indicate that 10–18% of cutting residues can be extracted from the forests for energy needs and some part of them must be left in the forests. Some biomass is used for duff under heavy mechanisms, some other part of it is hardly available from the forests as it is not economic to extract it.

The methods described above were used to get the general data which can be used for strategic planning only. Solutions for tactical and operational planning are expected to be achieved using the mathematical model for estimating the amount of cutting residues and the volumes of timber suitable for fuel on a forest compartment level. This model was developed by a team led by Dr. A. Tebėra at Kaunas Forest and Environmental Engineering College [12]. The model was developed on the base of intensive field studies carried out in 2006–2007 by the team itself. The main reason for developing such model was as follows: currently available methods of estimating the cutting residues were developed several decades ago and nowadays do not reflect the increased forest yield, economic and environmental conditions.

The model for calculating resources of biomass suitable for fuel for each forest compartment is based on standard stand-wise inventory data as the input [12]. First of all, the density of branch timber in kg/dm^3 (alive and dead branches) is defined for seven main forest tree species. Models to evaluate the volume of alive / dead branches are based on the second-degree polynomial functions and take into account the main parameters of a single tree – diameter at breast height, height class and age. An example of such model for pine trees is shown in Eq. 1:

$$\begin{aligned} V_{abr} = {} & 0.1224619D^2 - 0.77279D + 3.090 - \\ & - 0.0094262D^2h - 0.32971Dh + 3.8932h + \\ & + 0.004375Adh - 0.05479Ah - 0.021875DA + \\ & + 0.27396^{a}, \end{aligned} \quad (1)$$

where: V_{abr} – volume of alive branches, dm^3,

D – tree diameter at breast height, cm,

h – stand height class (1–5),

A – age, years.

To determine the amounts of branches potentially suitable for biofuel, another model is used (see Eq. 2):

$$\begin{aligned} V_{fuel} = {} & [20 + (-3.75T^2 + 25.25T - 1.25) \times \\ & \times (-0.333H + 1.3333)] V_{br} / 100, \end{aligned} \quad (2)$$

where: V_{fuel} – volume of branches suitable for fuel, m^3,

T – degree of soil fertility,

H – degree of soil humidity,

V_{br} – total volume of branches, m^3.

To operate the models on the stand level, models of tree number distribution by diameter classes are used. To run the model, special software has been developed, which is compatible with the functionality of the Integrated State Forest Cadastre Information System.

2.2. Methods for biomass fuel resources available from agriculture

To model the yields of agricultural crops, a soil database at a scale of 1 : 250000 was developed using a soil map of appropriate scale. The definitions of the study area soils were based on soil typological units of the old genetic soil classification of Lithuania (TDV-96) and on soil typological units (TDV-990-No) of the new soil classification system (LTDK-99) [13] which is based on the international soil classification [14]. To estimate the potential yield of all possible agricultural crops, the soils were grouped according to the soil type category and within soil type on soil subtype, soil genera, soil phase, species and soil variety categories. Within soil type category, soils were grouped into classes according to:

(1) the depth of calcaric material occurrence and soil hydromorphism (natural drainage), and (2) the texture of topsoil, subsurface and subsoil.

The agricultural conditions are different all over the country, there are differences in soil fertility, fragmentation of agricultural fields. This leads to different yields of agricultural crops. The yields of main agricultural crops (common winter wheat, winter rye, barley, potatoes, sugar beet and rape) important for biomass energy have been modelled (see an example in Fig. 1).

Only agricultural areas were taken into account; any other area, e. g. forest, built-up areas, orchards, natural grasslands, etc. were removed from the database.

For the modelling purposes and assuming which energy plants could be most appropriate for energy use within the Lithuanian agricultural sector, six bioenergy production lines were estimated using the above method:

- straw and grain for production of heat or heat and electricity, using three main cereals – wheat, rye, barley;
- grain, potatoes and sugar beet for bioethanol production; and
- rapeseed oil for biodiesel production.

The main assumptions used in energy assessment of the mentioned production lines are provided in Table 1.

The modelling of agricultural biomass available for fuel was performed assuming that the whole agricultural area is used for a single product line (e. g. cereal – wheat).

3. BIOMASS RESOURCES AVAILABLE FOR FUEL BY COUNTIES

3.1. Forest biomass resources

The total amount of forest biomass in Lithuanian counties is summarized in Table 2, and its special distribution is illustrated in Fig. 2. Taking into account only the above-ground biomass,

Table 1. **Main assumptions for energy assessment of six production lines**

Product line	Moisture content, %	Losses, %	Other use, %	Energy value, MWh/t	Extraction, %	Share grain-straw
Heat or heat/electricity generation						
Straw	15	10	50	3.44	20	1 : 1 (rye, wheat); 1 : 1.25 (barley)
Grain	15	10	50	4.72 (wheat, barley); 4.75 (rye)	20	
Bioethanol production						
Grain (wheat, rye)	15	10	50	6.43	27.30 wheat 30.42 rye	
Potatoes	Dry matter 18–25%			7.75	8.00	
Sugar beet				8.3268	8.60	
Biodiesel production						
Rape				9.25	33	

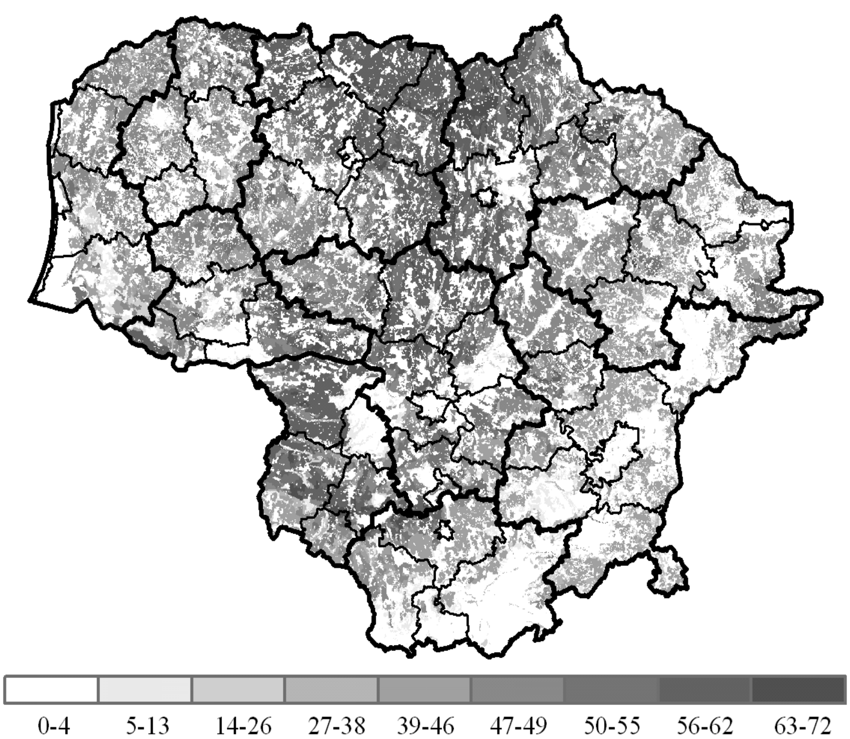

Fig. 1. The soil fertility grades for all Lithuanian agricultural areas

Fig. 2. Total forest biomass in Lithuanian counties, thous. tonnes

Table 2. **Total amount of forest biomass in Lithuanian counties**

County	Above-ground biomass	Below-ground biomass	Dead wood biomass
	Tonnes		
Alytus	28 592 799	6 576 344	2 645 493
Kaunas	24 205 474	5 567 259	2 333 100
Klaipėda	10 854 411	2 496 515	1 224 094
Marijampolė	10 641 838	2 447 623	933 215
Panevėžys	20 122 621	4 628 203	2 119 048
Šiauliai	20 147 231	4 633 863	2 213 325
Tauragė	14 603 454	3 358 794	1 370 378
Telšiai	11 939 912	2 746 180	1 343 051
Utena	23 963 128	5 511 519	2 362 769
Vilnius	42 234 082	9 713 839	3 900 544
Total in Lithuania	**207 304 950**	**47 680 139**	**20 445 018**

Table 3. **Amount of forest biomass and energy potential in forests of Lithuanian counties**

County	Small diameter trees from thinning cuts		Logging residues from all type of felling		Stumps from final felling	
	Tonnes	Energy value, MWh	Tonnes	Energy value, MWh	Tonnes	Energy value, MWh
Alytus	6 894	19 303	77 593	217 260	47 411	132 751
Kaunas	15 539	43 509	99 505	278 614	87 818	245 890
Klaipėda	5 633	15 772	32 882	92 070	25 103	70 288
Marijampolė	5 210	14 588	42 587	119 244	36 298	101 634
Panevėžys	13 005	36 414	89 476	250 533	74 433	208 412
Šiauliai	10 950	30 660	84 511	236 631	71 933	201 412
Tauragė	6 865	19 222	62 896	176 109	56 860	159 208
Telšiai	5 914	16 559	40 559	113 565	32 799	91 837
Utena	7 461	20 891	85 841	240 355	72 118	201 930
Vilnius	11 486	32 161	143 834	402 735	105 407	295 140
Total in Lithuania	**88 957**	**249 080**	**759 686**	**2 127 121**	**610 179**	**1 708 501**

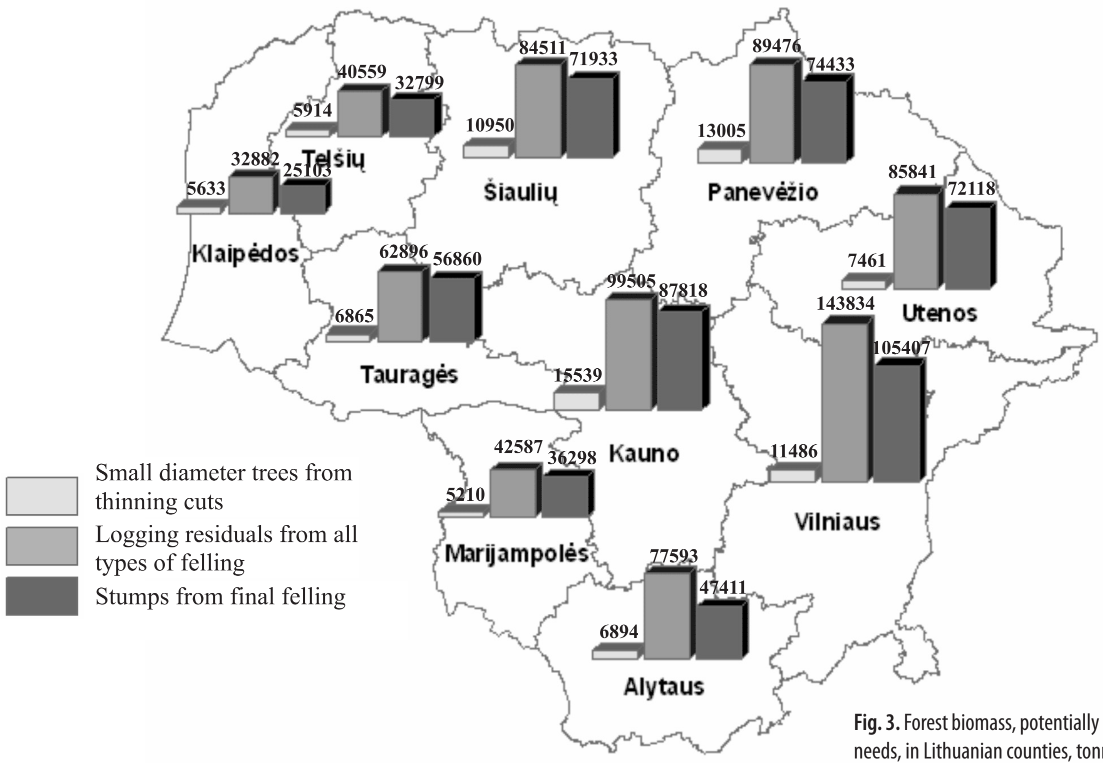

Fig. 3. Forest biomass, potentially usable as fuel for energy needs, in Lithuanian counties, tonnes

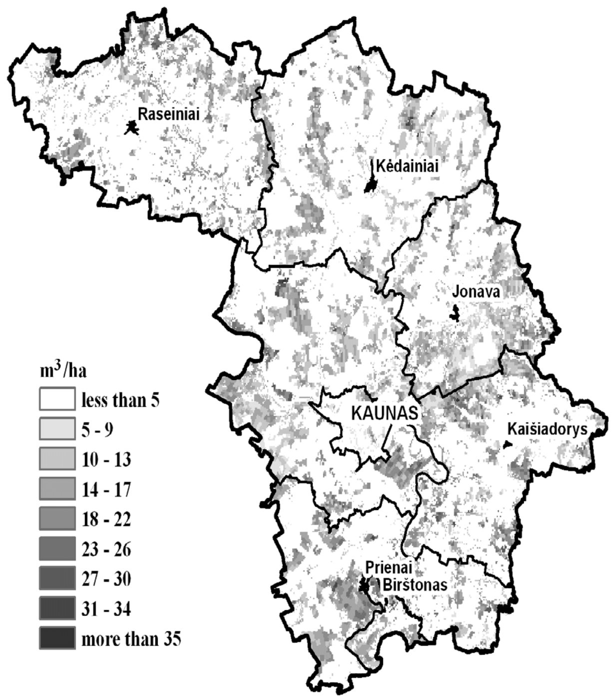

Fig. 4. The average availability of branches for fuel in forests of Kaunas county, m^3/ha

it exceeds 200 million tonnes in the whole country. All biomass amounts to 275 million tonnes.

Around 1.5 million tonnes of biomass annually fit the category of forest resources potentially suitable as a fuel for energetic needs (Table 3). Largest amounts of potential forest fuel resources are concentrated in the more forested south-eastern parts of the country (Fig. 3). One can clearly see that the largest potential is contained in utilization of logging residuals from all types of cuttings – 49–59% out of all amounts, averaging half of total forest biomass, suitable as fuel. Quite important source for biomass as fuel could make stumps from final felling, if operational technologies for collection and preparation for burning processes existed.

The amounts of cutting residues estimated at the forest compartment level, calculated using Eqns. 1 and 2 and the software developed, are provided in this paper in the form of a map for the Kaunas county (Fig. 4). True, these are only theoretical values, assuming that all branches are involved for bioenergy use throughout the whole forest area. A detailed forest management planning involves selecting some compartments assigned for a certain type of felling, estimating the costs of e. g. picking up branches and delivering them to the nearest road, etc.

3.2. Agricultural biomass resources

The assessment of the agricultural biomass potential appeared to be very different from that of forestry. The specifics of agricultural crops is highly dependent on various factors, including availability of production of purchasing companies, state priorities for certain crops, volumes and purchasing prices of strategic products like cereals, etc. This influences annual yields of different products significantly.

For assessment, the past and ongoing trends in the production of agricultural biomass, statistical data on yields, acreages and harvest amounts were collected for Kaunas County for the period 2000–2005 (six years). Practically none of agricultural crops maintained stable acreages during 2000–2005 (Fig. 5). Trends vary depending on the crop and municipality. Rape acreages have shown some steady tendency in all municipalities, but the acreages of winter rye have decreased.

Maximal theoretical yields of the main energy products were calculated for all counties of Lithuania (Table 4). The as-

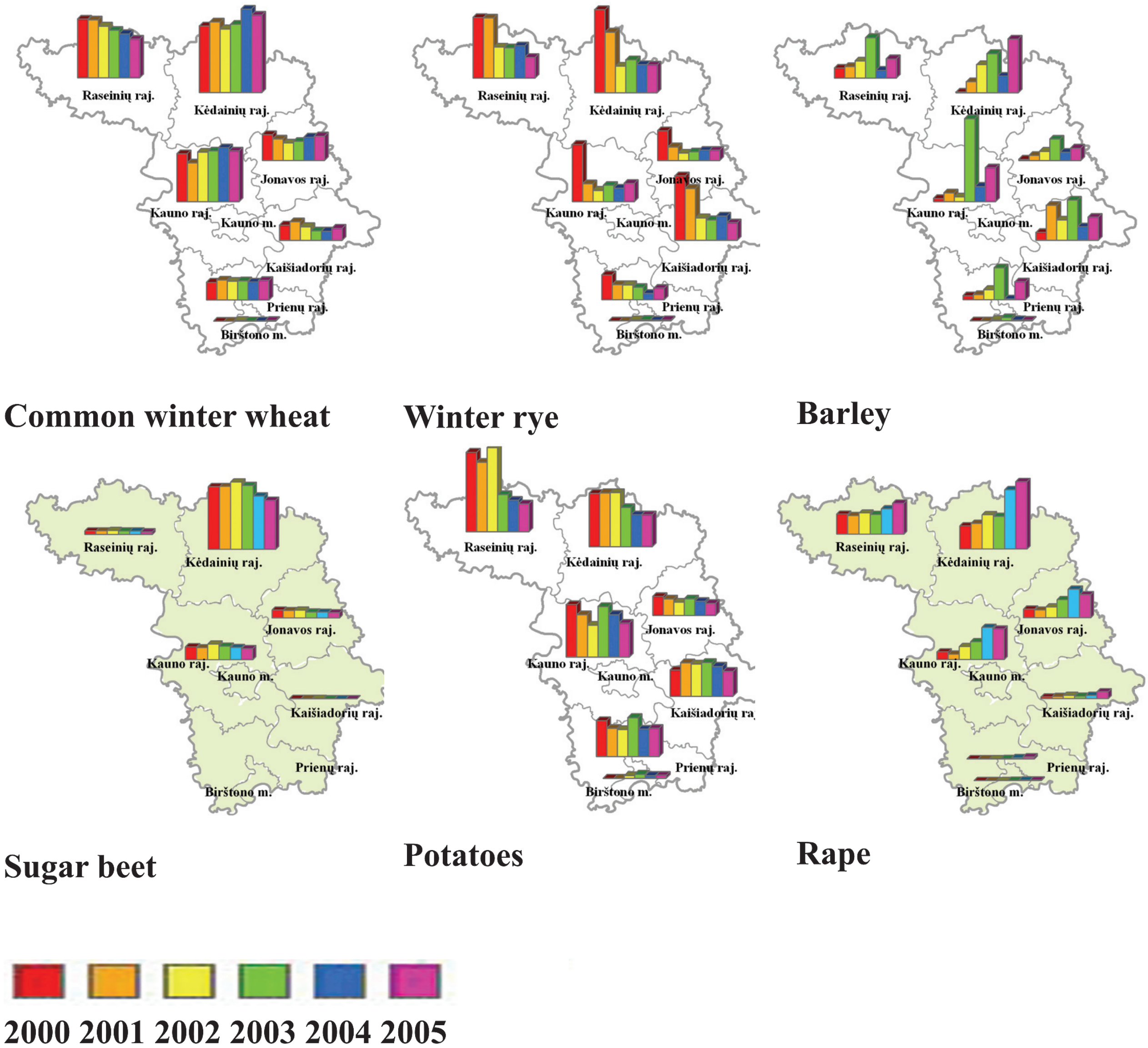

Fig. 5. Area under main agricultural crops in Kaunas County in 2000–2005

Table 4. **Theoretical yields of agricultural plants by Lithuanian counties, tonnes**

County	Area, thous. ha	Wheat	Rye	Barley	Potatoes	Sugar beet	Rape
Alytus	560	22 988	823 894	837 211	35 929	852 537	1 792
Kaunas	720	49 126	2 269 150	2 072 618	59 454	1 957 383	2 304
Klaipėda	310	30 245	1 211 089	1 196 502	35 812	1 101 098	992
Marijampolė	362	32 090	1 509 149	1 379 332	29 822	1 293 777	1 158
Panevėžys	570	51 808	2 570 040	2 298 182	54 417	2 132 585	1 824
Šiauliai	634	56 281	2 944 663	2 591 276	60 923	2 405 109	2 029
Tauragė	299	26 987	1 184 164	1 095 567	33 199	1 036 023	957
Telšiai	407	25 082	1 065 444	996 682	56 042	953 337	1 302
Utena	825	39 655	1 621 890	1 509 053	55 112	1 524 235	2 640
Vilnius	918	47 117	1 752 509	1 761 225	93 142	1 761 125	2 938
Total	**5 605**	**381 379**	**16 951 992**	**15 737 649**	**513 850**	**15 017 210**	**17 936**

sumption made here was that only a specific sort of agricultural plant is grown on all agricultural areas of a county. This provides a background for estimating the theoretical energy potential for six product lines in case 100% of yield of these plants would be used for energy needs (Table 5).

The figures discussed in Fig. 5 should be considered as the starting point for constructing operational bioenergy development scenarios in every county. The general figures can be used only on a very basic strategic planning level; however, the data sources developed within the frames of the study fit any task

Table 5. **Theoretical energy potential for six product lines in Lithuanian counties, MWh**

County	Area, thous. ha	Wheat	Rye	Barley	Potatoes	Sugar beet	Rape
Straw for heating and electricity generation needs							
Alytus	560	91 951	3 295 576	2 679 075			
Kaunas	720	196 502	9 076 599	6 632 379			
Klaipėda	310	120 982	4 844 357	3 828 806			
Marijampolė	362	128 360	6 036 596	4 413 863			
Panevėžys	570	207 234	10 280 162	7 354 182			
Šiauliai	634	225 126	11 778 652	8 292 083			
Tauragė	299	107 949	4 736 655	3 505 815			
Telšiai	407	100 327	4 261 774	3 189 383			
Utena	825	158 619	6 487 559	4 828 969			
Vilnius	918	91 951	3 295 576	2 679 075			
Grain for heating and electricity generation needs							
Alytus	560	231 873	10 778 461	9 782 758			
Kaunas	720	142 759	5 752 674	5 647 489			
Klaipėda	310	151 465	7 168 458	6 510 447			
Marijampolė	362	244 536	12 207 692	10 847 419			
Panevėžys	570	265 648	13 987 150	12 230 822			
Šiauliai	634	127 380	5 624 778	5 171 077			
Tauragė	299	118 386	5 060 857	4 704 341			
Telšiai	407	187 171	7 703 977	7 122 730			
Utena	825	222 391	8 324 420	8 312 982			
Vilnius	918	231 873	10 778 461	9 782 758			
Bioethanol production							
Alytus	560	46 435	1 664 266		21 486	548 182	
Kaunas	720	99 234	4 583 683		35 554	1 258 597	
Klaipėda	310	61 096	2 446 400		21 415	708 006	
Marijampolė	362	64 822	3 048 481		17 833	831 899	
Panevėžys	570	104 653	5 191 482		32 541	1 371 252	
Šiauliai	634	113 688	5 948 219		36 432	1 546 485	
Tauragės	299	54 514	2 392 011		19 853	666 163	
Telšiai	407	50 665	2 152 196		33 513	612 996	
Utena	825	80 103	3 276 217		32 957	980 083	
Vilnius	918	95 176	3 540 069		55 699	1 132 404	
Biodiesel production							
Alytus	560						16 576
Kaunas	720						21 312
Klaipėda	310						9 176
Marijampolė	362						10 715
Panevėžys	570						16 872
Šiauliai	634						18 766
Tauragė	299						8 850
Telšiai	407						12 047
Utena	825						24 420
Vilnius	918						27 173

Table 6. **Possible scenario for several product lines**

Product line	Share of energy use in total yield, %
Wheat straw for heating and electricity generation needs	30
Rye straw for heating and electricity generation needs	30
Barley straw for heating and electricity generation needs	30
Wheat grain for heating and electricity generation needs	5
Rye grain for heating and electricity generation needs	5
Barley grain for heating and electricity generation needs	5
Bioethanol production from wheat	10
Bioethanol production from rye	10
Bioethanol production from potatoes	15
Bioethanol production from sugar beet	15
Biodiesel production from rape seed oil	50

related to the local tactical or even operational planning of bioenergy-related projects.

4. GIS-MODELLING POSSIBILITIES FOR REGIONAL SPATIAL PLANNING NEEDS

Facts concerning biomass fuel potential resources available from forests and agriculture, presented above, can be used at the strategic planning level. However, it is extremely important to downscale the parameters to the level suitable for the tactical and even the operational planning. Here, we calculate the theoretical bioenergy potentials; however, the technical and especially the economic potential will depend on many other factors. These are ecologic, including land use and environmental impact criteria; socioeconomic, including employment, financing, resource use and social criteria; and planning aspects. Based on the above factors, various scenarios of the production and use of bioenergy should be generated. These scenarios could be based on the percentage of existing demand, current production level, political preferences and support programs for energy crops as well as existing prices of wood and agricultural products.

One of the possible scenarios for agricultural crops could be, e. g., the one presented in Table 6. Since agricultural crops are much more dependent on the state and EU support policy, products' purchasing prices, land quality, etc., there could be several scenarios developed for the needs of a region.

5. CONCLUSIONS

1. The total forest biomass in Lithuania amounts to 275 Mt; its above-ground biomass exceeds 200 Mt. Around 1.5 million tonnes of biomass fits the category of forest resources, potentially suitable as fuel for energy needs, annually resulting in more than 5 TWh.

2. A model for the estimation of biomass for fuel from forest cutting residues has been developed and seems to be operational for regional planning needs.

3. The maximal theoretic energy values of main cereals and other agricultural crops can be modelled using GIS-based approaches.

4. Relatively largest amounts of energy could be achieved using cereals and sugar beet as energy crops. Cereals could be used for heat and electricity generation as well as for bioethanol production, which is also a good possibility for sugar beet.

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BIOMASĖS IŠTEKLIŲ KURUI MODELIAVIMAS REGIONŲ LYGYJE

S a n t r a u k a

Aprašomas kirtimo atliekų, medienos tūrių ir žemės ūkio biomasės, tinkamų kurui, modeliavimo atvejis ir pavyzdys Lietuvoje. Išnagrinėti taikomi miško kirtimo atliekų vertinimo metodai, grindžiami apibendrintais miškotvarkos duomenimis, bei pateikti gauti rezultatai. Įprastiniai kirtimo apimčių skaičiavimo metodai buvo taikomi, siekiant gauti pradinius duomenis, tokius kaip mažo skersmens medelių iš ugdymo kirtimų, kirtimo atliekų ir kelmų iš pagrindinių kirtimų kiekiai, tolesniam miško biomasės, tinkamos kurui, potencialių kiekių nustatymui.

Geografinėmis informacinėmis sistemomis pagrįstas erdvinis modeliavimas buvo naudojamas siekiant nustatyti potencialius žemės ūkio biomasės, tinkamos kurui, išteklius. Aptartos pagrindinių žemės ūkio augalų derlių kitimo 2000–2005 metais tendencijos, pagrįstos oficialiąja statistika. Įprastiniai derliaus parametrai buvo perskaičiuoti į energetines vertes, siekiant apibūdinti šias sritis: šilumos gamybą iš šiaudų ir grūdų (kviečių, rugių, miežių), bioetanolio gamybą iš grūdų (kviečių, rugių, miežių), bulvių bei cukrinių runkelių ir biodyzelino gamybą iš rapsų aliejaus. Potencialūs bet kurių nagrinėjamų augalų derliai buvo sumodeliuoti visose Lietuvos apskrityse, remiantis informacija apie dirvožemius ir žemės naudojimą. Tikimasi, kad sprendimai, pateikiami šiame straipsnyje, bus taikomi rengiant operatyvinius bioenergetikos plėtros scenarijus.

Raktažodžiai: žemės ūkis, bioenergija, biomasė, kirtimo atliekos, geografinės informacinės sistemos, modeliavimas

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МОДЕЛИРОВАНИЕ ПРИГОДНОЙ ДЛЯ ТОПЛИВА БИОМАССЫ НА РЕГИОНАЛЬНОМ УРОВНЕ

Р е з ю м е

Описывается моделирование объемов отходов рубки леса и древесины, а также пригодной для топлива сельскохозяйственной биомассы в условиях Литвы. Проанализированы методы, применяемые для оценки отходов рубки, на основе данных лесоустройства; представлены полученные результаты. Применялись общепринятые методы расчёта объемов рубки для определения исходных данных, таких как количество деревьев малого диаметра из рубок ухода, отходов рубки и пней из рубок главного пользования, в целях определения потенциальных объемов лесной биомассы, пригодной для топлива.

Пространственное моделирование на основе географических информационных систем использовано для определения потенциальных ресурсов пригодной для топлива сельскохозяйственной биомассы. На основе статистических данных выявлены тенденции изменения урожая в течение 2000–2005 гг. Общепринятые параметры урожая были трансформированы в энергетические величины для характеристики по следующим областям: производства тепловой энергии из соломы и зерна пшеницы, ржи, ячменя, производства биоэтанола из зерна (пшеницы, ржи, ячменя), картофеля и сахарной свеклы, а также биодизелина из рапсового масла. Потенциальные урожаи любых обсуждаемых культур были смоделированы для всех округов Литвы на базе информации о почвах и использовании земли. Предполагается, что результаты, представленные в настоящей статье в виде таблиц и карт, станут основой для разработки оперативных сценариев развития биоэнергетики.

Ключевые слова: сельское хозяйство, биоэнергия, биомасса, отходы вырубки, географические информационные системы, моделирование