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The potential biomass for energy production in the Czech Republic

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Abstract

Biomass production is a promising alternative for the Czech Republic's (CZ) agricultural sector. Biomass could cover the domestic bio-energy demand of 250 PJ a^{-1} (predicted for 2030), and could be exported as bio-fuels to other EU countries. This study assesses the CZ's biomass production potential on a regional level and provides cost–supply curves for biomass from energy crops and agricultural and forestry residues. Agricultural productivity and the amount of land available for energy crop production are key variables in determining biomass potentials. Six scenarios for 2030 with different crop-yield levels, feed conversion efficiencies and land allocation procedures were built. The demand for food and fodder production was derived from FAO predictions for 2030. Biomass potential in the CZ is mainly determined by the development of food and fodder crop yields because the amount of land available for energy crop production increases with increasing productivity of food and fodder crops. In most scenarios the NUTS-3 regions CZ020, 31 and 32 provided the most land for energy-crop production and the highest biomass potentials. About 110 PJ a^{-1}, mostly from agricultural and forestry residues, can be provided from biomass when the present Czech agricultural productivity is maintained. About 195 PJ a^{-1} (105 PJ from energy crops) can be provided when production systems are optimised with regard to fertilizer regimes and 365 PJ a^{-1} (290 PJ from energy crops) when the yield level of Dutch agriculture is reached. Costs for woody biomass decrease with increasing plantation yield and range between 2.58 and 4.76 € GJ^{-1}. It was concluded that Czech agriculture could provide enough biomass for domestic demand and for export if agricultural productivity is increased.

Keywords: Czech Republic; Biomass potential; Agricultural production areas; Cost–supply curve

1. Introduction

The Czech Republic (CZ) became a European Union member on 1 May 2004, and thus Czech agricultural production is now directed by the EU's Common Agricultural Policy (CAP) and products must compete on the common European market. Today agriculture in most Eastern European countries is characterized by lower productivity than in Western European countries, in physical as well as in economic yield [1]. In CZ, physical yields of wheat, potatoes, sugar beet and rape seed are 23%, 45%, 21% and 49% lower than the average in the EU 15 countries [2], showing the potential for an increase in Czech agricultural productivity by investing in modern varieties, fertilizer and machinery. There are about 7.9 million ha of agricultural land in CZ, and 4% of the Czech GDP and 4.5% (225,000 people) of the labour force are in the agricultural sector [3,4]. It is very likely that Czech agriculture will undergo similar developments as observed previously in the EU 15 member states, like France and Spain where with a higher food and fodder production and a constant demand, agricultural land was set free. Increasing mechanization also leads to a loss of employment in rural areas [5]. Alternative income sources are

Abbreviations: APA, Agricultural production area; CZ, Czech Republic; LHV, Lower heating value; MZE (in Czech) and/or MA (in English), Ministry of agriculture; MZP (in Czech) and/or ME (in English), Ministry of the environment; NUTS, The nomenclature of territorial units for statistics; PES, Primary energy sources; RES, Renewable energy sources; SRC, Short rotation coppice

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therefore needed in rural areas and for the agricultural sector. Biomass production could become the most promising alternative for the generation of jobs in the Czech agricultural sector because the EU will need large areas of agricultural land for biomass production [6].

Biomass produced in CZ can serve two purposes: the supply of domestic energy and the export of bio-fuels to other European countries. Lower land use and labour costs in Eastern European countries [7,8], enable the lower-cost production of bio-fuels, making the export of bio-fuels to other EU countries an interesting alternative for Czech agriculture. In recent years, about 110,000 t wood pellets and briquettes (80% of that produced) and about 68,000 t of biodiesel have been exported annually from the CZ to other EU countries [9,10].

The consumption of total primary energy sources (PES) in CZ is relatively stable—around 1700 PJ (±5% in 1990–2003). The share of coal decreased from app. 65% in the year 1990 to 51% in the year 2001 and was replaced mainly by natural gas. In 2001, nuclear power contributed with 8.5%. Renewable energy sources (RES) are a relatively low portion of PES due to less favourable natural conditions (e.g. limited hydro- and wind-power potential), and the previous unilateral orientation on domestic coal use in the former centralised economy.

In 2000, the Czech Energy Policy set a goal to increase the RES share of total PES from 1.5% (year 2000) to 3–6% by the year 2010 and 4–8% by the year 2020. These targets were significantly revised and raised by new State Energy Policy (2003) to 15–16% RES share in PES structure and in electricity generation (16% of gross consumption) for the target year 2030. Biomass represents approximately 85% of RES share in the State Energy Policy (2004). Today 65% or 19.5 PJ year^{-1} of renewables is biomass [12]. The "Oleoprogram" of the Czech Ministry of Agriculture has supported the production of methyl-ester of rape seed oil since the early 1990s and about 55 million litres containing 0.41 PJ energy are produced yearly [12].

Previous studies estimated the bio-energy potential from energy crops and agricultural and forestry residues to be about 270–340 PJ yearly [13–15] assuming that 0.4–0.8 million ha (10–20% of agricultural land in CZ) are available for energy crop production because the land use for food and forage production has decreased over the last decade. None of these estimates, however, provides precise information about the regions with the highest potentials, the biomass supply costs, the kind of biomass production systems and the key variables determining biomass potential. This information will be needed to (a) plan infrastructure, like biomass processing units and plants and biomass transport and (b) support policies on a provincial to national level.

This study assesses the biomass production potential on a regional level in the different CZ regions and to provide biomass cost–supply curves for the CZ for different scenarios with varying key variables for biomass production.

Firstly, a methodology to assess regional biomass potential in the CZ that can also be useful for other national studies was developed. Secondly, the results, i.e., land availability for producing energy crops, biomass potential from energy crops and agricultural and forestry residues under different land use scenarios and biomass supply costs are presented. Biomass potentials from different biomass sources for the 14 NUTS-3 (the nomenclature of territorial units for statistics) regions and biomass cost–supply curves for the CZ are shown.

Finally, the methodology developed here and the results of the biomass potential assessment in different scenarios are discussed.

2. Methodology

The potential of biomass is assessed for three sources:

- biomass from agricultural residues,
- biomass from forestry residues and
- biomass from energy crops,

on the level of NUTS-3 regions (see Section 2.1).

Fig. 1 gives an overview of the methodology used here to assess the biomass and bio-energy potentials and costs.

2.1. Level of biomass potential assessment

Biomass potentials in the CZ are assessed on the level of the 14 NUTS-3 regions set up by EUROSTAT, the Statistical Office of the European Community [17] (see Fig. 2). This is the most detailed level on which data on agricultural production are available from EUROSTAT and from Czech statistics. Because NUTS-3 regions have identical borders with the CZ administrative counties information can be supplied with relevance to regional/county policy as well as national policies.

2.2. Data sources

Land quality data, the agricultural production area (APA) maps, APA specific yields and future yield predictions for the CZ have been obtained from the Czech Ministry of Agriculture (MZE). Actual land use and productivity data were taken from EUROSTAT and from the Czech Statistical Office (CSO). Other CSO data concern the most important crops grown on arable land and the production pattern for the NUTS-3 region, macroeconomic and employment information and energy statistics. Data on predictions for the food and feed demand were taken from the Food & Agriculture Organisation (FAO). Data specific for the description of the APAs were received from the Research Institute of Agricultural Economics (VUZE). Yield information for short rotation coppice with willow and poplar are derived from field trials in the CZ. Dutch yield levels were taken

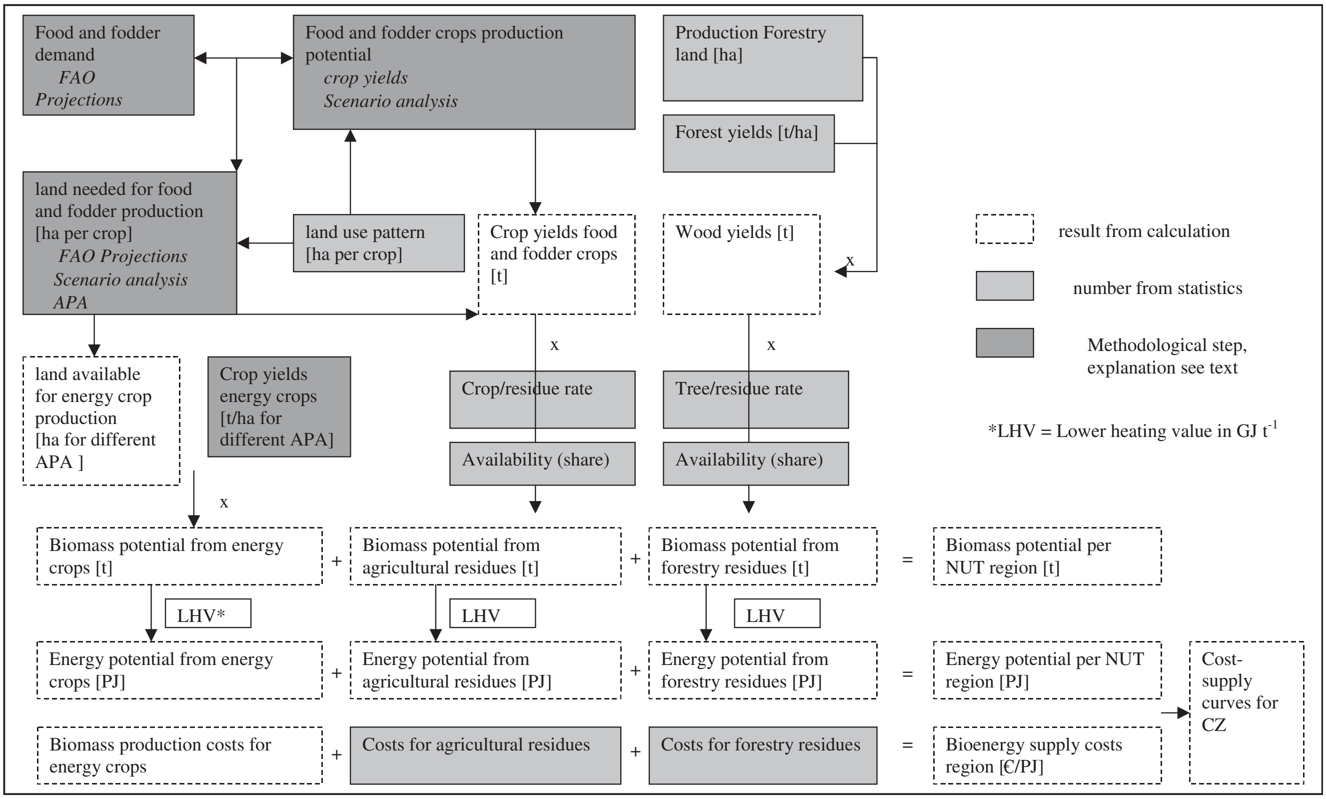
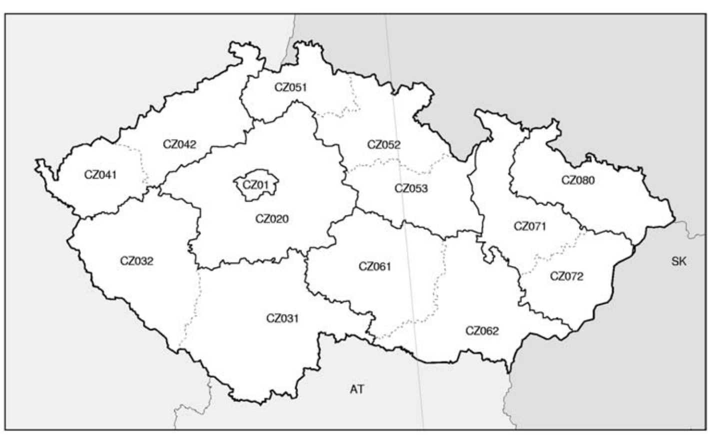


Fig. 1. Methodology for the biomass and bio-energy potential assessment in the Czech Republic.



Code	Name
CZ01	Praha
CZ020	Stredocesky
CZ031	Jihocesky
CZ032	Plzensky
CZ041	Karlovarsky
CZ042	Ustecky
CZ051	Liberecky
CZ052	Kralovehradecky
CZ053	Pardubicky
CZ061	Vysocina1
CZ062	Jihomoravsky
CZ071	Olomoucky
CZ072	Zlinsky
CZ080	Moravskovlezsky

Fig. 2. The map of the NUTS-3 regions of the Czech Republic with the nomenclature of the NUTS-3 regions of the Czech Republic [2].

from the Dutch Central Bureau for Statistics (Centraal Bureau voor de Statistiek), CBS.

2.3. *Assessment of the availability of land for biomass crop production*

The production of energy crops on agricultural land competes with the production of food and fodder crops, thus we assume that the production of energy crops will only be performed on land that is not needed for food and fodder production.

2.3.1. *Determination of food and fodder demand*

Land availability for energy crop production is based on food and fodder demand, which in this case was taken from the FAO 2003 projections [16]. The basic assumption is that the production of a crop (in t) should be equal to the demand (in t) for this crop in the CZ. The required demand of food products is the sum of domestic utilisation, and the import and export rate. The projections are based on the parameters population growth, gross domestic product (GDP) and caloric intake and show the production to be expected for the year 2030. According to FAO projections the CZ population will decrease and the GDP in 2030 will be more than 3 times the GDP of 1997–1999. The FAO projection of the caloric intake shows an increase in the consumption of calories from 6819 to 7980 calories per person and day.

For the fodder crops, for example maize, grass (meadows and pasture), lucerne and clover, the production needed in 2030 is determined per NUTS-3 region on the basis of FAO projections for the production of the livestock products (meat eggs and milk) (see Table 1).

By using the feed conversion factor in 2030 (kg fodder/kg livestock product) (see Table 2) the amount of fodder (kg) that is needed to produce 1 kg livestock product and the need for fodder production in tonne can be calculated. The projection for the feed conversion factor (for Eastern Europe) is taken from the IMAGE-model [18].

Using the total need for fodder production (tonne) in 2030 and the actual share of the different fodder crops in the NUTS-3 regions the needed production (tonne) per fodder crop per NUTS-3 region in 2030 is determined (see Table 3).

2.3.2. *Determination of food and fodder production potentials of NUTS-3 regions*

Whether the food and fodder demands can be covered and how much land would be needed to fulfil this demand were then analysed using information about the production potential, i.e., soil quality and potential crop yields, derived from the so-called 'production soil-ecological units' system (abbreviated BPEJ in Czech). This system, developed in 1989 to improve planning in centralised agriculture in former Czechoslovakia contains about 700 BPEJs with a description of specific characteristics relevant for crop production (e.g. soil quality, precipitation, etc.). Five APAs have been built on the basis of this system and common agricultural practices. They are named 'maize', 'cereal', 'sugar beet', 'grassland' and 'potato-APA' after the most important or specific crop produced in the area.

Table 4 shows some characteristics of these APAs. For every crop, APA-specific yields are derived either from [20] or field trials (see Table 4). Biomass potentials are determined per NUTS-3 region (see Fig. 2). From [17], data about the land use pattern (ha per crop) in different NUTS-3 regions are available. Information on land qualities and a relation between land quality and productivity are missing. To derive this information, maps depicting the APAs and NUTS regions were used to give a percentage of agricultural land belonging to a specific APA in each NUTS-3 region. By multiplying this percentage with the data on the agricultural land in ha per NUTS-3 region (from [17]), the amount of hectares per NUTS-3 region that belong to the five APAs was calculated. The number of hectares for each crop in the APA was calculated according to the procedure of the following example. It was assessed that 69% of the agricultural land or 501,000 ha in NUTS-3 region CZ020 belong to the sugar beet-APA. In the sugar beet-APA wheat has a share of 28% of the land (see Table 4). In NUTS-3 region CZ020 140,500 ha of wheat are produced on land with the productivity of the sugar beet-APA (see Table 5). The productivity in a NUTS-3 region can now be determined by using the APA specific yield data shown in Table 4. How much of the land would be available for the production of willow biomass is assessed in the next step.

2.3.3. *Determination of land availability for biomass production by scenario analysis*

Above it was determined that only land not needed to produce food and fodder, based on FAO projections for 2030, is available to produce biomass. The availability of land therefore depends on crop yields because the higher the yield on 1 ha, the fewer hectares are needed to produce food and fodder. Also optimal allocation, i.e., producing crops on the best-suited land for every crop, can decrease land demand. Because future yields depend on different, not easily predictable factors (availability of high-yielding varieties, resources available to farmers for investment in more efficient machines or fertilizer, kind of farming system like organic or high input system, etc.), that (strongly) depend on policies, six scenarios (for an overview see Fig. 3) were built to estimate yield levels (see Table 6).

Scenario 1—*Actual yields*: This scenario analyses the surplus of agricultural land under present production conditions and yields. Food and fodder crop production

Table 1
The projected production of livestock products in 2030 in the Czech Republic [16]

Livestock product	Production in 1000 t		
	1997–1999	2015	2030
Beef and buffalo meat	154.9	162.2	164.8
Mutton and goat meat	3.4	5.2	6.6
Pig meat	472.1	481.3	465.9
Poultry meat	220	242.1	259.1
Sum all meat	850.4	890.8	896.4
Milk	2764	3039.3	3380.4
Eggs	187.7	187.1	187.2

Table 2
The actual feed conversion factor (FCF status quo) and the feed conversion factor projected for 2030 (FCF 2030) per livestock product in the Eastern European countries

Livestock product	FCF status quo (kg DM fodder/kg product)	FCF 2030 (kg DM fodder/kg product)
Beef and buffalo meat	18.3	15.2
Mutton and goat	90.28	59.58
Pig meat	6.9	6.29
Poultry meat	3.8	3.2
Milk	1.12	1.12
Eggs	3.8	3.1

Table 3
The projections of the FAO for the production of the main crops per NUTS-3 region in the Czech Republic

Regions	Wheat 1000 t		Winter barley 1000 t		Spring barley 1000 t		Sugar beet 1000 t		Potato 1000 t	
	2000	2030	2000	2030	2000	2030	2000	2030	2000	2030
CZ01	38.9	39.1	2.8	2.6	10.5	9.9	12.5	14.9	8.7	6.9
CZ020	998.8	984.5	88.1	102.8	341.5	388.5	723.7	866.9	196	242
CZ031	416	461.2	35	56.8	141.8	214.7	0	0.0	136.9	190.5
CZ032	325.7	347.1	31.5	44.5	118.9	168.4	0	0.0	54.9	66.1
CZ041	54	56.1	4.3	6.3	18.7	24	0	0.0	6.2	6.4
CZ042	316	289.4	25.6	32.1	106	121.2	190.8	229.2	63.4	56.8
CZ051	68	55.2	5.9	7.8	23.4	29.5	7.7	10.0	17	12.5
CZ052	302.6	330.4	18.5	27.6	77.9	104.2	340.7	408.5	45	46.1
CZ053	273.4	260.9	26.6	34.4	103.4	130.2	203.3	244.1	41.9	59.9
CZ061	305.5	394.6	43.4	82.8	179	313	3.5	5.0	318.8	454.3
CZ062	634.1	707.8	61	81.8	234.5	306.7	238.6	298.9	102.8	110.9
CZ071	320	357.8	33.3	56	146.5	211.7	503.1	602.8	46.9	45.8
CZ072	200.6	206	13.3	21.6	61	81.7	93.8	112.6	67.1	49.2
CZ080	222.2	199.9	45.5	29.2	57	110.3	285.5	368.7	73.7	38.5
CZ	4475.8	4690	434.8	586.3	1620.1	2214	2603.2	3161.6	1179.3	1385.9

Regions	Rape 1000 t		Meadows 1000 t DM		Pasture 1000 t DM		Maize for fodder 1000 t DM		Other arable fodder crops 1000 t DM	
	2000	2030	2000	2030	2000	2030	2000	2030	2000	2030
CZ01	6.7	7.2	1.8	1.8	0.7	0.6	1.8	1.4	2.6	2.5
CZ020	198.4	197.5	149.5	154.6	47.1	48.6	344	313.2	268	276
CZ031	105.7	129.9	335.1	355.1	105.3	111.6	319.1	327	200.8	212.4
CZ032	92.6	96.9	221.3	232	69.8	72.9	276.7	251.1	228.3	167.3
CZ041	16.1	18.5	129.7	140.8	41.1	44.2	11.7	20.9	50.5	54.6
CZ042	35.5	32.8	142.6	152.6	45	47.9	80.4	68.5	87.5	93.2
CZ051	17.1	18.3	126.1	134.6	39.9	42.3	38	36.1	40.4	42.9
CZ052	53.6	64	145.7	153.7	46	48.3	155.5	176.9	114.4	120.5
CZ053	63.5	59.7	125.4	133.6	39.2	42	149.8	180.9	145.2	154.3
CZ061	87.2	114.1	182.4	192.5	57.1	60.6	302.1	299	218.6	231.2
CZ062	106.1	90.8	54.7	56.7	17.3	17.9	196.6	158.8	135.4	140
CZ071	75.1	58.4	102.4	108.7	32.1	34.2	135.3	159.7	109.6	116.1
CZ072	32.4	24.5	113.5	123	35.7	38.7	85	91.8	82.8	89.1
CZ080	51.6	45.7	178.3	188.7	56.2	59.3	89.8	102.1	125.8	127.1
CZ	941.6	958.3	2008.5	2128.4	632.5	669.1	2185.8	2187.4	1809.9	1827.2

in the present land use scenario (see Table 5) and with the actual yields (see Table 6) are calculated. The difference between the current production and the FAO-projected production demand for 2030 is calculated to analyse whether over-production would occur. When over-production was assessed, the land that is not needed to fulfil production demands in 2030 is seen as being available for biomass production. A basic assumption for this scenario is that the share of food and fodder crops between NUTS-3 regions will not be altered in the future.

Scenario 2—*Optimal yields*: This scenario has the same approach as in scenario 1, but the yields are not actual but 'optimal' yields, derived from information from the Ministry of Agriculture [21] and from the Central Control Testing Institute for Agriculture [22]. These yields are estimated for an optimal crop management system, defined by the use of a location-adapted amount of nitrogen fertilizer and an economically optimised system of agrochemical application under the best present technology available in CZ. Optimal yields used here are shown in Table 6. As in the first scenario it is assumed that the share of food and fodder crops between NUTS-3 regions will not be altered in the future.

Scenario 3—*Optimal yields but low feed conversion efficiency*: The same approach is used as in scenario 2, only it is assumed that the feed conversion efficiency stays at the present level (see Table 2). The consequences are that more food and fodder and land for food and fodder production will be needed than in scenario 2.

Scenario 4—*Optimal yields and allocation of crop production on NUTS*-3 *level*: The same yield level as in scenario 2 (optimal yields as shown in Table 6) is taken. But in comparison to scenario 2, where the land use pattern is not altered, in scenario 4, land allocation on NUTS-3 region level is optimised. For every crop within a NUTS-3 region, the areas of highest relative yield are determined by setting the yield for a specific crop in every APA in relation to the lowest APA-specific yield found for this crop. The production of crops is then, within a NUTS-3 region, allocated to the APA with the highest relative yield.

Scenario 5—*Optimal yields and allocation of crop production on county level*: This scenario uses the same assumptions as scenario 4, but the allocation of crop production to the area with the highest relative yield takes place on country instead of NUTS-3 region level meaning an attempt to obtain an optimal allocation of food and fodder production throughout the country. Thus, the place in the Czech Republic at which the highest optimal yield for every crop can be attained must be determined.

Scenario 6—*Actual yield level of the Netherlands*: In scenario 6 similar assumptions as in scenarios 1 and 2 are made, but for a higher yield level. Estimating future yields is difficult because the impact of breeding efforts can be high but cannot be quantified even by breeders. Other developments in crop production, like precision farming, can also contribute to unpredictable yield increases.

Table 4
Description of characteristics and biomass yields in the agricultural production areas (APA) of the Czech Republic

APA	Characteristics	Crops produced (share in %) (yield generally in t DM, only for sugar beet and potato in t FM)[a]	1000 ha of agricultural land in CZ	Willow/Poplar yields (t DM ha^{-1} a^{-1})[b]
Maize-sugar beet-cereals	Hot, dry climate, fertile soils, to 250 m a.s.	Wheat (26)[4.8], Spring barley (10)[3.8], winter barley (2)[5.0], maize (7)[9.8], sugar beet (1)[38.0], potato (1)[17.0], rape (2)[3.0], grass (5)[2.5].	287	7.33
Sugar beet-cereals	Warm climate, fertile soils, to 350 m a.s.	Wheat (28)[5.3], Spring barley (13)[4.0], winter barley (2)[5.5], maize (1)[9.0], sugar beet (7)[41.6], potato (1)[17.3], rape (6)[3.5], grass (5)[3.0].	1042	8.51
Cereals-forage	Slightly warm and wet climate, medium to fertile soils, up to 400-600 m a.s.	Wheat (22)[4.3], Spring barley (3.4)[5], winter barley (5)[3.9], maize (<1)[10.6], sugar beet (<1)[35.0], potato (1)[15.5], rape (8)[2.8], grass (12)[3.1].	1734	11.12
Potato	Slightly warm to slightly cold and wet climate, medium to less fertile soils, up to 400–600 m.	Wheat (13)[3.7], Spring barley (2.0)[5], winter barley (2)[3.2], potato (4)[19.4], rape (7)[2.3], grass (18)[3.4].	186	9.14
Grass	Cold and damp climate, less fertile soil, over 600 m a.s.	Wheat (8)[4.3], Spring barley (9)[2.6], winter barley (4)[n.a.], sugar beet (<1)[n.a.], potato (1)[15.3], rape (4)[2.4], grass (37)[2.8].	426	4.42
Average				8.10

Yield data are obtained from the Ministry of Agriculture [21] and from own data.
n.a. = not analysed.
[a]All yield data from the Ministry of Agriculture [21], only for potato from own data.
[b]Poplar/willow average yields estimated from field trials by Weger (1999–2003).

Therefore a comparison with the yield level in the Netherlands was chosen because it is a European country in which agricultural production methods are highly developed. Information on yield levels in the Netherlands is taken from National statistics [23]. To correct the yield in the different regions according to the land qualities given, the following formula was used:

$$Y_{2030} = \frac{Y_{\text{NL}}}{Y_{\text{CZ}}} Y_{\text{apasq}},$$

where Y_{2030} is the yield of the crop in 2030 (tonne/ha), Y_{NL} the actual yield of the crop in the Netherlands (tonne/ha), Y_{CZ} the average yield of the crop in the Czech Republic (tonne/ha) (average yield was calculated as average from yield data given for different APAs in Table 4), Y_{apasq} the actual yield of the crop in an agricultural production area (tonne/ha) (see Table 6).

2.4. Assessment of the biomass and bio-energy potential from energy crops

From the scenario analysis in the previous chapter the amount of land available for biomass crop production is calculated. This includes information about how available land is divided over the different APAs. From field trials yield numbers for poplar and willow clones of 4.42–11.12 t DM ha^{-1} a^{-1} are assessed for the different APAs (see Table 4). The biomass potential from SRC per NUTS-3 region is calculated by multiplying the number of hectares available for biomass crop production per APA with the APA specific biomass yield and by summing up the productivity data from different APAs in a NUTS-3 region. To derive the biomass energy potential the biomass potential in t DM per NUTS-3 region is multiplied with the lower heating value of SRC biomass of 19.4 GJ t^{-1} DM.

Table 5
The acreage of the main crops (1000 ha) per agricultural production area (APA) per NUTS-3 region in 2003

Regions	APA	Wheat	Winter barley	Spring barley	Sugar beet	Potato	Rape	Meadows	Pasture	Maize	Other arable fodder crops
		1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha	1000 ha
CZ01	Sugar beet	7.4	0.5	1.9	0.3	0.5	1.9	0.6	0.3	0.2	0.6
CZ020	Sugar beet	140.5	8.9	46.2	17.3	3.8	34.5	18.3	7.9	35.4	40
	Cereals	53.6	9.3	18	0.1	3.3	22.7	20.3	8.8	2.4	19.4
	Potato	8.2	0.9	4.9	0	4	5.6	7.5	3.2	0	4.9
	Grassland	0.8	0.3	0.6	0	0.1	0.5	2.4	1	0	0.7
CZ031	Cereals	79.2	8.4	26.5	0	3.6	28.4	48.2	20.8	30.1	34.1
	Potato	9.4	0.7	5.6	0	3.4	5.4	13.8	5.9	0	6.7
	Grassland	10.5	2	8	0	1	5.8	50.1	21.6	0	11.7
CZ032	Cereals	70.8	7.9	27.1	0	2.5	29.7	48.6	21	26.1	53.3
	Potato	2.1	0.2	1.4	0	0.6	1.4	3.4	1.5	0	1.7
	Grassland	4	0.8	3.4	0	0.3	2.6	21.4	9.2	0	5.1
CZ041	Cereals	11.2	1.1	4	0	0.3	4.9	21.2	9.2	1.1	9.8
	Grassland	1.5	0.3	1.2	0	0.1	1	23	10	0	3.5
CZ042	Sugar beet	32	1.6	10.6	4.5	1.1	4	8.2	3.6	7.4	8.6
	Cereals	32.1	4.3	10.9	0.1	2.4	6.9	24.1	10.4	1.3	11
	Grassland	2.7	0.7	2	0	0.4	0.9	15.6	6.7	0	2.3
CZ051	Sugar beet	0.4	0	0.1	0.1	0	0.1	0.3	0.1	0.1	0.2
	Cereals	14.2	1.5	5.2	0.1	0.9	5.4	24.9	10.8	3.5	8.5
	Grassland	1.3	0.3	1	0	0.2	0.7	17.3	7.5	0	1.9
CZ052	Sugar beet	33.9	1.3	8.6	8.1	0.9	6.9	10.3	4.4	14.8	12.8
	Cereals	27.1	2.9	7	0.1	1.6	9.5	23.8	10.3	2.1	13
	Grassland	2.2	0.4	1.3	0	0.3	1.2	14.8	6.4	0	2.7
CZ053	Sugar beet	32	2	12.3	4.8	0.9	8.7	10.8	4.6	14.4	17.5
	Cereals	23.9	4	9.4	0.1	1.6	11.2	23.5	10.1	1.9	16.7
	Grassland	0.9	0.3	0.8	0	0.1	0.7	7.3	3.1	0	1.7
CZ061	Cereals	26.3	5.8	11.9	0.1	1.1	8.6	8	3.4	28.5	12.3
	Potato	44.5	6.5	35.4	0	15	23.6	32.4	14	0	34.5
	Grassland	7.3	2.9	7.5	0	0.6	3.7	17.5	7.5	0	8.9
CZ062	Maize	89.4	6.4	30.6	2.9	4.3	13.4	8.6	3.7	19.2	19.8
	Sugar beet	16.7	1.3	6.7	3	0.1	5.7	1.5	0.7	0.7	3.5
	Cereals	26.5	5.6	10.8	0.1	1.7	15.6	7.2	3.1	0.2	6.9
	Grassland	1.1	0.4	1	0	0.1	1	2.4	1	0	0.8
CZ071	Sugar beet	41	3	18.2	12	1.1	12.1	7.7	3.3	13.5	13.9
	Cereals	20.9	4.3	9.4	0.1	1.3	9.6	11.4	4.9	1.3	9
	Grassland	3.7	1.4	3.8	0	0.5	2.6	15.8	6.8	0	4.1
CZ072	Maize	1.4	0.1	1.1	0.03	0.1	0.1	0.4	0.2	2.1	0.6
	Sugar beet	20.8	0.9	5.8	2.2	1.1	3.9	5.9	2.5	6.1	8
	Cereals	17	2	4.8	0.03	2.2	5.4	13.9	6	0.9	8.3
	Grassland	2.9	0.6	1.9	0	0.8	1.4	18.6	8	0	3.7
CZ080	Sugar beet	14.2	5.5	5.3	4	0.6	3.3	4.3	1.8	6.8	6.8
	Cereals	30.4	3.9	4.3	3.4	3.2	12.1	26.8	11.6	2.7	18.6
	Grassland	4.3	0.13	4.3	0	0.9	2.6	29.6	12.8	0	6.8
CZ	Maize	90.8	6.5	31.7	2.93	4.4	13.5	9	3.9	21.3	20.4
	Sugar beet	338.9	25	115.7	56.3	10.1	81.1	67.9	29.2	99.4	111.9
	Cereals	433.2	61	149.3	4.23	25.7	170	301.9	130.4	102.1	220.9
	Potato	64.2	8.3	47.3	0	23	36	57.1	24.6	0	47.8
	Grassland	43.2	10.53	36.8	0	5.4	24.7	235.8	101.6	0	53.9
	Total	970.3	111.33	380.8	63.46	68.6	325.3	671.7	289.7	222.8	454.9

2.5. *Assessment of the biomass potential from agricultural residues*

The quantities of wheat, barley and rape produced per APA and per NUTS-3 region, as predicted by FAO for 2030 (see Table 3), were used to calculate the biomass potential of agricultural residues. Crop residue rates used are from Fischer et al. [24] and are shown in Table 7. Data given for the category 'high inputs' were taken for the productivity level in Dutch agriculture. The level of 'intermediate input' reflects the productivity of Czech agriculture at present. For scenarios 2–5, with optimised yields, the residue shares from the high and intermediate input levels, as given in Fischer et al. [24], were averaged.

Scenario	1	2	3	4	5	6
Demand for and Production of food	As predicted by FAO for 2030 [18]					
Yield level	Actual yield	Optimized production systems				Yield level of the Netherlands
Feed conversion efficiency	As predicted by FAO for 2030		As in 2004	As predicted by FAO for 2030		
Allocation of land	Actual land use pattern kept			Allocation to areas with highest relative yield within NUTS-3 region	Allocation to areas with highest relative yield within the CZ	Actual land use pattern kept

Fig. 3. Overview of the scenarios to determine the surplus agricultural land, respectively the land available for biomass crop production within the Czech Republic.

Heating values of the residues are taken from Hartmann [25]. They are 17.2 J kg^{-1} DM for wheat straw, 17.5 J kg^{-1} DM for barley straw and 17.1 J kg^{-1} DM for rape straw. It is assumed that 30% of agricultural residues are available.

2.6. Assessment of the biomass potential from agricultural and forestry residues

The amount of forestry residues is calculated from the amount of wood produced in different NUTS-3 regions (see Table 8) and with a wood to residue ratio of 1:0.15. Here a residue availability of 25% is assumed based on ecological limitations. Residues contain nutrients that cannot totally be removed if soil fertility and forest productivity are to be maintained. The lower heating value of forest residues is 14.3 MJ kg^{-1} (at a biomass water content of 20–25%).

2.7. Cost assessment for poplar and willow production

Production costs for biomass from short rotation coppice (SRC) (willow and poplar clones) were calculated using an average cost model (i.e., average values were used when cost data from several sources were available) with features of low input farming for 1 ha [26,27]. For SRC production a lifetime of 20 years with a cutting cycle of 4 years (see [9]) and an interest rate of 4% was assumed. The costs are calculated for 21 years because of the year needed to prepare and establish the plantation.

Total costs are assessed as the sum of fixed costs, establishment costs for the plantation, maintenance costs (e.g. for fertilization) and harvest costs. The harvest costs differ for the biomasses from different APAs because harvest costs per hectare increase with the amount of biomass to be harvested. Yields of willow and poplar differ between APAs due to the land quality differences (see Table 4).

Because SRC is a perennial crop some cost items, like those for establishment (ploughing, plantings, etc.) are not equally divided over the production period but appear in the first year or, in the case of harvesting, every 4 years. All cost items were therefore calculated to net present values (NPV) using the following formula:

Net present value (NPV):

$$\mathrm{NPV}q = \sum_{a=0}^{n} q(a)/(1+r)^a, \quad (2)$$

where r is the interest rate, $r = 0.04$, q the costs in year a and a the year.

These costs have then been annualised by the annuity factor (see formula 3).

$$\mathrm{AF} = \frac{r}{1-(1+r)^{-a}}, \quad (3)$$

where AF is the annuity factor, a the years (lifetime) and r the interest rate, $r = 0.04$.

The costs per t biomass (dry matter) from SRC are calculated by dividing the yearly annualised biomass production costs by the annualised biomass yield. The production costs per GJ are calculated by dividing the production costs per t DM by the value for the lower heating value of dry SRC biomass of 19.4 GJ t^{-1}.

Costs are based on $€_{2000}$ levels. Although it can be expected that cost levels will increase in 2015 and 2030 due to inflation and GDP growth, this is not included in the cost calculation because of the following:

- An extra conversion factor over time will make the cost calculation itself less transparent as this factor will influence the cost levels of all factors.
- A comparison with current price levels of (for example) food products and fossil fuels becomes more difficult as this will mean that also food and fuel prices need to be converted over time to the year 2015 and 2030.

2.8. Setting up a cost–supply curve

To set up a cost–supply curve different biomass sources (from energy crops, agricultural and forestry residues) are sorted by prices starting with the cheapest. In the cost–supply curve the production costs per GJ are then shown against the total energy supply (in PJ) (see e.g. [28]).

Table 6
The actual, optimal and high (on Dutch level) yield of the main crops per agricultural production area in the Czech Republic

Crop		Agricultural production areas (APAs)														
		Maize			Sugar beet			Cereals			Potato			Grass		
		Actual yields	Optimal yields	Yield level NL[a]	Actual yields	Optimal yields	Yield level NL[a]	Actual yields	Optimal yields	Yield level NL[a]	Actual yields	Optimal yields	Yield level NL[a]	Actual yields	Optimal yields	Yield level NL[a]
Wheat	t DM ha^{-1}	4.8	4.9	8.9	5.3	5.5	9.9	4.3	5.0	8.0	3.7	4.7	6.9	4.3	5.0	8.0
Winter barley	t DM ha^{-1}	5.0	5.0	6.6	5.5	5.5	7.0	3.9	5.0	5.9	3.2	4.3	5.2	n.a.	n.a.	n.a.
Spring barley	t DM ha^{-1}	3.8	5.0	6.7	4.0	5.5	7.4	3.4	5.0	5.2	3.0	4.3	4.3	2.6	4.3	3.5
Sugar beet	t FM ha^{-1}	38.0	47.0	56.3	41.6	47.0	61.6	35.0	47.0	51.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Potato	t FM ha^{-1}	17.0	26.0	43.9	17.3	26.0	44.6	15.5	26.0	40.0	19.4	30.0	50.0	15.3	26.0	39.5
Rape	t DM ha^{-1}	3.0	3.0	3.4	3.5	3.5	4.0	2.8	2.8	3.2	2.3	2.7	2.6	2.4	2.7	2.7
Meadows	t DM ha^{-1}	2.5	4.5	9.3	3.0	5.4	11.2	3.1	5.6	11.6	3.4	6.2	12.7	2.8	5.1	10.4
Pasture	t DM ha^{-1}	1.8	2.9	6.7	2.2	3.6	8.2	2.3	3.7	8.6	2.5	4.0	9.3	2.1	3.2	7.4
Maize silage	t DM ha^{-1}	9.8	14.0	19.6	9.0	14.0	18.0	10.6	14.0	21.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other AF[b]		4.6	8.5	11.9	4.3	7.9	11.1	3.8	7.0	9.8	4.0	7.4	10.3	3.8	7.0	9.8

[a]NL = The Netherlands.
[b]AF = Other arable fodder crops.

Table 7
Share of residues of total harvestable biomass that was used to calculate amounts of residues in different scenarios [24]

Crops	Actual yields (scenario 1)	Optimized yields (scenarios 2–5)	Dutch yield level (scenario 6)
Winter wheat	0.6	0.55	0.5
Winter barley	0.6	0.55	0.5
Summer barley	0.7	0.65	0.6
Winter rape	0.82	0.79	0.75

Table 8
Forest production in NUTS-3 regions in CZ, shown for different tree species [20]

Region	Beech (t)	Oak (t)	Birch (t)	Poplar (t)	Willow (t)	Spruce (t)	Pine (t)	Larch (t)
CZ01	79	1910	341	30	6	852	1138	499
CZ020	26,770	49,216	13,713	2743	188	209,990	115,096	40,632
CZ031	27,579	18,427	12,100	375	59	392,440	162,436	15,318
CZ032	16,222	13,462	7216	631	73	307,657	96,862	17,544
CZ041	6358	2511	7895	286	48	155,461	18,395	7494
CZ042	19,243	20,506	18,653	2060	103	79,905	19,722	23,362
CZ051	13,809	5693	9740	349	29	108,738	43,952	8906
CZ052	8270	22,655	8309	383	856	158,517	26,402	15,701
CZ053	14,170	10,321	5401	1021	68	158,367	40,459	17,380
CZ061	10,229	6924	4449	249	33	353,741	40,300	14,617
CZ062	32,326	66,494	4942	8058	1068	112,636	52,476	26,163
CZ071	47,497	14,324	6341	1323	280	224,689	15,710	25,143
CZ072	81,224	30,687	5120	1398	190	174,046	19,769	18,984
CZ080	46,615	11,744	4416	982	366	276,466	12,963	16,008
CZ	350,391	274,874	108,636	19,888	3367	2,713,505	665,690	247,751

3. Results

3.1. Land availability for energy crop production

Fig. 4 shows agricultural land availability as assessed for the different scenarios shown. In scenario 1, with the assumption of an actual yield level, only 20,000 ha would be available for future energy crop production when the FAO 2030 production goals are to be fulfilled. Yield levels to be reached with the optimisation of production systems (like improvements of agro techniques and mechanisation, selection of better clones and optimisation of fertilization), as assumed in scenarios 2–5, would set free about 800,000 ha for biomass crop production. A comparison of land availability in scenarios 2 and 3 shows the impact of improved feed conversion efficiency. When the feed conversion efficiency stays on the status quo level, as assumed in scenario 3, about 357,000 more ha of feed and fodder crops would be needed to fulfil the feed and fodder demand. Land availability increases by 15,700 ha when a better allocation of land use (i.e., food crops are produced on the areas with the highest relative yield) is performed within the NUTS-3 region. When land allocation is optimised on a national instead of on the NUTS-3 region level another 12,700 ha can be set free for biomass crop production. In scenario 6, which envisages a yield on the level of Dutch agriculture, nearly 2 million ha become available for biomass crop production.

In scenario 1 only regions CZ041 and 42 provide land for biomass crop production, but in scenarios 2–6 land would be available in all NUTS-3 regions. An increase in land availability from scenario 1 to scenarios 2–5 can be seen for those NUTS-3 regions that have comparatively high acreages like CZ020, 31, 32, 61 and 62 (see Fig. 4). Here the more area becomes available, the higher the yields increase. This is due to a linear relationship between yield increase and share of land to become available, respectively land that is not needed for food and fodder production. If reallocation of land use within the country occurs, like in scenario 5, a shift of land use for food and fodder production to those areas that are best suitable for food and fodder production occurs. Therefore in NUTS-3 regions like CZ020, with a high share of land suitable for producing cereals, rape, sugar beet and maize, less land becomes available for biomass crop production than in regions CZ031 and 32 that have bigger areas with lower quality land.

3.2. Biomass and energy potential

Fig. 5 shows the potentials of energy from biomass, derived from SRC plantation or agricultural and forestry residues, for the six scenarios analysed here.

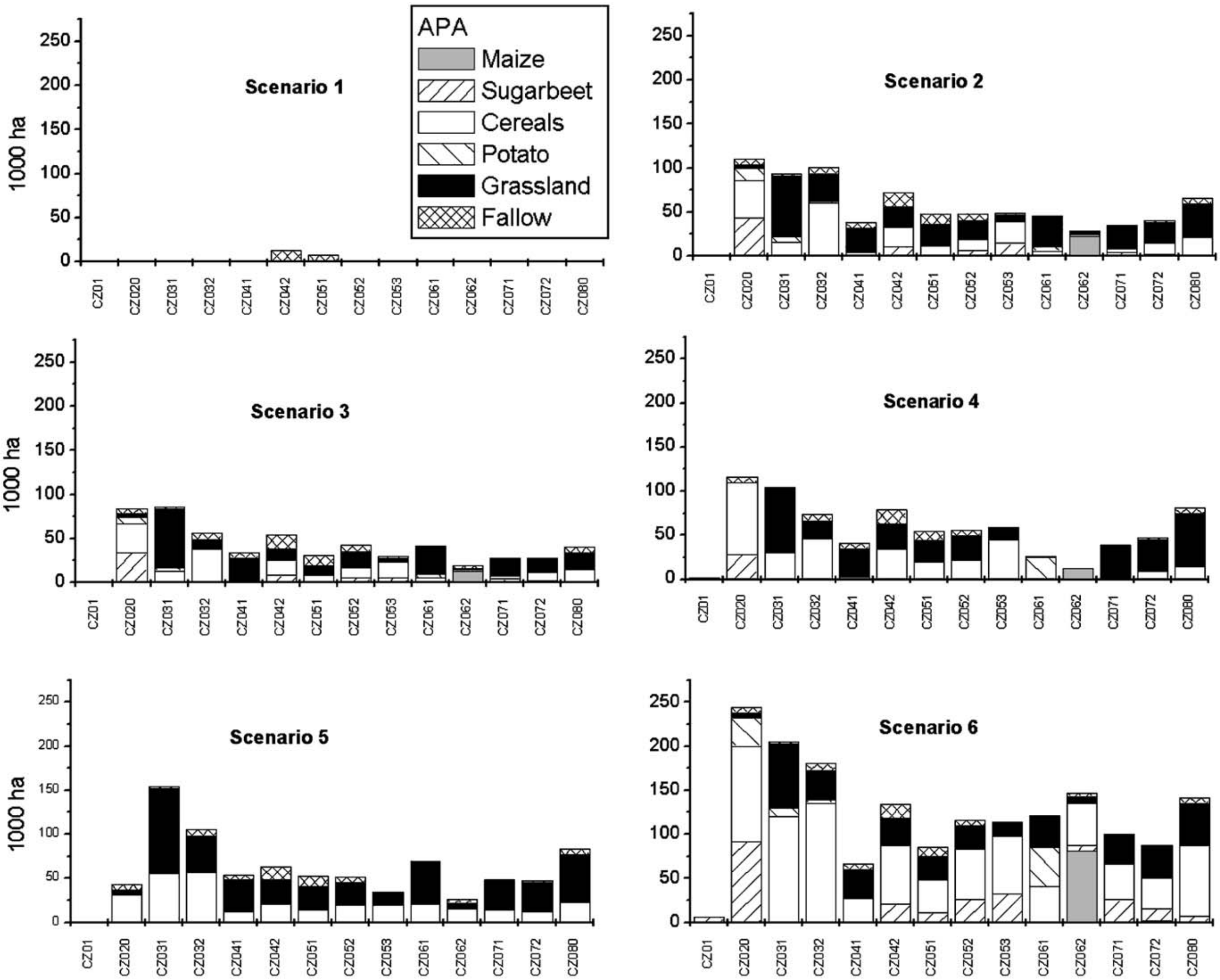


Fig. 4. Land available for the production of biomass crops in different scenarios (explanation for scenarios see Section 2.3.3) per Agricultural production area (APA).

In all scenarios the highest biomass and bio-energy potentials were assessed for the NUTS-3 regions CZ020, 31 and 32 because they have the highest amounts of land available for biomass production. The amount of SRC biomass available follows the amount of land available as shown in Fig. 4. Not only has the amount, but also land quality influenced the potentials. In regions CZ020, 31 and 32 a lot of high productive land is available for biomass production. Here a big part of the area belongs to the cereals-APA where the highest SRC yields can be harvested (see Table 4). The amount of forestry residues stays the same because no differences in forestry production between the five scenarios are assumed here. The amount of agricultural residues decreases with productivity. The share of residues is higher in production systems with low input (see Table 7). The amount of food to be produced stays the same over all scenarios (see FAO projection for food crop production demand in Table 3), but the higher the share of residues, the more residues are produced.

3.3. Biomass costs

The costs for agricultural residues are 1.25 Euro GJ^{-1} for rape straw, 1.85 Euro GJ^{-1} for cereal straw [29] and 1.42 Euro GJ^{-1} for forestry residues [30].

The costs for the production of SRC are calculated specific for every agricultural production area because the harvest costs increase with the biomass yield per ha and the SRC biomass yields are APA specific. Here the costs are calculated for a 20-year plantation lifetime, plus 1 year for plantation preparation and establishment, and a 4-year rotation cycle (see Table 9).

Table 10 shows the production costs per tonne dry biomass and per GJ. There is a strong relation between SRC yields per ha and costs. The higher the yields of SRC are, the lower the biomass production costs are.

Most of the data used for this calculation are obtained from the economic model of Kapok et al. and Havlícková et al. [26,27].

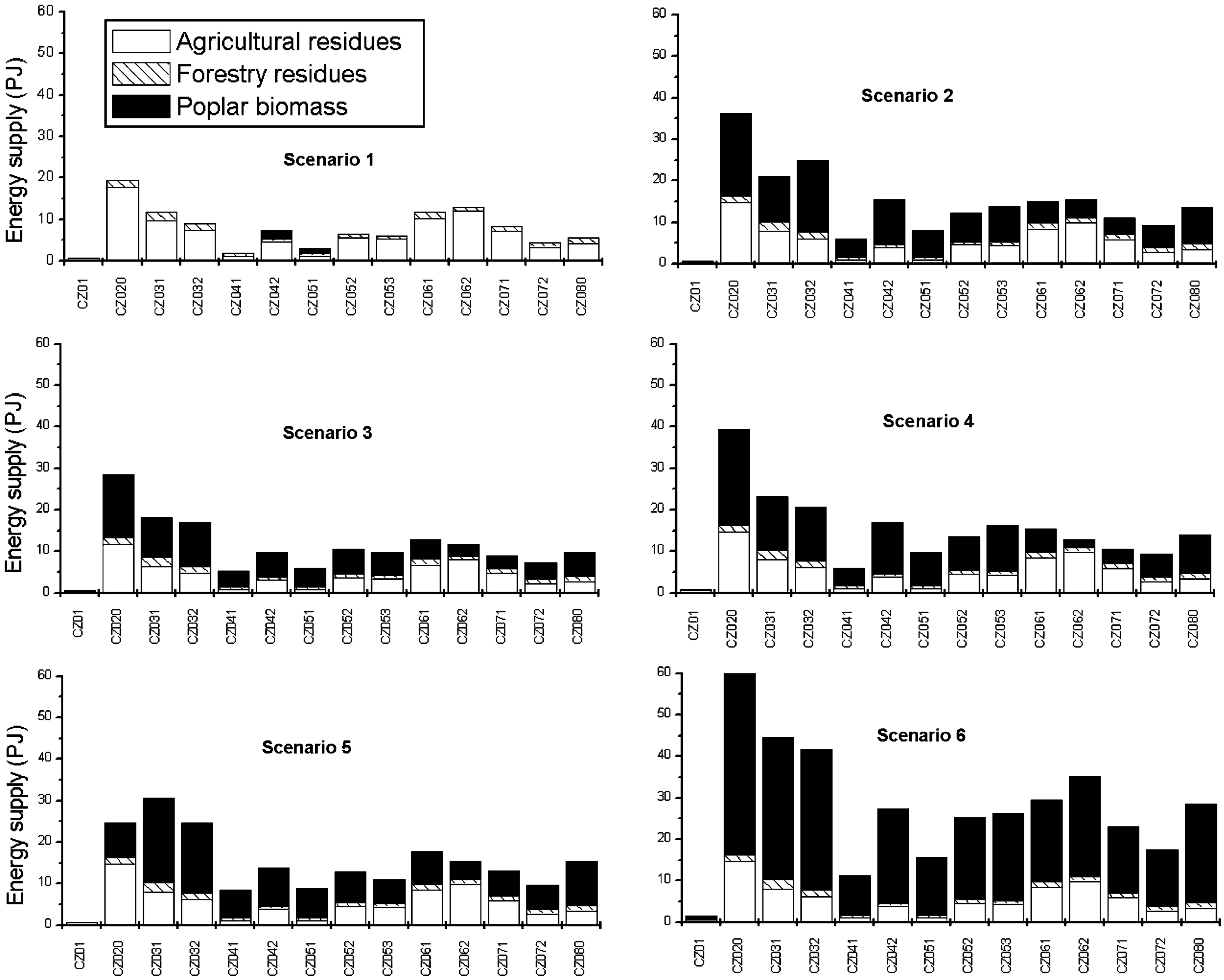


Fig. 5. Energy potentials from different biomass sources in the 14 NUTS-3-regions of the Czech Republic, assessed for six scenarios.

3.4. *Cost–supply curves for the CZ*

Table 11 shows an overview of the total potential biomass energy from different sources and under different scenarios in the CZ. Agricultural residues contribute the biggest share of biomass in the first scenario, and biomass from SRC in the scenarios 2–6. These energy potentials are available at different costs. In all scenarios the agricultural residues from rape straw (1.25 Euro GJ^{-1}) are the cheapest energy source. In scenarios 2–5 the highest biomass energy supply costs are assessed for biomass from SRC produced in the grassland-APA (4.76 Euro GJ^{-1}). The reason for this is the low biomass yield harvested form SRC on the comparatively low quality land in the APA 'grassland'.

The cost–supply curves for the different scenarios in Fig. 6 show the amount of energy that can be supplied at certain costs.

4. Discussion

The analysis of the regional biomass potential for the CZ has shown that more energy from biomass than the 250 PJ a^{-1} of domestic demand as predicted by the Czech energy politicians for 2030 [11], can become available if Czech agricultural productivity can be increased significantly. Two main factors, land availability for energy crop production and energy crop yields, determine the biomass potential in CZ. The study showed that the land potentially available for biomass crop production mainly depends on the yield of food and fodder crops. If the productivity of Czech agriculture stays at the present level, and assuming that food and fodder crops are to be the preferred production alternative, only about 110 PJ of bio-energy could become available of which 97% comes from agricultural and forestry residues. About 195 PJ bio-energy can be produced when moderate yield increases, to be

Table 9
Costs of poplar production in SRC in the Czech Republic, calculated for the different agricultural production areas (APAs)—average cost model for 1 ha 4-year rotation. 20-year lifetime

Action/material	APA	Times cost item appears in production	Production costs per 21 years (calculated by NPV[a]) € ha^{-1}	Production costs per year (21 economic years. annualized) € ha^{-1} a^{-1}
Fixed costs				
Land rent[b]		20		32.02
Land tax		20		10.00
Overhead costs		12	294	21.70
Social and health insurance		11	377	27.70
Establishment costs				
Soil preparation for planting[c]		1	132	9.50
Plantings and transport[d]		1	881	62.80
Planting		1	227	16.20
Maintenance costs				
Fertilization[e]		7	341	25.10
Weeding and equipment		5	977	84.20
Equipment for labor security		1	29	2.10
Harvest costs				
Harvest[f]	Maize	5	2422	161.80
	Sugarbeet	5		187.80
	Cereals	5		245.40
	Potato	5		201.70
	Grass	5		97.50
Soil preparation to its original use (stump removal. ploughing)		1	276	19.70
Total costs				
Total cost	Maize			472.82
	Sugar beet			498.82
	Cereals			556.42
	Potato			512.72
	Grass			408.52

Sources: [21,31]. Calculations of Weger et al. (2004).
[a]NPV = Net present value; all cost items that appear irregularly over the production, for example in the first or last year, are calculated back to the value in year 0; interest rate is 4%.
[b]Actual land rent is 31.75 € ha^{-1}.
[c]Ploughing costs are 144 € ha^{-1}.
[d]10,000 plantings ha^{-1}. costs for these plantings are 952 € ha^{-1}.
[e]The costs for fertilizer are based on an input of 4.2 kg N t^{-1} DM [34]. a loss of 20 percent of fertilizer and the use of the fertilizer LAV (ammonium nitrate. 27.5% N).
[f]Harvest costs are 13.5 € t^{-1}.

Table 10
The actual costs of SRC biomass production in different agricultural production areas (APA)

	Yield (t DM ha^{-1})	Costs per ton (Euro t^{-1})	Costs per GJ (Euro GJ^{-1})
APA			
Maize	7.33	64.50	3.32
Sugar beet	8.51	58.62	3.02
Cereals	11.12	50.04	2.58
Potato	9.14	56.10	2.89
Grassland	4.42	92.43	4.76

realised on short term with improved fertilization and mechanisation strategies, occur. An increase of feed conversion efficiencies—and thus a lower feed and fodder demand—from the present to a higher level as predicted for 2030 by FAO [16] contributes to the potential of 20 PJ bio-energy by setting land free for the production of energy crops. The bio-energy potential can be nearly doubled if yield increases to the level of Dutch agriculture by improving agro-technological efficiency (especially higher intensity and improved mechanization of crop production). The costs assessed for bio-energy range between 1.25 and

Table 11
The energy supply (ES) potential for the Czech Republic divided into different biomass sources and assessed for different scenarios

Biomass source	Scenario					
	1 (PJ)	2 (PJ)	3 (PJ)	4 (PJ)	5 (PJ)	6 (PJ)
Agricultural residues, rape straw	22.4	18.4	18.4	18.4	18.4	14.7
Agricultural residues, cereal straw	67.6	56.2	56.2	56.2	56.2	44.7
Forestry residues	15.6	15.6	15.6	15.6	15.6	15.6
Biomass from SRC	3.1	104.7	84.2	109.3	105.1	289.4
Total	108.7	194.9	174.4	199.5	195.3	364.4

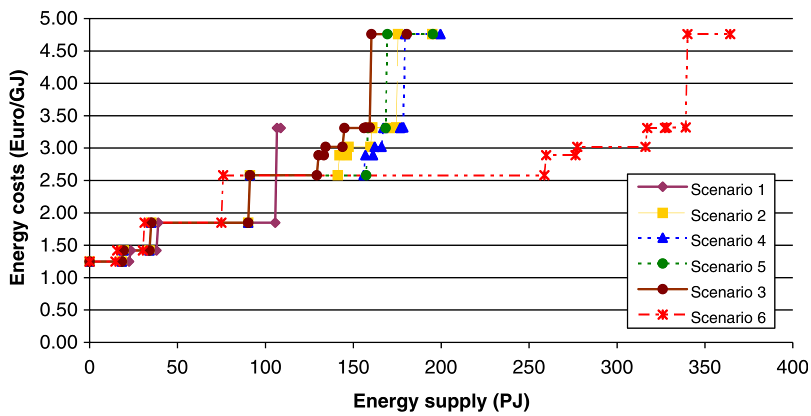


Fig. 6. Cost-supply curve for biomass energy in the Czech Republic for 2030.

4.76 € GJ^{-1}. Agricultural residues are the cheapest and biomass from SRC produced on land with low soil quality is the most expensive source for bio-energy. According to our analysis and present technologies biomass from SRC cannot be provided at a lower price than 2.58 € GJ^{-1}. This raises the questions whether biomass production in CZ is competitive on the EU or World market and how biomass production costs could be lowered. In the following chapters uncertainties in the biomass potential and cost analysis are discussed and the results of this study are compared with those of previous studies.

4.1. Uncertainties in the assessment of biomass potentials

The yield level of food, fodder and energy crops has been identified as the main factor determining the biomass potential because (a) higher productivity of food and fodder crops sets land free for the production of energy crops (b) the productivity of energy crops determines the amount of biomass that can be produced on the areas available for energy crop production.

The biomass potential therefore differs strongly with the yields predicted for 2030. These predictions contain several uncertainties because the impact of future breeding efforts and technology development like, for example, precision farming, is difficult to predict. In scenario 6, with yields on the level of Dutch agriculture, yield increases of about 40% (potato, fodder crops) to 54% (cereals) and 90 % (rape seed) were assumed. A comparison of the Czech and Dutch yield level has to be seen under the constraints of eco-physiological site conditions for crop production, like sum and distribution of precipitation, temperature and length of vegetation period. These conditions are favourable for crop production in most of the Netherlands, which along with agro-technological efficiency, is an important reason for the high yield levels there. Our prediction for 2030, however, appears realistic since analysis of Rabbinge and Diepen [33] showed that the current yield levels of cereals in CZ are only at 45% of the simulated water limited yield while they are on a level of 79% in the Benelux countries. It was concluded that the application of agricultural technology and production methods, especially the intensity of production, presently applied in the Benelux countries, could fulfil the biggest part of the predicted yield increases.

Increases in energy crop yields can significantly increase the biomass potential calculated here. Here we assumed SRC yields to be as they were measured in today's field trials with traditional varieties. It is to be expected that future SCR yields will increase because of breeding efforts. Actual breeding activities on willow for SRC by Svalöf Weibull AB have already resulted in a 10–20% increase in yield [34]. Mead [35] made an inventory on breeding efforts of tree species for SRC where it is concluded that typical gains for first and second generation breeding programs for most tree species are 10–20% and 20–30%, respectively. The overall gains of breeding eucalyptus in Brazil were

2.1–2.5% per year. If here a gain of willow breeding of 1% per year is assumed, the yields of willow will increase by 25% until 2030. This additional yield increase would deliver another 21 (scenario 3) to 72 PJ a^{-1} (scenario 6).

Here it was assumed that SRC is produced on all land available for energy crop production. Alternatively more productive crops, like the perennial C4 grass miscanthus, could be produced on the available land. In field trials it was shown that, because of higher light energy and water use efficiency, miscanthus builds about 40% higher biomass yields than C3 crops like willow [36]. So far little experience with miscanthus production in CZ has been made and the presently high establishment costs lead to higher biomass production costs for miscanthus compared to willow biomass [37]. Further development of the crop production system could make miscanthus an interesting energy crop for CZ. Growing miscanthus instead of willow would increase the biomass potential by about 34 (scenario 3) to 116 (scenario 6) PJ a^{-1}.

In 1999, the Czech Ministry of Agriculture estimated that the total area of agricultural land in CZ unsuitable for producing food is about 1.3 million ha. Of this land about 800,000 ha of mainly grasslands are maintained with state subsidies [38]. Jiranek and Weger [39] estimate that at least 500,000 ha of this land could be used for biomass production and another 35,000 ha of devastated land, partly contaminated with heavy metals, are available. If part of this land is taken out of production because the use is economically not profitable it is to be expected that the yield levels of SRC on this land are rather low. Assuming a yield of 4.42 t DM ha^{-1} a^{-1} (yield on the grassland APA) 500,000 ha low quality land could deliver an additional 43 PJ.

Uncertainties in the biomass potential can also arise from possible negative consequences that a great change of farming practise, which may include pest or disease outbreaks, and large-scale production of new biomass crops could have. These should be taken into account because they may have influence on future development of energy crops and their production areas. Implementation barriers, like acceptance problems with non-native species, lack of knowledge and scepticism towards new crops can hamper the realization of biomass production. However, the main aim of this study is to show the potentials for biomass production in CZ and more research is needed to show how these potentials can be realized.

4.2. Biomass production costs and options for improvement

The costs for biomass from SRC in CZ are here assessed with 2.58–4.76 € GJ^{-1}. In literature, production costs of woody biomass range from 0.5 −17.7 US$ GJ^{-1} worldwide or 2.5–16.4 US$ GJ^{-1} in Europe [40]. That means the costs for woody biomass from CZ range at the lower level. Furthermore lower production costs are to be expected in the future for several reasons. The costs of biomass production from SRC are dominated by the costs for

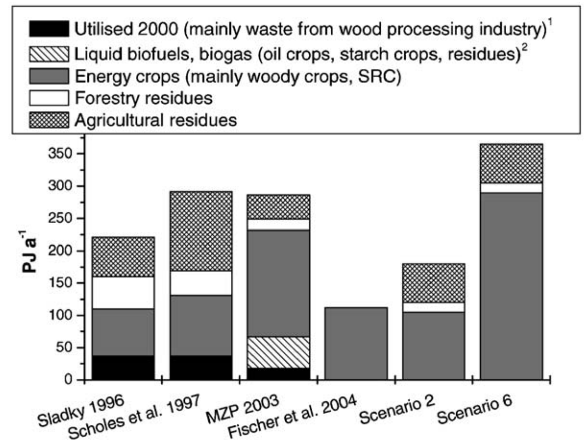


Fig. 7. Bio-energy potentials assessed for the Czech Republic by different studies. 1. Different numbers on bio-energy actually produced are found in Czech statistics. 2. The Ministry of Environment (MZP) uses the additional category of liquid fuels (from rapeseed oil and ethanol from cereals) and biogas (main from organic wastes and agricultural residues.

planting and harvesting. In CZ not yet many experiences with SRC production have been made so far. It is to be expected that, by learning and developing better technologies for establishing and harvesting, the production systems in the CZ will become more efficient.

As shown here, the costs strongly depend on the yield of SRC. Especially breeding efforts, as discussed above, will lead to yield increases and therefore to a reduction of the production costs per t biomass and GJ bio-energy, respectively.

The Czech Ministry of Agriculture expects higher land use prices in future. Therefore the development of land use costs stays a factor of uncertainty for the assessment of future biomass production cost.

4.3. Biomass potentials of the CZ assessed by different approaches

In this study a detailed analysis of the biomass production potentials in the different NUTS-3 regions of the CZ was performed; such a detailed analysis was not yet done before. There are some studies that give estimates for biomass potentials on the CZ national level (see Fig. 7). The studies of Sladky [13] and MZP [15] are rough estimates based on aggregated statistic data of land use, expert estimates or average yields for residues and energy crops. This study includes the analysis of APA specific crop yields that were measured in field trials. The results on bio-energy potentials from energy crops from this study and for those scenarios that assume a moderate improvement of agricultural production systems (scenarios 2–5) are very much in line with the results of the studies done by Scholes et al. [14] and Fischer et al. [41]. Both studies used, like in the approach applied here, maps on land quality and applied land quality specific energy crop yields. Both studies, however, also considered other perennial energy crops, like miscanthus or dock hybrid, but they used other approaches to define land availability. Fischer et al. [41] modelled energy crop production by excluding production on agricultural land that is suitable[1] or very suitable for at least one of the major cereals in Europe. Sladky [13], Scholes et al. [14] and MZP [15] assumed a general availability of 10–20% of agricultural land for energy crop production. In this study land availability for energy crop production was modelled for different scenarios of crop productivity and considered the food and fodder demand.

Differences in the results on bio-energy potentials from agricultural residues arise from assumptions on the kind of straw to be used and the share of residues available for energetic use. Scholes et al. [14], for example, assumed a total availability of straw while in this study, for reasons of soil fertility maintenance, an availability of straw for energetic use of only 30% was assumed.

None of the previous studies performed scenario analysis and they therefore provide only one number for the bio-energy potential. Because this study performed scenario analysis, it could identify the key parameter influencing the bio-energy potential and the magnitude of their influence. The results of scenario 6, as shown in Fig. 7, show the influence of yields and agricultural productivity on the bio-energy potential. In this scenario the bio-energy potential from energy crops is two to three times as high as estimated by the previous study and could more than cover the predicted domestic demand of bio-energy of 250 PJ a^{-1}.

5. Conclusions

The NUTS-3-regions CZ020, 31 and 32 have the highest bio-energy production potential in the CZ, regardless of agricultural trends.

If Czech agriculture would stay at the present level of intensity and development, hardly any area for the production of energy crops would be available because it will be needed for (low productivity) food and fodder crop production. The bio-energy potential of the CZ mainly depends on the productivity of agriculture and development of yield levels of food, fodder and energy crops. Under slightly improved production systems a bio-energy potential of about 195 PJ a^{-1} could be realised of which about 54% are from energy crops. If future Czech agriculture would develop towards the level of intensity and technology that is realised in WEC, like the Netherlands or Germany, the bio-energy potential could reach 365 PJ a^{-1}, of which 80% are from energy crops. Another 160 PJ could become available when energy crop production methods are further developed and all land resources are used. The potential supply of about 525 PJ a^{-1} covers twice the domestic demand and would allow for the export of biomass to other EU countries.

[1]Suitability reflects the yield potential for a certain crop in a grid cell, six suitability classes from very suitable to not suitable are formulated (see [41]).

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