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PAVEL DITL, JAROSLAV SKŘIVÁNEK*

THE LIMITS OF RENEWABLE ENERGY SOURCES IN THE CZECH REPUBLIC

OGRANICZENIA ODNAWIALNYCH ŹRÓDEŁ ENERGII W REPUBLICE CZESKIEJ

A b s t r a c t

The method of material and energy balancing in the macro-system earth-surrounding was applied for evaluation of the present state, for prognosis and determination of limits for utilisation of renewable energy resources and for understanding of circulation of phytomass and CO_2 and for energy production. It was demonstrated that without regard to the type of phytomass the specific output of photosynthesis in kW/ha is approximately constant with the average value of 3,16 kW/ha. By qualified calculation at estimated production areas and conversion efficiency to utilisable energy it was estimated that the present energy consumption could be covered by production of phytomass by about 6,7%. The applied method is not specific for conditions of the Czech Republic and could be utilised generally.

Keywords: renewable energy sources, carbon dioxide, environment

S t r e s z c z e n i e

Dla oceny stanu obecnego i w przyszłości oraz dla określenia ograniczeń wykorzystania energii odnawialnej zastosowano metodę bilansowania masy i energii w otoczeniu Ziemi na podstawie analizy krążenia fitomasy i CO_2. Przyjęto, że charakterystyczna wydajność fotosyntezy ma średnią, stałą wartość 3,16 kW/ha, bez względu na rodzaj fitomasy. Na podstawie obliczeń założonej powierzchni produkcji oraz wydajności przetwarzania w energię użyteczną oszacowano, że przy obecnym zużyciu energii może być ono pokryte z produkcji fitomasy w około 6,7%. Zaproponowana metoda nie odnosi się jedynie do warunków Republiki Czeskiej i może być ogólnie stosowana.

Słowa kluczowe: odnawialne źródła energii, dwutlenek węgla, środowisko

* Prof. Ing. Pavel Ditl, DrSc., Prof. Ing. Jaroslav Skřivánek, DrSc.,
Ústav procesní a zpracovatelské techniky, České vysoké učení technické v Praze.

1. Introduction

Recently problems of energy, possibilities of renewable energy resources and their impact on development of environment are frequently discussed but a question remains whether the human society can survive without fossil energy resources. The published information significantly mutually differs and they are given in inhomogeneous and incorrect units and are technically unsoundly interpreted.

According to the International Energy Agency is production of energy in the year 2004 in the Czech Republic (CR) and production and consumption of electric energy as follows:

CR 2004	http://www.eia.doe.gov/emeu/international/contents.html			
	kWh/year	%	kJ/year	kW/capita
Total energy consumed	5,19E+11	100	1,867E+15	**5,921**
Electric energy-production	7,91E+10		2,849E+14	0,903
Electric energy-consumption	5,88E+10	11,34	2,117E+14	0,671
Fossil fuels-consumption	2,20E+11	42,44	7,923E+14	2,512
Natural gas-consumption	9,93E+10	19,15	3,576E+14	1,134
Crude oil-consumption	1,23E+11	23,62	4,410E+14	1,398

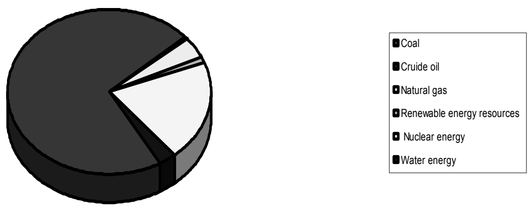

Fig. 1. Electric power production by sources – Czech Republic 2004

Rys. 1. Źródła energii elektrycznej – Republika Czeska 2004

Further it could be seen that other energy resources contribute at present only little to the energy balance.

The aim of our contribution is as follows:

1. On basis of estimates of real production of biomass and valid physical laws to estimate the limiting possibilities of individual renewable energy resources and to judge which one of them could contribute to independence on classical energy resources.
2. To judge if energy independence at utilisation of renewable energy resources could be achieved.
3. To evaluate possibilities of production of energy from phytomass by various methods of conversion of phytomass to other types of fuels.
4. To valuate systematically circulation of CO_2.

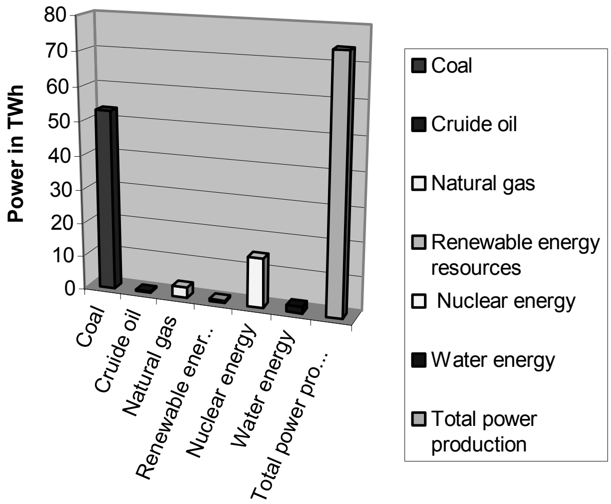

Fig. 2. Total and percentage electric energy production – Czech Republic 2001

Rys. 2. Całkowita i procentowa produkcja energii elektrycznej – Republika Czeska 2001

2. Renewable energy resources

Renewable energy resource is defined as utilisable energy resource, whose energetic potential is permanently and spontaneously renewed by natural processes. All natural processes are derived from activity of sun, while geothermal resources available in the Czech Republic are negligible (are of negligible importance). Natural processes initiated by sun radiation could be dividend into the following groups: wind, water flows and production of phytomass and direct use of sun energy. Interesting information is given in the study „Renewable energy resources and possibilities of their utilisation in the Czech Republic“, which is available at the web site:
www.cez.cz/presentation/cze/GetFile?type=FilFile&version=-&id=33187&download=true-

Energy of wind is given by kinetic energy of wind whose calculation is rather problematic, but some estimates from literature are given. The statistics of ERU (Energy Regulated Authority) for the year 2006 see www.eru.cz; stated that the total rough production in the Czech Republic was 84 288,3 GWh, out of which wind power plants produced 49 GWh, what was about 0,06%. From pages of the Czech Society for Wind Energy www.csve.cz; it was possible to find out that WU (wind units) installed in the year 2006 were an output of about 56 MW (ERU stated only 44 MW). By a simple calculation the average utilisation in the WU in the year 2006 was about 10% (according ot ERU 13%). In the total energy balance this represented a negligible contribution.

Utilisable **energy of water flows** represents their potential energy and calculations are documenting its possibilities in the CR:

Average height	H1=	550	m		
Hřensko (locality)	H2=	150	m		
Flow rate	Q =	229 400	kg/s		
Hydropotencial	P =Q.(H1-H2).g	2,83876E+13	kJ/year		
Utilisable hydropotencial 26%		7,38078E+12	kJ/year	2,05	TWh/year

In comparison with the year 2004, when energy consumption was 1,867E+15 kJ/year this represents about 0,4% of yearly energy consumption.

The power output of **solar collectors** at favourable conditions is about 50 Wm^{-2}. At maximum utilisation of available area about 0,1%, i.e. 78 km^2 and average sunshine 5 hrs/day we could get the output of 39 MW = 2,5623E+11 kJ/year = 0,071175 TWh/year, which is not solving the situation at all.

The main part forms the **utilisable energy from phytomass**. Yearly production of phytomass on agricultural and forest lands can be relatively accurately evaluated if we take into account as the basis the known yearly production of hydrocarbons (cellulose, starch, sugar, etc.) without regard to the type of phytomass. Formation of cellulose is given by reaction

$$CO_2 + H_2O + \text{energy of solar radiation} = H–CO–H + O_2$$

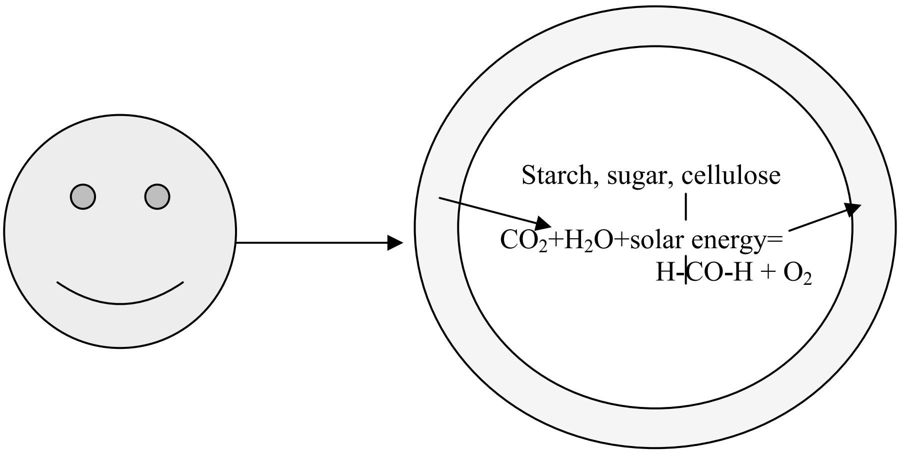

Fig. 3. Principle of photosynthesis

Rys. 3. Zasada fotosyntezy

From this equation it is possible to calculate the amount of energy which could be liberated for the given yearly production of phytomass.

Utilisable part of energy is reduced for energy necessary for evaporation of water contained in phytomass. In this way it is easy to determine the amount of consumed and converted sun energy.

3. Ways of utilisation of phytomass for production of energy

Now we will consider ways how to utilise this energy with a highest efficiency. The basic structural unit of cellulose could react in three ways:

Combustion $H–CO–H + O_2 = H_2O + CO_2$

Biogas $2\ H–CO–H = CH_4 + CO_2$

Bioethanol $3\ H–CO–H = C_2H_5OH + CO_2$

The last reaction takes place in water and water must be finally separated. Also combustion is accompanied by separation of water by evaporation. By giving reaction heats and by execution of enthalpy balance of individual processes we could reach conclusions on energetic advantages of individual routs.

From carbohydrates fats and proteins can form. Proteins are not a significant source of energy while fats, first of all vegetable are sources of energy. The principle of combustion of fats could be easily presented as combustion of stearic acid

$$\begin{array}{l} H-C-H \\ \quad\ | \\ H-C-H\ +\ 9/2\ O_2\ =\ 3\ CO_2\ +\ 3\ H_2O \\ \quad\ | \\ H-C-H \end{array}$$

Methane and ethanol represent fuels that could be further combusted.

$$CH_4 + 2\ O_2 = 2\ H_2O + CO_2$$
$$C_2H_5OH + 3\ O_2 = 3\ H_2O + 2\ CO_2$$

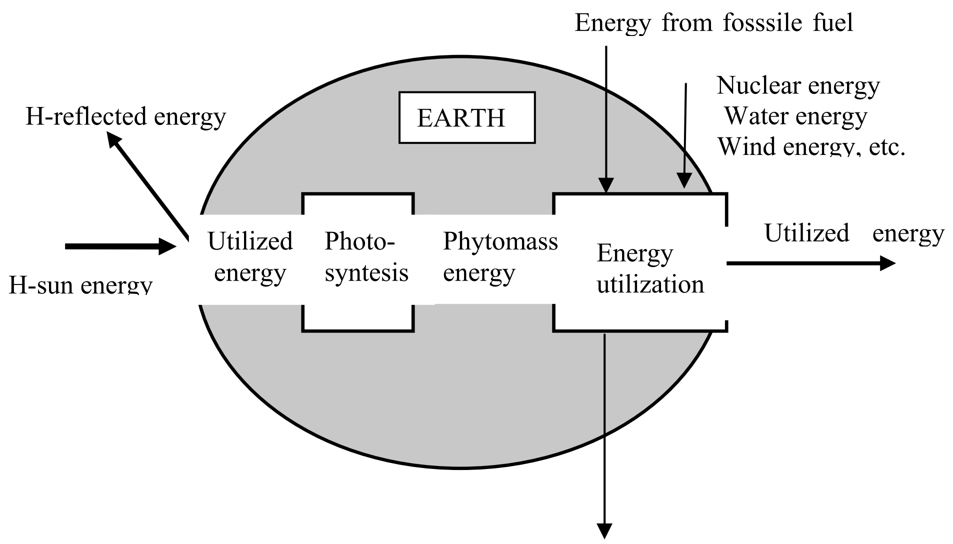

Fig. 4. Schematic diagram of energy balance

Rys. 4. Schemat bliansu energii

We could see that all products of photosynthesis are decomposed to CO_2 and H_2O in the molar ratio 1:1 and in the same ratio both CO_2 and H_2O are consumed at photosynthesis. This means that this whole process could not rock the boat and the equilibrium circulation of CO_2 and H_2O on earth. The equilibrium circulation could be disequilibriated only by accumulation of fuel mass e.g. by exploitation of fuel deposits or by origin of new deposits. At present first of all exploitation of fuels is concerned. At combustion of fossil fuels the ratio of produced CO_2 to H_2O could change from 1:2 for the case of combustion of methane (natural gas) up to 1:0 at combustion of coke. Legislative interventions prefer combustion of methane but this leads to destruction of the basis of the most valuable raw material for chemical industry.

In Fig. 4 is schematically displayed conversion of sun radiation on phytomass and further its conversion to utilisable and lost thermal energy. Energy contained in phytomass is larger for thermal losses of processes than energy utilised on earth. Analysis of losses in processes utilising individual renewable resources are not considered in this contribution but it is obvious that first of all the water content in phytomass is of primary importance. If heats of combustion of individual renewable resources and their specific production per ha are known we could determine the specific production of energy in kW/ha for individual plants. This is made in the next table. It could be seen that the specific energy productions are similar with the exception of sugar beet.

The weighted mean over production area is 3,16 kW/ha, while for sugar beet it is equal to 4,89 kW/ha. But if we take into consideration the rise in outputs in t/ha and the rise of sugar content from 12% to 18,8% by wt. in recent years it is logical. This would lead to the conclusion that 20 years ago sugar beet would have not fallen out of the average. Crop breeding seems to be a significant route toward increase of energy produced from renewable resources.

If we multiply the mean specific energy production by the sum of production area of forest and agricultural land given in the next table we obtain the maximum theoretical energy production from phytomass. This makes about 37% of the present energy consumption in the CR.

	% total area	km^2
Agric. land	54,10	42198
Forests	34,67	27040
Others	11,23	8762
Total	100,00	78000

Limiting energy output of agricultural and forest land (without reserves for production of food, paper and technical wood)	21 875 6,899E+14 36,94	MW kJ/year %

Data of the Czech Energy agency for the year 2005 are given for comparison. The present utilisation of the recoverable energy sources, available and economic potential – and vision up to the year 2010 are compared in the next table taken from literature.

Resource Hydrocarbons	**Water content** [wt. %]	**Heating value** [MJ/kg-wet]	**Heating value** [MJ/kg-dry]	**Production Dry matter** [t/ha/year]	**Specific output** [kW/ha]	**Production area** [km^2]	**Production energy** [kJ/year]	**Output per person** [kW/person]
1. Wood								
3riquettes	8,00	17,50	19,22		0,00			
'ire wood	50,00	9,50	20,22	6,17	3,96	27040	3,374E+14	1,070
ndustrial waste-chips of soft wood	50,00	9,50	20,22					
ndustrial waste-chips of soft wood	20,00	15,20	19,49					
Crushed brushwood	30,00	13,30	19,73					
;traw (grain and rape seed)	15,00	14,50	17,43	4,00	2,21	6250	4,356E+13	0,138
:nergetic hay	15,00	12,00	14,48	3,50	1,61			
2. Cereals					0,00			
Vheet (grain)	15,00	14,08	17,00	5,00	2,70	8676	7,375E+13	0,234
3arley (grain)	15,00	14,51	17,50	3,75	2,08	5436	3,567E+13	0,113
)ats (grain)	15,00	14,93	18,00	3,00	1,71	544	2,938E+12	0,009
3. Sugars								
;accharose			16,50					
;lucose			15,61					
;ugar of beet	18,50	% saccharase	16,50	9,36	4,89	590	9,108E+12	0,029
4. Fats								
;tearic acid			40,00					
'almitic acid			38,90					
Rape seed oil-production of seed	42,50	% oil	36,80	1,25	1,46	3504	1,612E+13	0,051
				average	**3,16**	52040		1,644

Data are given in 10^{15}J/year

	state 2000	Available potential	Economic potential
Biomass	21,1	83,7	50,9
Solar thermal systems	0,356	11,5	4,0
Photovoltaic systems	0,0001	0,1	0,1
Water power plants			
– large	5,664	5,7	2,93
– small	2,448	4,1	0,1
Wind power plants	0,018	4,0	2,5
Heat pumps	2,8	8,8	1,52
Wastes	0,976	3,7	0,105
Geothermal energy	0,105	0,105	0,105
TOTAL	33,46	121	67,5

The given available energy potential from biomass in the year 2010 equal to $83{,}7\cdot10^{15}$ kJ/year = 0,837exp+14 represents $0{,}837/18{,}67\cdot100 = 4{,}65\%$ of the total yearly energy consumption. Our estimate on basis of the made calculations and estimates of the maximum possible utilisation of production and utilisation of biomass with assumptions stated earlier in this paper is equal to 6,7%. That is a very good agreement.

4. Valuation of possibilities given by different methods of conversion of fuels

1. Carbohydrates: (glucose + cellulose, etc.) → ethanol → CO_2, H_2O

The following reactions could be of importance and could be written for a general carbohydrate in the form

$C_nH_{2n}O_n = n/3C_2H_5OH + n/3CO_2$ 0,084 MJ kg carbohydrate^{-1}
$n/3C_2H_5OH + nO_2 = 2/3nCO_2 + nH_2O$ -15,700 MJ kg carbohydrate^{-1}
-15,617 MJ kg carbohydrate^{-1}

100,54 % heating value of pure carbohydrate
Production CO_2 – fermentation, 100 CO_2 1/90 kmol CO_2 kg
Production CO_2 – combustion, < 21% vol. 2/90 carbohydrate^{-1}

2. Carbohydrates: (glukose + cellulose, etc.) → CH_4 → CO_2, H_2O

The following reactions could take place. For a general carbohydrate they could be written in the form:

$C_nH_{2n}O_n = n/2CH_4 + n/2CO_2$ -0,748 MJ kg carbohydrate^{-1}
$n/2CH_4 + 3/2nO_2 = n/2CO_2 + nH_2O$ -14,868 MJ kg carbohydrate^{-1}
-15,617 MJ kg carbohydrate^{-1}

95,21 % heating value of pure carbohydrate
Production CO_2 – anaerobic, 100% CO_2 1,5/90 kmol CO_2 kg
Production CO_2 – combustion, < 21% vol. 1,5/90 carbohydrate^{-1}

3. Combustion of phytomass: Carbohydrates (glucose + cellulose,etc.) → CO_2, H_2O

Here are of importance reactions that could be written for a general carbohydrate in the form

$C_nH_{2n}O_n + nO_2 = nH_2O + nCO_2$ -15,617 MJ kg carbohydrate^{-1}

Production of CO_2 – by combustion < 21% vol. 3/90 kmol CO_2 kg carbohydrate^{-1}

From the given data it could be seen that any carbohydrate supplies the same amount of energy per kg. Moreover it could be seen that different routes differ as power production is concerned only within the range of several percent. Production of CO_2 per kg of carbohydrate is the same at different methods of conversion of biomass, but they differ significantly whether CO_2 forms in a dilute form (flue gases) or if it forms as pure CO_2 which could be utilised in other processes. In this case the most advantageous route is via methane.

One of basic indicators of efficiency of the combustion process is the adiabatic combustion temperature. This is first of all affected by content of water in the fuel. The higher is this temperature, the more is this process energetically more efficient and investment costs are lower. The calculated adiabatic temperatures for combustion of fire wood, ethanol, methane and biogas are compared in the next table.

Fuel	Conversion [%]	Excess O_2 [%]	Adiabatic temperature [°C]
Fire wood 50 mass % water	98	20	1367
Wood 25 mass % water	98	20	1594
Wood 10 mass % water	98	20	1699
Bioethanol	98	20	1986
Rough biogas (CH_4):(CO_2) = 1:1	98	20	1652
Purified biomass (CH_4)	98	20	2555

On basis of adiabatic temperatures it is possible to determine thermal efficiencies for the given temperatures of flue gases leaving the boiler. It could be seen from this table that the lowest adiabatic temperature has the fire wood, the highest purified biomass (methane). It could be also seen that the difference of thermal efficiencies of raw and purified biomass are sufficiently large so that removal of CO_2 pays of.

5. Valuation of circulation of CO_2

On basis of the above given information it could be seen that at steady state when fossil fuels are not utilised and neither phytomass is accumulated by carbonisation nor CO_2 is accumulated on the earth surface the content of CO_2 in the atmosphere remains constant. The eventual rise of concentration of CO_2 is thus due to the difference between the production of CO_2 from fossil fuels and eventually by positive accumulation of phytomass on earth. According to EIA http://www.eia.doe.gov/emeu/international/carbondioxide.htm_ production of CO_2 in the CR in the year 2004 was 112 mil. t/year. In the next table is given the corresponding volume of CO_2 and the amount of phytomass is calculated (on basis of the above given data) which would consume this amount of CO_2. In this table is also given the yearly production of wood phytomass if all available forest land is utilised (for cultivation of wood for production of energy). It could be seen that at conditions of the Czech Republic this phytomass would consume only 21,8% of production of CO_2 . This is a reason why it is necessary in the world wide not to reduce but expand accumulation of phytomass for the time period when fossil fuels are still exploited.

CR 2004	mil. t CO_2/year	kmol CO_2/ /year	kmol CO_2/ /tfyto	tfyto/ /year	Nm^3 CO_2/ /year
Production CO_2	112,41	2,55E+09	33,33	7,66E+07	5,72E+10
Max. consumption CO_2 by photosynthesis				1,67E+07	= 21,8%

To give an idea how the CR is affecting the balance of CO_2 in the atmosphere we could calculate the yearly rise of CO_2 in the "chimney" above the Czech Republic, this accounts for 5,72E+10/(78000 km^2 x 8,135km x 1,00E+9) = 0,009%.

6. Conclusions

On basis of the made analysis of available data the following conclusions could be made:

1. The method of material and energy balancing in the macrosystem earth-surrounding was applied for evaluation of the present state, for prognosis and determination of limits for utilisation of renewable energy resources and for understanding of circulation of phytomass and CO_2 and for energy production.

2. The close connection between circulation of CO_2, H_2O a O_2 was quantified.
3. It was demonstrated that without regard to the type of phytomass the specific output of photosynthesis in kW/ha is approximately constant with the average value of 3,16 kW/ha.
4. By qualified calculation at estimated production areas and conversion efficiency to utilisable energy it was estimated that the present energy consumption could be covered by production of phytomass by about 6.7 %. In the year 2004 the renewable energy resources (mostly hydro energy) have participated on energy production by 0.96%.
5. Methods of energy production from phytomass were valuated according to various methods of conversion of phytomass to other types of fuels. Direct combustion of phytomass for energy production seems not to be the optimum method.
6. It was concluded that increase of conc. of CO_2 in the atmosphere is the question of production of CO_2 from fossil fuels and consumption of CO_2 by photosynthesis. This means that the Czech Republic will remain a polluter of atmosphere by CO_2 up to the time when fossil fuels will not be available any more.
7. The applied method is not specific for conditions of the Czech Republic and could be utilised generally.

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