# Modeling of LCA-chain segment for Biofuels As an instrument for the protection of the population

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*Abstract:* - The sustainably development is connected with information needs. The development of biofuels and renewable energy sources utilization requires a lot of analysis, to be implemented well. The countries that support these activities must often deal with problems arising both from the often high prices of energy and from criticism of various kinds of arguments from high environmental burden induced by these sources to the topics focused on their inefficiency. However, these problems are caused by lack of information in the implementation of policy decisions. A clear answer as to what resources should be given priority or how to compile ranking of priorities and to what the arguments are true, can be given by the most accurate mapping of these processes. This article focuses on a possible sample procedure.

*Key -Words:* modeling, sustainable development, Petri nets, decision making support, biofuels, energy and material flows, environmental burden.

## 1 Introduction

The current development in EU focuses on environmental protection and sustainability [3,5,8,17,18]. At the end of 2010 the energy share of biofuels for transport in each of the Member States of the European Union was 5.75% of the energy supplied for transport [2]. These steps, which are taken in the context of efforts to solve environmental problems, are enforced especially by public administration and have been struggling with still increasing criticism since the introduction of the obligation to use biofuels in transport fuels. Public administration often plays the role of the body, which determines the conditions for development and focus of the entrepreneur and research activities [11,12,13,14,16].

The authorities, however, need sufficiently processed data for effective decision making. As the concrete experience shows, many of these problems arise from lack of knowledge of specific material and energy flow processes, about which a decision should be made [11,12].

Even basic knowledge of material and energy flows of monitored processes coupled with the quantification of individual items can give a clear answer to the question, how much environmental burden a concrete process induces, [2,8,9] and which of the possible processes will deliver the best results under the given circumstances. Analysis of one type of renewable energy source may not be always sufficient; for the correct decision it may be needed to perform a comparative analysis of various sources and set the ranking of their preference under given circumstances.

Comparative analysis of the possible alternatives provides significant support in selecting the best solution for a particular purpose, which can be at the same time environment friendly, economically advantageous and socially beneficial.

Properly established portfolio of renewable resources can form an efficient instrument for the protection of population in terms of effective enforcement of sustainability with a positive impact on all of its three pillars.

Such solutions exist in practice and show considerable success [6].

The article deals with modeling and comparison of selected alternatives used in the utilization of renewable energy sources in central Europe on the example of rapeseed oil and bio-ethanol.

The models as well as auxiliary calculations are based primarily on collected data.

Used empirical data were acquired in the Czech Republic and are relevant as an information base for decision-making in terms of the Czech Republic, or countries with similar soil type and climatic conditions.

The energy consumption spent to obtain energy in the form of selected biofuels was compared.

The comparison analyses bio-diesel produced from oil rape, bioethanol made from wheat and from sugar beet.

## 1.1 Rapeseed oil

For the balance of inputs and outputs of the process of growing rape plant and other crops used for energy recovery, the analysis of energy and material inputs of this process is very significant.

Empirical data show that during one cycle (season) of oil rape cultivation heavy machinery is used at least 20 times, as shown in table 1.

Activity 2, settlement policies and activity 8, rolling may not always be performed, but in the company where empirical data were collected, these activities were included in the standard.

During activities, 10, 13 and 14, around 220 to 230 kg nitrogen per ha is brought into the soil, other fertilizers were not investigated.

For a complete calculation of the whole part of the LCA chain these flows must also be included. In this article they were neglected due to lack of accurate empirical data. The article focuses predominantly on the fuel consumption during the season.

Generally, the sprayer will go to the field at least four times during the spring. Consumption of diesel per trip varies significantly depending on the type of activity, for example for medium-deep plowing it was estimated at 22.38 liters, for deep plowing at 35.70 liters of diesel fuel per hectare.

Considering all the activities it was found that during the whole cycle of growing oilseed rape the consumption of machinery in the field is 116.89 l diesel per hectare.

Table1: Consumption of fuel during one cycle of rape cultivation

| | Activity | Machinery | Period | Diesel fuel consumption l/ha |
|---|---|---|---|---|
| 1 | Stubble | Tractor and stubble plow | July | 6,42 |
| 2 | Leveling of stubble | Tractor and leveler | July/August | 5,31 |
| 3 | Plowing | Tractor and plow | August | 22,38 |
| 4 | Leveling | Tractor and compactor | till 15.8. | 5,14 |
| 5 | Leveling | Tractor and leveler | till 15.8. | 5,31 |
| 6 | Fertilizing (fertilizers according to soil analysis) | Sprayer | till 15.8 | 4,4 |
| 7 | Sowing | Tractor and sowing machine | till 15.8 | 2,96 |
| 8 | Rolling | Tractor and roller | August | 2,7 |
| 9 | Herbicides (against weed) | Sprayer | September | 4,4 |
| 10 | Nitrogen fertilization | Sprayer | September | 4,4 |
| 11 | Fungicide | Sprayer | September | 4,4 |
| 12 | Nitrate fertilization | Tractor and spreader | March | 1,27 |
| 13-14 | Nitrogen fertilization | Sprayer | March | 8,8 |
| 15-18 | Fertilization / Spraying | Sprayer | spring | 17,6 |
| 19 | Pre-harvest treatment | Sprayer | spring | 4,4 |
| 20 | Harvest | Harvester | July / August | 17 |
| | Total | | | 116,89 |

Source: [10]

Another selected biofuel is the bioethanol produced from sugar beet.

## 1.2 Sugar beet

Bioethanol (or in general ethanol) is an alternative to gasoline and in the past it was used in many countries in case of lack of petrol. With the development of the use of biofuels the demand for this fuel increases.

It should be added that, as a replacement for car gasoline, many other biofuels can be used starting with wood gas on one side and with synthetic gasoline from biomass on the other side.

One of the possibilities in the climatic conditions of central Europe is the production of ethanol from sugar beet. Empiric data show, that the total number of trips of heavy machinery to the field for sugar beet was 19, see table 2. Fertilization takes place on the basis of soil analysis, but is done generally during activities 2. About 50-60 kg of nitrogen per hectare is brought in the form of manure, which must always be plowed into the soil in a very short time.

During activity 8 about 60-90 kg of nitrogen per hectare is released in the form of liquid fertilizer. Nitrate fertilizer used in May and other fertilizers are significantly influenced by soil analyzes. The values therefore represent an average. When these calculations are used for a wider area, it is impossible to get, for the reasons mentioned above, completely accurate data.

The table 2 includes, therefore, information obtained by averaging of the data. Number of sprayers' spring trips with fertilizers and sprays under standard conditions was set at six, but with regards to the situation with the pests and weeds it may not be a final number.

The total fuel consumption should be around 195 l per hectare of beet fields, but strongly depends on the need for spraying, and also replacement of medium-deep plowing (22.38 l / ha) by deep plowing (35.70 l / ha) which may take place under certain circumstances, so consumption may be much higher.

A significant difference compared with oilseed rape is the consumption of a special type of sugar beet harvester, which is almost three times higher per hectare.

Table 2: Consumption of fuel during one cycle of the sugar beet

| | Activity | Machinery | Period | Diesel fuel consumption l/ha |
|---|---|---|---|---|
| 1 | Stubble | Tractor and stubble plow | August | 6,42 |
| 2 | Fertilizing – fertilizer according to soil analysis | Tractor and spreader | August / September | 20,41 |
| 3 | Plowing in of manure | Tractor and plow | August / September | 22,38 |
| 4 | Leveling | Tractor and leveler | August / September | 5,31 |
| 5 | Medium-deep plowing | Tractor and plow | October / November | 22,38 |
| 6 | Soil loosening | Tractor and plow | October / November | 22,38 |
| 7 | Leveling | Tractor and leveler | October / November | 5,31 |
| 8 | Fertilization (according to soil analysis) | Sprayer | October / November | 4,4 |
| 9 | Preparation | Tractor and leveler | March | 5,31 |
| 10 | Preparation of "finishing" | Tractor and compactor | March | 5,14 |
| 11 | Sowing | Tractor and | March | 2,56 |

| | | | | |
|---|---|---|---|---|
| | | sowing machine | | |
| 12-17 | Fertilization / Spraying | Sprayer | spring | 26,4 |
| 18 | Fertilizer - nitrate | Tractor and spreader | May | 1,27 |
| 19 | Harvest | Harvester | End of September / November | 45 |
| | Total | | | 194,67 |

Source: [10]

### 1.3 Wheat

In comparison with the rape plant and sugar beet the number of necessary operations for wheat is only 16, but even here, the use of sprayers may not be final and according to soil analysis it may be necessary to apply phosphorus, calcium, magnesium or potassium into the soil at the beginning of the cycle.

During the cycle illustrated in table 3, it was considered to use a field where oilseed rape had grown before wheat. This procedure requires using a total herbicide for disposal of weeds that grow from the remnants of rape – activity 3.

180 to 190 kg nitrogen per hectare is delivered into the soil during spring. Overall fuel consumption was set at 82.1 liters per hectare of cultivated wheat.

Table 3: Consumption of fuel during one cycle of wheat

| | Activity | Machinery | Period | Diesel fuel consumption l/ha |
|---|---|---|---|---|
| 1 | Stubble | Tractor and stubble plow | August | 6,42 |
| 2 | Leveling | Tractor + leveler | August | 5,31 |
| 3 | Herbicides | Sprayer | September | 4,4 |
| 4 | Preparation | Tractor and compactor | September | 5,14 |
| 5 | Sowing | Tractor and sowing machine | September/October | 2,96 |
| 6 | Herbicides | Sprayer | September/October | 4,4 |
| 7 | Fertilization - nitrate | Tractor + spreader | February / March | 1,27 |
| 8-13 | Fertilization / Spraying | Sprayer | spring | 26,4 |
| 14-15 | Nitrogen fertilization | Sprayer | spring | 8,8 |
| 16 | Harvest | Harvester | July / August | 17 |
| | Total | | | 82,1 |

Source: [10]

An interesting option here would be parallel comparison to results of organic farming.

## 2 Fuel consumption in the context of biofuel yield

According to data obtained from the Ministry of Environment for the year 2008, the average yield of oil rape was equal to 3 tons per hectare [15,19]. 4.06 hectoliters of biofuel (Rapeseed Methyl Ester - RME) could be obtained from one ton of oil rape. A simple calculation shows that 1,285 liters of biofuel can be obtained from one hectare under the given conditions. After comparison with the observed consumption during cultivation, we find that for one liter of biofuel 0.09 liters of diesel was consumed.

Table 5 contains compared data for individual crops that are relevant for decision making and further processing and converted to required units. The results are based on fuel consumption attributable to all energy crops described in table 1, 2 and 3 and the calculated energy content of fuels produced. Empirically found data indicate the amount of crop per 1 ha, amount of fuel obtainable from 1 t of crops and the amount of fuel consumed per 1 ha. The amount of biofuels per 1 ha was calculated by multiplying related items.

The energy content of used and obtained fuel was calculated based on the tables which show energy content in 1 kg of fuel and density of the fuel. Concrete values, which were used in calculations contained in table 5, are listed in table 4.

Table 4. Values used for calculations

| | (MJ/kg) | density kg/l | MJ/l |
|---|---|---|---|
| Calorific value of bioethanol | 26,8 | 0,789 | 21,15 |
| Calorific value of diesel | 42,61 | 0,84 | 35,79 |
| Calorific value of RME | 37,1 | 0,88 | 32,65 |
| Caloric value of rapeseed oil | 36 | 0,915 | 32,94 |

Source: [1,6,13]

The volume of biofuel obtainable from 1 ha is listed in the fourth line of Table 5. Calculation is done with formula

$V = R \times F_{rec}$ (1)

where R is the crop recovery from one hectare in ton, $F_{rec}$ is the fuel recovery in l per hectare and V is the volume of biofuel in l obtainable from 1 hectare of field.

The amount of energy contained in biofuel produced in such a way is listed in the fifth line of Table 5 and is calculated with formula

$E = V \times C_v$ (2)

where E is the amount of energy in MJ in biofuel produced from one hectare, V is the volume of biofuel in liter obtainable from 1 hectare of field and $C_v$ is the caloric value of one liter of the biofuel.

Expended energy calculated from fuel consumption per 1 hectare with help of the data listed in Table 4 is shown in line 7 of Table 5 and is calculated with formula

$E_e = F_c \times d \times C_v$ (3)

where $E_e$ is the amount of expended energy, $F_c$ is the diesel fuel consumption for one hectare in liters, d is the density for diesel from Table 4 and $C_v$ is the caloric value for diesel fuel from Table 4 in MJ/kg.

The eighth line of Table 5 contains first partial result of this calculation and shows the diesel fuel consumption recalculated to one liter of biofuel. The objective of this calculation was to determine what proportion of energy is spent to obtain one MJ of biofuels. The resulting value then shows to what extent the production of particular biofuels is sustainable.

The calculated result was obtained according to formula

$D_c = F_c/V$ (4)

where $D_c$ is the diesel fuel consumption spent on one liter of biofuel obtained.

In the ninth line of Table 5 is the same value, but expressed in MJ calculated with help of values from Table 4 according to formula

$E_c = D_c \times d \times C_v$ (5)

where $E_c$ is the energy consumption of diesel, consumed for production of 1 MJ of particular biofuel.

The second partial result of the calculation is listed in line 10 of Table 5. It is the net gain of energy obtained from 1 hectare expressed in MJ. Transfer of each value to MJ was necessary in order to be able to compare the different options. The values were calculated according formula

$NG = E - E_e$ (6)

NG stands for net energy consumption. However, it is necessary to consider that the calculation does not include all energy inputs of monitored process and, therefore, to be able to formulate a clear answer it would be necessary to complete the input data.

The net gain of energy was calculated by subtracting consumed energy from recovered energy in MJ per ha.

Table 5: Approximate yield of fuel per hectare, fuel consumption per ha for cultivation

| Line | Crop | Sugar beet | Oil rape | Wheat |
|---|---|---|---|---|
| 2 | Recovery t/ha | 50 | 3 | 5 |
| 3 | Fuel Recovery l/t | 100 | 406 | 357 |
| 4 | The volume of biofuel l/ha | 5000 | 1285 | 1785 |
| 5 | Amount of energy MJ/ha | 105726 | 41953 | 37744 |
| 6 | Fuel consumption l/ha | 194,67 | 116,89 | 82,1 |
| 7 | Energy expended MJ/ha | 6967,71 | 4183,77 | 2938,56 |

| | | | | |
|---|---|---|---|---|
| 8 | Fuel consumption per 1 l of biofuel obtained | 0,04 | 0,09 | 0,05 |
| 9 | Energy consumption on 1 MJ of biofuel obtained | 0,0659034 | 0,099726 | 0,0778545 |
| 10 | The net gain of energy from 1 ha [MJ] | 98758,29 | 37768,91 | 34805,63 |

source: own according [2,9,15,19]

Using the data in table 4 and 5 we come to the analogous results for wheat and sugar beet. Taking into account that one hectare of wheat can deliver 1785 liters of bioethanol, and during one cycle of production 82.1 liters of diesel is consumed, we find that for one liter of bioethanol from wheat 0.05 liters of diesel will be used.

Although during one cycle nearly 195 l of diesel is required for one hectare of sugar beet, in the overall view for one liter of biofuel from sugar beet only 0.04 liters of diesel is needed, because the yield is much higher

Although for this option the ratio price / performance is the best, the observed price of 1 liter of bioethanol from wheat is 19.41 CZK per liter and the price of equivalent quantity of bioethanol from sugar beet is 26.26CZK. This raises a potential conflict if is better to use a larger area of agricultural land for growing wheat for non-food purposes to save money or grow sugar beet in smaller areas and accept higher fuel prices.

However, it still remains a question whether it is possible to use organic waste from biofuel production in any energetic way, e.g. by methods of hydrothermal carbonisation etc. Then not only positive economic effects could be achieved, but also environmental effects.

The solution could lie in a different setting of subsidy policy as well as reduction of administrative burden for renewable sources use as well, because those should be used reasonably and with minimum loss. The performed physical analysis of the cost for obtaining bioethanol in both cases can not justify the price difference.

However, it is also necessary to add that appropriate use of ecosystems is vital and, therefore, it is not possible to transfer large areas to just one type of crop due to adverse effects on soil, possible overpopulation of pests and so on. This problem can be solved by appropriate combination of energy crops with other agricultural crops.

In this case, it is important to know the order of preferred species of energy crops according to their expected yields. This is the only way to eliminate unnecessary increase of environmental burden and thus choose the optimal option for eliminating unnecessary negative impact on the population.

The presented analysis could constitute an introduction to this issue.

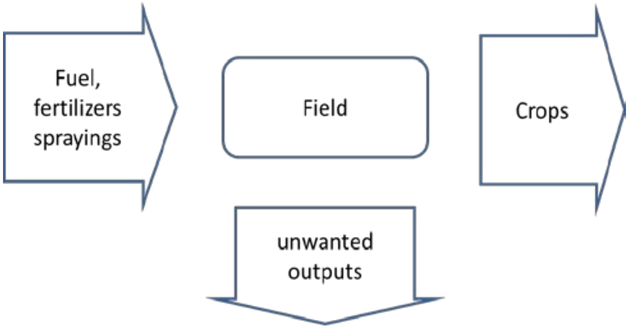
Another option might be to use plant waste in the next step for the production of biofuels of second generation, which could significantly improve the energy balance of individual crops if suitable processes were used.

## 3 Modeling of environmental burden produced

The process of energy consumption as an input of monitored processes may be understood in terms of protection of population as a risk factor, as it is associated with production of emissions. Evaluation of the risk must be always based on data about the quantity and type of emissions produced. One of the ways to get these values, if they were not measured, is to create a model. The monitored process, including emissions produced, may be illustrated by a model based on Petri nets. Petri nets have been chosen because they are, among others, a tool used for modeling the LCA.

The general scheme of this model may look like this:

Fig.1 General scheme of material flow model



Source: own

Similarly as with any process, there are material and energy input and output flows, some of which are desirable from environmental and civil security point of view and others not.

### 3.1 Theoretical bacground of Petri nets

The Petri net could be in general defined like a 5-tuple GPN = <P,T,QP,QT, QE>, Where P is a finite set of places represented by circles, T is a finite set o transitions represented by lines or rectangles.

$P \cap T=0$

QP is an ordered 4-tuple $QP=<C,IC,M0C,UP>$, which defines the qualities of k places of the set P. QT is an ordered 5-tuple $QT=<QC,\tau,PR,IF,UT>$, which defines the qualities of r transtitions of the set T.

QE is an ordered 3-tuple $QE=<IE,EE,LE>$, which defines the qualities of edges and is given by forward and backward incidence function.

An ordered 4-tuple, that defines the qualities of k places of the set P can be defined: C is a finite set of the colors used, $IC:P*T \rightarrow R*C$, R ist the set of real numbers, $IC((n,c)m,i,j)$, where $m \epsilon <1,h>$, $i \epsilon <1,k>$, $j \epsilon <1,r>$, is the forward incidence function.

$M0C:P*R \rightarrow C$ is an initial marking and UP is a finite set of qualities of tokens in the places $pi \epsilon P$, $UP=\{up1,up2, \dots ,upk\}$.

An ordered 5-tuple, that defines the qualities of r transitions of the set T can be defined: $QC:T*P \rightarrow R*C$, R is set of real numbers, $QC((n,c)m,i,j)$, where $m \epsilon <1,h>$, $i \epsilon <1,k>$, $j \epsilon <1,r>$, is the backward incidence function. T is a finite set of times of firings of r transitionsT. $\tau = \{\tau 1,\tau 2, \dots ,\tau r\}$.

PR is a finite set of predicates, $PR = \{pr1,pr2, \dots ,pr3\}$, where for each $l \epsilon <l,q>$, then $prl \epsilon \{TRUE, FALSE\}$ holds true. Each predicate $prl \epsilon PR$ can be conected with arbitrarz transition $tj \epsilon T$ bz normal or inhibit arc. This conection is given bz incidence function IF.

$IF> T*PR \rightarrow \{1,-1,0\}$ is an incidence function and mens

$IF(tj,prl)=1$ and exist connection between transition $tj \epsilon T$ and predicate $prl \epsilon PR$, is the transition $tj \epsilon T$ enabled if the value of predicate $prl \epsilon PR$ is TRUE.

$IF(tj,prl)=-1$ and exist connection between transition $tj \epsilon T$ and predicate $prl \epsilon PR$, is the transition $tj \epsilon T$ enabled if the value of predicate $prl \epsilon PR$ is FALSE.

$IF(tj,prl)=$ and connection between transition $tj \epsilon T$ and predicate $prl \epsilon PR$, dont exist, is the firing of transition $tj \epsilon T$ not determined by predicate $prl \epsilon PR$.

UT is a finite set of qualities of transitions $tj \epsilon T$, $UT=\{ut1,ut2, \dots ,utr\}$, which can be deterministic, stochastic or fuzzy.

The finite set of qualities of edges, which is given by forward and backward incidence function, can be defined as $QE=<IE,EE.LE>$

Where IE is a finite set of inhibit arcs (ie), $IE=\{ie1,ie2, \dots ,ieie\}$.

EE is a finite set of emptz arcs (ee), $EE=\{ee1,ee2, \dots ,eeee\}$.

LE is a finite set of logical arcs (le), $LE=\{le1,le2, \dots ,lele\}$ [16].

This definition allows a mathematical description of any type of Petri nets with which should be worked.

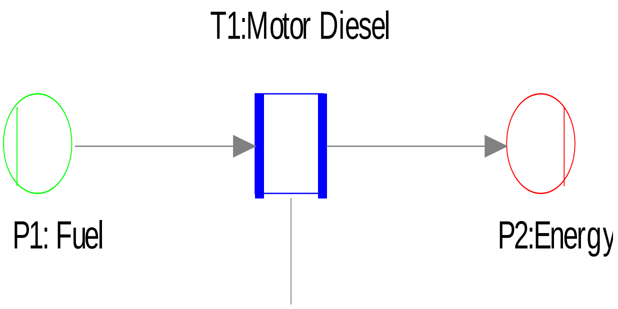
### 3.2 Model construction

The model implemented in the Umberto environment with colored Petri nets is shown in fig. 2: Thanks to using non live colored Petri nets, the graphical interpretation of the model is identical with the general proposal in fig. 1.

To enter into the model it is necessary to specify the value of fuel consumed in kg, which was the amount of 116.89 for rape plant, 82.1 for wheat and 194.67 for sugar beet calculated by multiplying the fuel density 0.84 kg / l.

The fuel weight is based on rounding to 98 kg / ha for rape, 69kg/ha for wheat and 164kg/ha for sugar beet.

Fig. 2.Model of energy consumption



Source: own

In order to calculate emitted pollution data a standard diesel engine without a catalytic converter on the effectiveness of 30% and a maximum power of 1000 kW was used [7]. Since the used machinery differs in performance and parameters, this option was chosen to simplify the model as a general representative for all use of agricultural machinery. The presented results are therefore to be understood as an educated guess, and not as an exact calculation, which is not feasible due to the different conditions.

After finishing all auxiliary calculations and obtaining additional necessary empirical data the model can be mathematically described as:

$P=\{p1,p2,p3\}$, $T=\{t1\}$, UP={fuel, mechanic energy, sulfur dioxide, NOx, particles, carbon monooxide, NMVOC, carbon dioxide, methane, dinitrogen monooxide},

IC:

| P*T→R*C | $p_1$ |
|---|---|
| $t_1$,fuel | 8065,9 |

Source: own

QC:

| T*P→R*C | $p_2$ | $p_3$ |
|---|---|---|
| $t_1$, mechanic energy | 100 | 0 |
| $t_1$, sulfur dioxide | 0 | 26,591 |
| $t_1$, NOx | 0 | 332,9 |
| $t_1$, particles | 0 | 27,7 |
| $t_1$, carbon monooxide | 0 | 72,1 |
| $t_1$, NMVOC | 0 | 1,05 |
| $t_1$, carbon dioxide | 0 | 25563 |
| $t_1$, methane | 0 | 1,05 |
| $t_1$, dinitrogen monooxide | 0 | 1,05 |

Source: own

Values are calculated for p2 in MJ and for p1 and p3 in g.

The real emissions in practice may differ from the calculated values. This deviation should not be significant, since in all cases a diesel engine and the volume of burnt fuel are precisely specified.

Modeling results for particular crops and related material and energetic flows calculated per 1 ha are listed in Table 6.

Table 6: Modeling results

| | RME | Bioethanol (wheat) | Bioethanol (sugar beet) |
|---|---|---|---|
| Emitted substance | Quantity [kg] | Quantity [kg] | Quantity [kg] |
| $NO_x$ | 4.045 | 2.8 | 6.75 |
| $CO_2$ (fossil) | 310.6 | 215.5 | 518.2 |
| CO | 0.87 | 0.608 | 1.46 |
| $CH_4$ | 0.012 | 0.009 | 0.02 |
| $SO_2$ | 0.323 | 0.224 | 0.539 |
| particles | 0.337 | 0.233 | 0.562 |

source: Umberto model based on [7]

As the results in Table 6 show, the outputs are mainly focused on pollutants emitted into the atmosphere. As , the induced environmental burden could be estimated on the basis of the modelling results, it is in this sense a tool usable for predicting the environmental burden at different use of biofuels and help for predicting the potential risks to the population.

The model allows performing calculations for any other crop as well. The basic prerequisite is knowledge of total fuel consumption per 1 ha per season. Alternatively, the basis of the model makes it possible to prepare calculations resulting from determining other parameters for any material or energy flow indicated in the list of types of tokens (UP).

At the same time, the number of tokens could be increased and in such a way it is possible include more items in the balance of material and energy flows.

### 3.3 Additional remarks

Using this procedure, if the LCA chain is completed, the model will deliver very accurate estimates of environmental burden induced by different types of biofuels production.

Because the model constructed is designed to be used as a support tool for decision making, it is appropriate to include the accuracy of the initial conditions of the model into the discussion.

At the conclusion of analysis, the energy yield obtained using biofuels was compared with the results that can be achieved by utilizing the same area by photovoltaic panels. According to data available on the Web intended to estimate the annual output of electricity using photovoltaic panels [4], it has been calculated that from one hectare 4 827 945,60 MJ/ha gross can be obtained. Available LCA analysis [1] indicates that the energy return of modern photovoltaic panels is around 3-4 years. The energy spent on photovoltaic panel production taking into account expected lifetime of photovoltaic panels (20 years) can be calculated according to formula

$$Ep= Eg-Es \quad (7)$$

where Ep is the net energy produced, Eg is the gross energy produced and Es is the energy spent in production of photovoltaic panels.

The value of Es is estimated for lifetime of 20 years and invested energy return 3,8 years according to formula

$$Es= (Eg/Lt) \times Er \quad (8)$$

where Lt is the lifetime and Er is the expected time of energy return.

After substituting into (8) we get

$$Es= (4\ 827\ 945{,}60/20) \times 3{,}8$$

$$Es= 917\ 309{,}66$$

After substituting into (7) we get

Ep = 4 827 945,60 -

Ep = 3 910 635,94 MJ/a.

The comparison with other renewable energy sources analyzed above is listed in Table 7.

Table 7: Comparison of selected renewable energy sources

| Renewable energy source | Energy in form of | Net gain from 1 ha in MJ/a |
|---|---|---|
| oil rape | rapeseed oil | 37 768,91 |
| wheat | bioethanol | 34 805,63 |
| sugar beet | bioethanol | 98 758,29 |
| photovoltaic | electricity | 3 910 635,94 |

Source: own according [4]

To be able to express definite conclusions, these values must be, of course, further refined, especially the consistent inclusion of all energy input costs. Given that the values for photovoltaic panels should include the entire chain of LCA, and in this sense should be final, we can expect more changes in the values of biofuels. As the calculations for biofuels do not include all energy inputs, it is evident that the net energy gain will probably continue to deteriorate when adding further data.

When requirements for careful use of renewable resources are formulated with regards to their effectiveness, for instance the [19],[20] or [6], it is obvious that the correct selection of the optimal combination of renewable sources is critical both for the price and availability.

As visible from the data listed in Table. 7, due to the low efficiency of the first generation biofuels obtained, more research in this area is needed. This could result in the overall review of priorities in the use of renewable energy sources.

## 4 Conclusion

This article analyzed the key segment of the life cycle assessment chain (LCA), in this case for three selected types of biofuels grown in central Europe. Even if it is a relatively simple comparison of three variants use of energy crops, the selection is not completely trivial. Each of these variants induces another environmental burden at the production stage, as well as by the actual use, and also significantly different results.

Therefore, the final selection will depend on which factors should be taken into account. For the selected method of treatment, the best results are shown by bioethanol production from sugar beet. This option combines both the lowest proportion of energy invested in the acquired energy content of fuel, and also the lowest emission, calculated on a unit of energy obtained. However, it is associated with the biggest amount of emissions per one hectare of cultivated area.

The combination of low environmental burden per 1 ha of farmland and the amount of energy comparable to obtain with rapeseed oil is offered by the option to produce bioethanol from wheat. Popular RME seems to be in all variants in terms of induced emission and energy obtained the worst. The analysis thus points at a possible improper setup of subsidy policy in this area, possibly problematic functioning market mechanism, because it would be more logical to use those sources, which provide less environmental burden per unit of energy gained.

Further research can then focus, as mentioned in the concluding remarks to a broader comparison of available renewable resources.

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