

THE INFLUENCE OF TILLAGE TECHNOLOGY ON AVAILABLE ENERGY FROM RAPESEED PLANTATION

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Abstract

The model, recently developed by present authors defines the energetic efficiency of plantation, as a ratio of total energy produced to the sum of energy inputs. It is explicitly expressed in terms of crop yield, caloric values and mass fractions of crop components used for biofuel production - on the side of outputs. Caloric values of fuel used in subsequent agricultural operations together with fuel consumption in those operations, as well as transportation distances and fuel caloric value and its consumption during transportation of goods (production means and products) between fields used in production and also during transport to customers, etc. The model is defined in mathematical form, as well as computer algorithm, enabling computations for real situation, is developed. Several examples of application are given showing that the range of energetic efficiency can vary substantially depending upon production technologies applied.

Key words: biofuel, energy efficiency, mathematical modelling, production system

1. INTRODUCTION

Recently Mathews (2009) indicated biofuels derived from biomass as the main remedy that can be offered to mitigate the danger mentioned. Therefore, the search for biomass resources and for the most effective cultivation technologies is well substantiated. Similar trend concern conversion of biomass to energy. A number of papers have been published dealing with cultivation of several plants e.g. Painuly et al. (1995) or Abnisa et al. (2011) as well as various aspects of cultivation and processing cf. Juliszewski and Zajac (2007), Jasinska and Kotecki (1999), Igilinski et al. (2009). Assumption that fuels derived from biomass, at least partly, may substitute fossil fuels imposes expectation that biomass as energetic resource should assure a real gain of energy. Any agricultural or industrial processing technology requires some inputs of energy in order to facilitate production processes. In terms of fuels derived from biomass it is obviously related to both: agricultural and industrial processes used in production. The gain of energy means that the amount of energy obtained in the form of biofuel should be larger than the sum of energy inputs introduced during all production processes. Characteristic, that can be used for estimation of the role of energy fluxes needed to maintain production processes is called EROI or EROEI – „energy return on energy invested” cf. Pickard (2014), and is defined as follows:

$$\mathcal{E} = \frac{\sum_{p=1}^P (E_{out})_p}{E_{cr} + \sum_{p=1}^P (E_{in})_p + E_{rem}} \quad (1)$$

where:

E_{out} – is total usable energy delivered by energy gathering system during the p -th year of its existence, E_{in} – represents total energy expended during that year, E_{cr} – is energy needed for creation of that system, and E_{rem} – is energy needed for remediation of that system after the end of its life at P -th year.

It is important to mention that quantity defined by eq. (1) is different than energy conversion efficiency that is expressed as:

$$\eta = \frac{E_{out}}{E_{in}} = \frac{E_{out}}{E_{out} + E_w} \quad (2)$$

where:

E_{in} and E_{out} – represent input and output energy to and from converter, while E_w – corresponds to energy dissipated by that converter.

The form of both equations is similar, their meaning is ‘however, different. The energy, E_{in} , inputs to the production system are not directly converted into output. This is only energy that is needed to maintain production process E_{in} . In some cases, this amount might be very small, while in the other even very large as compared to E_{out} . In consequence the range of variation of, ε , is contained within the limits $-\infty \leq \varepsilon \leq \infty$. The other quantity, η , relates energies being directly converted one into the other, and it can be easily proved that changes of this characteristic occur only in the limits: $0 \leq \eta \leq 1$. A number of papers dedicated to the discussion of perspectives of biofuel production in several countries e.g. Raslavicius and Bazaras (2010), Fontaras et al. (2012), Painuly et al. (1995), Wasiak et al. (2008) have appeared in the literature. Various approaches to production as well as use of biofuels are also reviewed by Russo et al. (2012). Similar considerations can also be done through exergy analysis. Such work performed by Talens et al. (2007) show low exergy loss in the process of biodiesel production, and also indicate possibilities of further decrease with improvement of technology. In the case of bioethanol Liao et al. (2011) demonstrate that production of this fuel not always fulfills the requirements of sustainability i.e. that bioethanol production is not sufficiently efficient. The paper Talens et al. (2007), mentioned earlier, introduces a notion of the scale of the techno-system showing that efficiency can be determined by various processes differently acting at different scale levels. The highest level is of global size, while the next levels are more and more local, and specific factors might play a role at each level. Several papers are concerned with empirical studies on energy efficiency (or energy demand) of agriculture in general e.g. Singh et al. (2008) or Schneider and Smith (2009), Alluvione et al. (2011), as well as studies dedicated especially to „energetic” plantations: Uril (1998), Kim, Bruce and Dale (2005), Karkaciera et al. (2006), Muller (2009), Meehan et al. (2013), or Smith, Thelen and MacDonald (2013). Those works provide important sets of data that enable more general analysis of the factors deciding on the energetic efficiency of biofuel production systems. Slightly different approach to the scale of a techno-system is given by Prasad, Singh and Joshi (2007) or Giampietro et al. (1997) discussing feasibility analysis with respect to the size of the production system.

The present paper is aimed to presents construction of the model that describes effects of subsidiary processes, operating at individual elements of biofuel production system, on energetic efficiency of that system, and also to present results of computations that estimate the main effects related to the real characteristics of production equipment. The paper directly concerns agricultural subsystem of the production system, and only indirectly takes into account coupling to the industrial subsystem.

2. THE MODEL

Mathematical models of production processes are already established tools for studying various aspects of the effects the choice of technology, operational conditions, etc. onto the process itself or resulting product. Several examples of such approach are given by e.g. Ziabicki, A. at al. (1998), Blim, A. at al. (2005) Zubrzycki J. at al.(2012), Świć A. at al. (2012). In the present paper the approach given in Wasiak A., Orynycz O. (2014), and Orynycz O. Wasiak A. (2014) is continued.

The energetic effectiveness, ε , related to one year of production in the agricultural subsystem, is expressed as follows:

$$\varepsilon = \frac{E_{bio}}{E_{ex} + E_{tr} + E_{emb}} \quad (3)$$

where:

E_{bio} – is energy obtained from the field,

E_{ex} – is energy expended on tillage operations,

E_{tr} – is energy consumed for transportation outside of fields,

E_{emb} – is a fraction of embodied energy contained in production means, that is spend during tillage operations and transport executed during production year.

are the contributing energies.

Energy obtained from the plantation equals to:

$$E_{bio} = A \times M_{crop}(c_f, c_w, c_{cp}, \dots) \times \gamma \times \sum_{k=1}^n \alpha_k \times W_{bio,k} \quad (4)$$

where:

A – is plantation area,

$M_{crop}(c_f, c_w, c_{cp}, \dots)$ – is crop yield dependent upon concentrations of following factors: c_f – fertilizer, c_w – water, c_{cp} – crop protection means, maintained during cultivation. This dependence should be estimated on the basis of empirical field studies,

γ – general mass fraction of biofuel in the crop,

α_k – mass fraction of k species of biofuel,

$W_{bio,k}$ – low caloric value of k -species of biofuel.

The energy consumed on the field during agro-technical operations can be expressed as follows:

$$E_{ex,agr} = W_{fuel} A \times \sum_{i=1}^m \left[\frac{\omega_i}{d_i} \right] + \sum_{i=1}^m \sum_{k=1}^K \gamma_k \times Em_{ik} \quad (5)$$

where:

ω_i – the fuel consumption per unit of the distance passed during the individual agro-technical process,

d_i – width of the land strip operated in the single course of i -th operation,

W_{fuel} – the low caloric value of the fuel used for operations (might be fossil fuel or biofuel),

m – the number of the agro-technical operations (in each one of the operations the width of the worked field, d_i , and the consumption of fuel, ω_i , can be different),

γ_k – is a fraction of embodied energy contained in one of the, k , technical means employed at i -th operation (machines, fertilizers, etc.). It may be estimated e.g. as ratio of the time of particular operation to the total expected life time of particular equipment,

Em_k – is embodied energy contained in k -th technical mean.

Equation 6, in turn, concerns transportation of goods outside of the field. This term is especially important for big plantations that are arranged in several fields separated sometimes by quite long distances. Another contribution of transport is significant when crops must be transported through long distance to industrial facilities for processing. It is expressed as:

$$E_{tr} = \sum_{p=1}^p L_p \times \{ \beta_p \times W_{fuel, tr} + Emt_p \} \quad (6)$$

where:

L_p – is a distance driven outside of the field in p -th route,

β_p – is fuel consumption during p -th route,

$W_{fuel, tr}$ – is low caloric value of the fuel used in transport,

Emt_p – is fraction of embodied energy of a given transportation mean corresponding to the unit of distance driven.

Individual contributions to the energetic efficiency depend upon various factors. Especially, E_{bio} , and $E_{ex, agr}$ depend i.a. on plantation area, A , while, E_{tr} , apparently does not. Embodied energy¹ terms, Em_{ik} , and E_{mt} do not depend explicitly on, A , it is clear, however, that in practice the field's area affects the distance driven on that field. It means that efficiency, ε , depend upon the size of plantation in complicated manner affected by various relationships. During numerical computations some dependencies were introduced e.g. energy spend during transportation might depend upon field's area in the cases of very big fields requiring several subsequent transports of goods, machinery etc. during elaboration of the same field.

Analysis of the definition given by formula (3) leads to the conclusion that simple additivity rule can be derived for the case when energy production subsystems are connected in series. Such consideration is especially important for biofuel production system, which is composed of at least two subsystems. It can be shown that, for such a case, (taking into account that, E_{bio} , is estimated from the final energy yield of the whole system) the reciprocal of total efficiency of the composed system is given as a sum of reciprocals of efficiencies of subsystems i.e.

$$\frac{1}{\varepsilon_{tot}} = \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} \quad (7)$$

where: ε_{tot} – is the energetic efficiency of the total system

ε_1 and ε_2 - are efficiencies of individual subsystems.

The equation (7) will be especially valuable after the model of efficiency of industrial subsystem is developed, and need for estimation of total efficiency will appear.

¹ Embodied energy is the energy consumed during production of particular technical object, and raw materials needed to its production. The part of embodied energy, associated to a given tool, consumed during particular operation may be estimated e.g. as proportional to the ratio of time during which the tool was used to the total "life time" of that tool.

3. NUMERICAL COMPUTATIONS

In order to perform numerical computations the computer program was developed in spreadsheet EXCEL. The main assumptions made were: plantation is considered as built of several fields (size of each given through its dimensions, a_i , and b_i) separated by some distances, l_i , and separated by a distance, c , from the main base. The speed of movement during each operation is given, and maximum daily working time, t_{max} , is specified. It is assumed that after maximum working time is reached the working machines are moving to the base, and return to the same place next day. Fuel consumption on the unit of the driven way is given as a constant defined for each operation. The specific yield of the unit area of plantation, as well as the yield of biofuel from the mass unit of biomass are also introduced as constants that are specified for each computation.

Results presented in this paper have been computed for equal sizes of fields, however any arbitrary configuration of field's sizes can be considered. Initial parameters used for computations are given in Table 1.

Table 1. Values of parameters taken into computations

$V = 6 \text{ km/h}$ $t_{max} = 10 \text{ h}$						
$1 \leq i \leq n$ $a_i = b_i$						
$n = 5$	$a_i = 0,1 \text{ km}$			$a_i = 0,5 \text{ km}$		
	$b_i = 0,1 \text{ km}$			$b_i = 0,5 \text{ km}$		
$c \text{ [km]}$	1	5	10	1	5	10
$l \text{ [km]}$	0,2	0,2	0,2	0,2	0,2	0,2
$l \text{ [km]}$	0,4	0,4	0,4	0,4	0,4	0,4
$l \text{ [km]}$	0,6	0,6	0,6	0,6	0,6	0,6
$l \text{ [km]}$	1	1	1	1	1	1

4. RESULTS

Results of computations presented here were performed for rapeseed plantation under several assumptions. As seen in Table 1. two sets of computations were performed for plantations consisted of five fields of the same area. Two sizes of plantations are compared. Computations were performed for different distances between fields, l , and several values of the distance of plantation from the base, c . Moreover, production process has been assumed as consisting of five operations, each requiring the same technical equipment and conditions (what, in consequence results in the same energy consumption in each operation – this assumption is a simplification made for convenience, but is not required by the program, and easily can be avoided in future computations).

The first important result is a distance driven on the fields under various conditions of equipment used and sizes of individual fields. This result is shown in Table 2. One can easily see that the distances, D_{agr} , substantially differ depending on both size of plantation and width of the elaborated strip of land during one pass through the field (properties of the equipment). It is not shown here, but it can be easily proved, that this distance is independent of the distribution of sizes of individual fields.

Table 2. Dependence of the distance, D_{agr} , driven on the fields of plantation upon tillage conditions

Strip width = 0,5 m		
$A [km^2]$	0,01	0,25
$D_{agr} [km]$	100	2500
Strip width = 4 m		
$D_{agr} [km]$	12,5	321,5

The distance driven outside of the fields, D_{out} , is shown in Fig. 1.

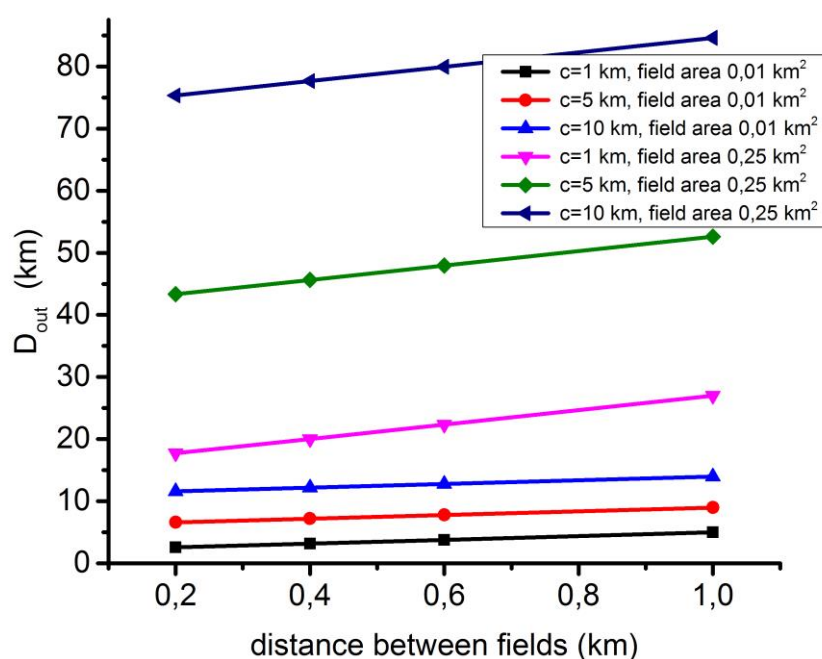


Fig. 1. The distance driven outside of the fields, D_{out} , as a function of plantation characteristics for the operation width 4m

It is clearly seen that this distance linearly depends upon the distance between fields, l , and is strongly affected by the area of the fields. This behavior evidently results of the maximum working time, and need to drive back with the all machines. One can imagine that another assumption e.g. leaving machines on the field, and transport back only people, would substantially change the situation. Consequently, it can be concluded, that organization of the work is an important factor determining the final efficiency of plantation. Fig. 2, in turn shows the ration of distances, D_{out}/D_{agr} , the distances driven outside and inside of the fields. It again reflects the effect of field's size on the distance driven. Consequently, one can expect that the differences seen in those figures have also corresponding influence on the energy consumption during production operations. The sum of amounts of energy spend on tillage operations, and on transportation within plantation is given in Table 3.

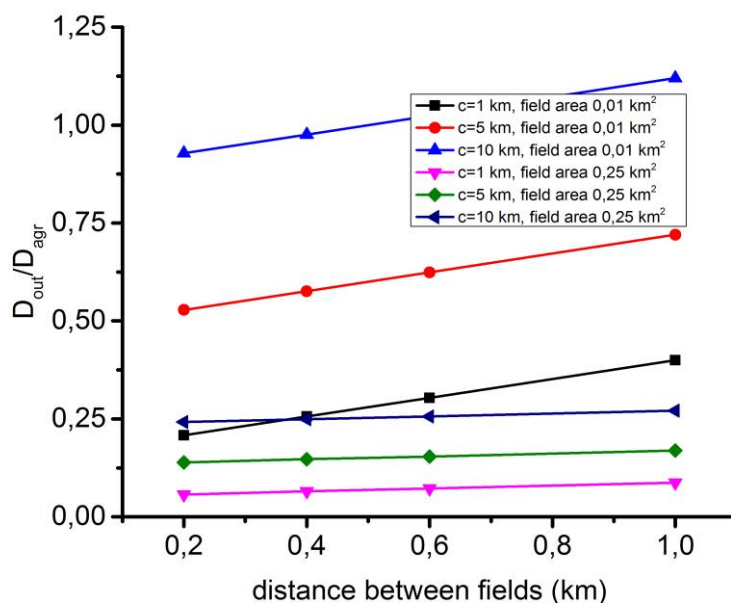


Fig. 2. Ratio, D_{out}/D_{agr} , for operation width 4m, and several values of other parameters

It can be clearly seen in Table 3. that the amount of energy spend during agricultural production is strongly affected by size and other topological characteristics of plantation, and (as it was earlier mentioned) might also depend upon organization of work.

Table 3. Sum of amounts of energy spend on the field and driving between fields, $E_{out} + E_{agr}$, as a function of plantation, and equipment characteristics

0,5 [m]	A = 0,01[km ²]			A = 0,25[km ²]		
$c \backslash l$ [km]	1	5	10	1	5	10
0,2	1160	1376	1640	30044	35383	42058
0,4	1176	1392	1649	30353	35693	42367
0,6	1191	1407	1657	30663	36003	42677
1	1221	1437	1674	31283	36622	43297
4 [m]	A = 0,01 [km ²]			A = 0,25 [km ²]		
$c \backslash l$ [km]	1	5	10	1	5	10
0,2	220	436	841	3880	4805	5960
0,4	239	455	725	3938	4862	6018
0,6	259	475	745	3995	4919	6075
1	297	513	783	4110	5034	6190

Finally, the energetic efficiency computed according to the model of rapeseed plantation with assumed characteristics is presented in Table 4. Estimation of the values presented here are based upon the assumption that 1500 dcm³ of oil can be obtained from 1 hm² of plantation area. The results show quite large differences corresponding to different sizes and machinery working on the fields.

Table 4. Energetic efficiency resulting of computations performed for one operation performed the plantation as assumed above

Strip width = 0,5 m						
A [km ²]	0,01			0,25		
c l [km]	1	5	10	1	5	10
0,2	224	189	159	216	184	155
0,4	221	187	158	214	182	154
0,6	218	185	157	212	181	152
1	213	181	155	208	178	150
Strip width = 4 m						
A [km ²]	0,01			0,25		
c l [km]	1	5	10	1	5	10
0,2	1184	597	309	1672	1351	1089
0,4	1087	571	358	1648	1335	1078
0,6	1006	548	349	1624	1319	1068
1	874	506	332	1579	1289	1048

It is worth to mention that changes in the number of operations, and technical characteristics of tools used in particular operations might further change the results. So the presented figures are only examples of possible effects. It also should be mentioned as indicated in the recent paper Wasiak A., Orynycz O. (2015) that since the computations presented above consider one agricultural operation, but the value of energy obtained from the crop is the same independent upon history of crop production – the final result will decrease substantially with increasing of the number of operation. Assuming that each operation consumes the same amount of energy one can obtain the final energy efficiency as presented in Table 5. and Table 6.

Table 5. Values of energy efficiency computed for the system of separated fields as function of a number of operations with 0,5 m width of operation strip (biofuel yield 1500 dm³/ha)

operation width [m]	number of operations	A = 0,01[km ²]			A = 0,25 [km ²]		
		c = 1	c = 5	c = 10	c = 1	c = 5	c = 10
0,5	1	224	189	159	216	184	155
0,5	2	112	95	80	108	92	78
0,5	3	75	63	53	72	62	52
0,5	4	56	48	40	54	46	39
0,5	5	45	38	32	44	37	31

Table 6. Values of energy efficiency computed for the system of separated fields as function of a number of operations with 4 m width of operation strip (biofuel yield 1500 dm³/ha)

operation width [m]	number of operations	A = 0,01[km ²]			A = 0,25 [km ²]		
		c = 1	c = 5	c = 10	c = 1	c = 5	c = 10
4	1	1184	597	309	1672	1351	1089
4	2	592	299	299	836	676	545
4	3	395	199	199	558	451	363
4	4	296	150	150	418	338	273
4	5	237	120	120	335	271	218

5. CONCLUSIONS

Mathematical model and computations performed according to this model reveal a number of various productive factors affecting energetic efficiency of agricultural subsystem dedicated to biofuel production. Those factors can be enumerated as: the technical parameters of applied machines, the distance traveled on the field during agricultural operations, the number of operations (and consequently upon production technology), the distances travelled between fields (which depends on the degree of dispersion of the plantation and upon the sizes of individual fields. The choice of production technology may change the value of energetic efficiency from ca. 200 to above 1000.

Obviously several other factors, like transport from plantation to industrial facility, energy inputs needed to run industrial processes, as well as embodied energy in agricultural as well industrial production means (tools, various media, chemicals, etc) decrease the global values of energetic efficiency. All those factors require further studies.

Energetic efficiency of agricultural subsystem depends also upon the scale of the industrial production subsystem, which extorts the suitable scale (size) of the plantation, and also affects the consumption of fuels (energy) during the agro-technical operations and transportation. Again some deeper research is needed to cope with this respect.

Another, more general, conclusion may also be derived from the conducted calculations: namely the model can be used to the analysis of various, different than the rapeseed, energetic plantations. Also different variants of energetic utilization of the crops, e.g. the grain of maize converted to bioethanol,

as well as utilization of the stem for biogas generation, optimization of production can be one of the important uses of the model for the real plantations.

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REFERENCES

- Abnisa, WM, Wan Daud, A, Husin, WNW & Sahu, JN 2011, 'Utilization possibilities of palm shell as a source of biomass energy in Malaysia by producing bio-oil in pyrolysis process', *Biomass and Bioenergy*, vol. 35, no. 5, pp. 1863-1872.
- Alluvione, F, Moretti, B, Sacco, D & Grignani, C 2011, 'EUE (energy use efficiency) of cropping systems for a sustainable agriculture', *Energy*, vol. 36, no. 7, pp. 4468-4481.
- Blim, A, Oldak, E, Wasiak, A & Jarecki, L 2005, 'Effects of zone heating on pet fibers structures and dynamics of melt spinning process. Part I. Crystallinity and molecular orientation', *Polymers*, vol. 50, no. 1, pp. 48-59 (Polish).
- Fontaras, G, Skoulou, V, Zanakis, G, Zabaniotou & Samaras, Z 2010, 'Integrated environmental assessment of energy crops for biofuel and energy production in Greece', *Renewable Energy*, vol. 43, pp. 201-209.
- Giampietro, M, Ulgiati, S & Pimentel, D 1997, 'Feasibility of Large-Scale Biofuel Production', *BioScience*, vol. 47, no. 9, pp. 587-600.
- Igliński, B, Buczkowski, R & Cichosz, M 2009, *Technologie bioenergetyczne (Bioenergetic Technologies)*, Nicolaus Copernicus University Publisher, Toruń.
- Jasińska, Z & Kotecki, A 1999, *Szczegółowa uprawa roślin (Detailed Tillage of Plants)*, Wrocław Agricultural Academy, Wrocław.
- Juliszewski, T & Zajac, T 2007, *Biopaliwa rzepakowe (Rapeseed Biofuels)*, PWRiL Governmental Agricultural and Forestry Publishing House, Poznań.
- Karkaciera, O, Gokalp Goktolga, Z & Cicek, A 2006, 'A regression analysis of the effect of energy use in agriculture', *Energy Policy*, vol. 34, no. 18, pp. 796-800.
- Liao, W, Heijungs, R & Huppes, G 2011, 'Is bioethanol a sustainable energy source? An energy-, exergy-, and energy-based thermodynamic system analysis', *Renewable Energy*, vol. 36, no. 12, pp. 3479-3487.
- Lorencowicz, E 2012, *Poradnik użytkownika techniki rolniczej w tabelach (Handbook for the user of agrotechnology)*, Agencja Promocji Rolnictwa i Agrobiznesu (Agrobusiness and Agriculture Promotion Agency), Bydgoszcz.
- Mathews, JA 2009, 'From the petroeconomy to the bioeconomy: Integrating bioenergy production with agricultural demands', *Biofuels, Bioproducts and Biorefining*, vol. 3, no. 6, pp. 613-632.
- Meehan, G, Finnan, JM & Mc Donnell, KP 2013, 'A Comparison of the Energy Yield at the End User for Miscanthus giganteus Using Two Different Harvesting and Transport System', *BioEnergy Research*, vol. 6, no. 2, pp. 813-821.
- Muller, A 2009, 'Sustainable agriculture and the production of biomass for energy use', *Climatic Change*, vol. 94, no. 3, pp. 319-331.
- Orynycz, O & Wasiak, A 2014, 'Effects of tillage technology on energetic efficiency of rapeseed plantation for biofuel production', *Applied Computer Science*, vol.10, no. 2, pp. 67-76.

- Painuly, JP, Hemlata, R & Parikh, J 1995, 'A rural energy-agriculture interaction model applied to Karnataka state', *Energy*, vol. 20, no. 3, pp. 219-233.
- Perrier, T 2014, Private communication – agricultural enterprise, *Barycz*.
- Pickard, WF 2014, 'Energy Return on Energy Invested (EROI): A quintessential but possibly Inadequate Metric for Sustainability in a Solar-Powered World? ', *Proceedings of the IEEE*, vol. 102, no. 8, pp. 1118-1122.
- Prasad, S, Singh, A & Joshi, HC 2007, 'Ethanol as an alternative fuel from agricultural, industrial and urban residues', *Resources, Conservation and Recycling*, vol. 50, no. 1, pp. 1-39.
- Raslavicius, L & Bazaras, Z 2010, 'Ecological assessment and economic feasibility to utilize first generation biofuels in cogeneration output cycle - The case of Lithuania', *Energy* vol. 35, no. 9, pp. 3666-3673.
- Russo, D, Dassisti, M, Lawlor, V & Olabi, AG 2012, 'State of the art of biofuels from pure plant oil', *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 4056-4070.
- Schneider, UA & Smith, P 2009, 'Energy intensities and greenhouse gas emission mitigation in global agriculture', *Energy Efficiency*, vol. 2, no. 2, pp. 195-206.
- Singh, KP, Prakash, V, Srinivas, K & Srivastva, AK 2008, 'Effect of tillage management on energy-use efficiency and economics of soybean (*Glycine max*) based cropping systems under the rainfed conditions in North-West Himalayan Region', *Soil & Tillage Research*, vol. 100, no. 1-2, pp. 78-82.
- Smith, SL, Thelen, KD & MacDonald, SJ 2013, 'Yield and quality analyses of bioenergy crops grown on a regulatory brownfield', *Biomass and Bioenergy*, vol. 49, pp. 123-130.
- Świć, A, Zubrzycki, J & Taranenko, V 2012, 'Modelling and systemic analysis of models of dynamic systems of shaft machining', *11th International Conference on Industrial, Service and Humanoid Robotics (ROBTEP 2012)*, Strbske Pleso, Slovakia, pp. 211-220.
- Talens, L, Villalba, G & Gabarrell, X 2007, 'Exergy analysis applied to biodiesel production', *Resources, Conservation and Recycling*, vol. 51, no. 2, pp. 397-407.
- Uri, ND 1998, 'Conservation tillage and the use of energy and other inputs in US agriculture', *Energy Economics*, vol. 20, no. 4, pp. 389-410.
- Wasiak, A, Orynycz, O & Nosal, M 2008, 'Perspektywy produkcji biopaliw w regionie Podlaskim. (Perspectives of biofuel production in Podlaskie region)', *Ekonomia i Zarządzanie (Economy and Management)*, no.11, pp. 249-264.
- Wasiak, A & Orynycz, O 2014, 'Formulation of a Model for Energetic Efficiency of Agricultural Subsystem of Biofuel Production', *IEEE ENERGYCON IEEE Xplore*, Dubrovnik, Croatia, pp. 1333-1337.
- Wasiak, A & Orynycz, O 2015, 'The effects of energy contributions into subsidiary processes on energetic efficiency of biomass plantation supplying biofuel production system', *Agriculture and Agricultural Science Proceedia*, vol. 7, pp. 292-300.
- Ziabicki, A, Jarecki, L & Wasiak, A 1998, 'Modelling of melt spinning', *Computational and Theoretical Polymer Science*, vol. 8, no. 1-2, pp. 143-157.
- Zubrzycki, J, Świć, A & Taranenko, V 2013, 'Mathematical model of the hole drilling process and typical automated process for designing hole drilling operations', *11th International Conference on Industrial, Service and Humanoid Robotics (ROBTEP 2012)*, Strbske Pleso, Slovakia, pp. 221-229.