

**ENERGETIC EFFICIENCY OF SALIX VIMINALIS PLANTATION****Olga ORYNYCZ, Artur CHODORSKI, Andrzej WASIAK**

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E-mail of corresponding author: [o.orynycz@pb.edu.pl](mailto:o.orynycz@pb.edu.pl)**Keywords:** willow, salix viminalis, EROEI, energetic efficiency**ABSTRACT**

Energetic efficiency, based on a version of EROEI indicator, of salix viminalis plantation is estimated for realistic tillage technology. For different plantation sizes, different sets of machines are selected for performing agro-technical operations. Obtained results are dependent upon plantation size, and characteristics of technical devices applied. Potential values of energetic efficiency are rather high, but it has to be taken into account that the study is confined to the limited number of operations corresponding to strictly agricultural operations. Addition of other steps in production system is supposed to decrease final values.

**INTRODUCTION**

Biomass became considered as an alternative source of energy that might replace fossil fuels (at least for some time). This idea results of two factors: first is expectation of sc. "oil peak" – that implies possible shortages of resources. and the second widely discussed climatic effects of use of the fossil fuels. Exploitation of biomass seems to mitigate the both threads mentioned. The energetic use of biomass various origins (both wild or planted) requires inputs of energy on various steps of production. Therefore, it is important that sum of the energy inputs, given to all steps of production, does not exceed final amount of energy obtained from biomass. The effects of biofuel use for sustainability of agriculture have been recently discussed by Wasiak (2016). The characteristic describing energetic efficiency of particular energy producing system under the name EROEI was introduced by Cleveland et al. (1984), Murphy et al. (2010), Murphy et al. (2011) and also Zhang and Colosi (2013). The later Authors indicated, however that various calculation procedures being used might cause discrepancies in results and cause ambiguities of interpretation. Various analyses concerning energetic use of biomass were also published (cf. Field et al. (2007), Mediavilla et al. (2013), Arodudu et al. (2014) and Liu (2017). Recently also Pickard (2014) discussed the applicability of the EROEI to situations of modern technology and introduced some modifications. The following formula was proposed for any system used to convert some material resources onto energy:

$$EROEI = \frac{E_{out}}{E_{cr} + \sum E_{in} + E_{liq}} \quad (1)$$

where  $E_{out}$  – is the energy obtained at the end (exit) of the system,  $E_{cr}$  – is energy needed for creation of the system,  $E_{liq}$  – is energy needed for liquidation of that system. The  $E_{in}$  denotes one of many possible inputs of energy needed for subsequent steps of converting the particular resource or byproduct finally leading to energy. Obviously the EROEI indicator is a dimensionless quantity.

This formula was used by Wasiak and Orynycz (2014) as well as Wasiak and Orynycz (2015) in formulation of the model for energetic effectiveness of agricultural subsystem being the part of biodiesel production system. In this case it was assumed that energetic efficiency indicator,  $\varepsilon$ , is computed for already existing system, liquidation of which is not planned within the period of consideration. Therefore, the formula assumes form:

$$\varepsilon = \frac{E_{out}}{\sum E_{in}} \quad (2)$$

where meaning of symbols is the same as in Eq. 1.

The model is based on computation of contributions of energy consumption, by individual operations,  $E_{in}$ . For each operation a partial energetic efficiency,  $\varepsilon_i$ , can be defined as ratio of final energy obtained in form of biofuel to the particular value of any individual contribution:

$$\varepsilon_i = \frac{E_{out}}{E_{in(i)}} \quad (3)$$

and therefore:

$$\varepsilon^{-1} = \sum \varepsilon_i^{-1} \quad (4)$$

This approach enables recognition of the effects of contributions of individual technological operations on the final energetic effectiveness of production systems.

Slightly different approach is being used in agricultural community. The procedure introduced by Anuszewski (1987) was used by several authors e.g. Dobek (2007), Grzybek (2011) and others. The approach of those authors mainly differs from EROEI by taking into account the contribution of human work energy consumption.

Willow (*salix viminalis*) is one of the most popular plants (especially in Poland) that is used for energetic purposes. Analyses based on empirical studies performed by several authors e.g. Kwaśniewski (2010), Stolarski et al. (2011), Stolarski et al. (2016) show rather low values of energetic effectiveness, but evidently dependent upon technological and natural factors. The methodology used in those works corresponds to mentioned earlier Anuszewski's approach. Similar approach is also applied by Gallagher and Murphy (2013) to computation of energy balance of willow converted to biogas indicating promising possibility of such technology. The work contains detailed analysis of energy consumption in agricultural operations on willow plantation.

The present work contains preliminary computations of energetic efficiency based on purely technical considerations.

## RESULTS AND DISCUSSION

The scope of the work is confined to only agricultural operations. It will be extended by separate computations of other components of production system, like drying, transport, converting into a specific fuel (pellet, briquette, gaseous fuel, etc.). The fuel consumption is estimated on the basis of assumption 192 g/kWh, and corresponding technical data of individual machines. The estimated values are approximately in agreement with the data reported in the book of Lorencowicz (2012). Machines are arbitrarily chosen according to the size of plantation. Results of computations presented here concern plantation size equal one and one hundred hectares. In this case the use of including 66 KM tractor KUBOTA M6040 was assumed. The choice of machines, as well as results of computation of consumed energy are shown in Table 1. It is seen that the most energy consuming operations are ploughing and cutting of crops. In the case of one-hectare planting of willow is assumed to be performed manually, and since we are interested in contributions in energy consumption only resulting from use of technical equipment, the energy contributed by human work is not taken into account.

Table 1. Energy consumption by individual operations on 1ha field

Operation	Machine	Specific fuel consumption	Operational capacity	Operation time	Fuel consumption	Consumed energy
		[dm <sup>3</sup> /h]	[ha/h]	[h]	[dm <sup>3</sup> ]	[GJ]
Planting	Manual *)					*)
Ploughing	Plough Unia Grudziądz 100B	12	0.6	1.7	36.7	1.3
Cultivation	Cultivator Unia Grudziądz ARESL/S	11	1.6	0.625	7.5	0.3
Spraying	Sprayer Pilmet 300LM	8	4	0.25	2.75	0.1
Fertilization	Fertilizer spreader SIPMA RN 410 ANTEK	8	3	0.33	2.67	0.1
Cutting	Mower Husqvarna 555FXT	1.36	0.024	41.7	333.33	11.7
TOTAL						13.5

\*) Human energy consumption for manual operations is not considered

The other choice of much more powerful machines is presented for 100 ha field. The choice, as well as computed working time, fuel consumption and resulting energy consumption are shown in Table 2. In this case the use of tractor 186 KM FENDT 718 VARIO was assumed. Obviously, energy consumption in all individual operations is higher than in the case of one-hectare field. In the case of large field two variants are considered. The first is mechanical planting of willow cuttings, and the second – performing this operation manually. The energy consumption for the first case is estimated basing on operation time and fuel consumption, while for the second, the energy of human work is omitted. Results of energy consumption for both cases are reported in the Table 2. The column “Consumed energy” is split into two columns correspondingly containing data for the cases of mechanical and manual planting.

Agricultural operations are frequently accompanied with transport of various materials, and equipment. It can be transport of fertilizers, crop protection means as well as seedlings, etc. Practically, it concerns each operation. Such transport obviously consumes some energy, and should be included into calculations of energetic effectiveness. In the present work, this contribution is intentionally omitted in all operations, because transport energy consumption will be calculated for all operations as separate component.

The energy obtained from plantation is computed basing on the yield and low caloric value of final woody biofuel (pellet, briquette) in normal combustion (19 MJ/Mg i.e. 19 MJ per one metric ton).

Table 2. Energy consumption by individual operations on 100 ha field

Operation	Machine	Specific fuel consumption	Operational capacity	Operation Time	Fuel consumption	Consumed energy	
						Mechanical planting	Manual planting
		[dm <sup>3</sup> /h]	[ha/h]	[h]	[dm <sup>3</sup> ]	[GJ]	[GJ]
Planting	Planting machine SPAPPERI TP	12	0.36	277.8	3333.3	116.7	*)
Ploughing	Plough	22.5	1.8	55.6	1250	43.8	43.8
Cultivation	Cultivator Agro Masz 5.6m	21	2.4	41.7	875	30.7	30.7
Spraying	Sprayer Pilmet EuropaXL 3000l	12	10	10	120	4.2	4.2
Fertilization	Fertilizer spreader AMAZON E ZA-M ultra	14	14	7.7	100	3.5	3.5
Cutting	Forage harvester Claas 940	55	2.4	41.7	2291.6	80.3	80.3
TOTAL						279.2	162.5

\*) Human energy consumption for manual operations is not considered

Finally energetic efficiency for this step of production system is obtained by division of the energy yield from obtained solid biofuel by the energy consumption.

As for the energy yield two values are considered as lower and upper limits of values usually obtained in practice, also in both cases of energy yield the values of energy efficiency are reported in two columns for mechanical and manual planting. It should be noted that, as mentioned earlier, mechanical planting for one-hectare field was not considered. The obtained results are rather high, and very different for small and big plantation. The later values might result of not good choice of devices used in small plantation (too much fuel consuming, too small operational capacity – especially for chosen mower).

Table 3. Comparison of energetic efficiency,  $\epsilon$ , for 1 ha and 100 ha fields treated with various machines

Plantation size [ha]	Energy yield 300 [GJ/ha]		Energy yield 580 [GJ/ha]	
	Mechanical planting	Manual planting *)	Mechanical planting	Manual planting *)
1	-	22.22	-	42.96
100	107.5	207.7	207.7	356.9

\*) Human energy consumption for manual operations is not considered

The obtained values seem to be higher than those reported by other Authors, but it has to be recognized, that those are values of partial energetic efficiency (computed according

to Eq. 3), in which the only part of production system is concerned. Operations like watering the fields, transportation of goods and equipment between and inside of fields, drying of crops, pelletizing, etc. are not considered, and those operations surely will decrease the final energetic effectiveness of the whole production system. This study also does not consider indirect energy consumption (embodied energy), which also causes a decrease of energetic efficiency. All the omitted factors will be the subject of further studies.

## CONCLUSIONS

Presented results of preliminary study show that energetic efficiency of willow plantation may strongly be affected by the choice of equipment used for performing agro-technical operations. It also depends upon size of plantation in that sense that it may be difficult to optimize choice of equipment for particular plantations areas. The resulting values of energetic efficiency are varying between about 20 and about 360 depending on size of plantation and choice of operating equipment. Those values appear to be rather high as compared to the results presented in the literature. The main goal of this work is, however, to recognize the role of subsequent steps of production in forming final energetic efficiency of production system. Taking into account Eq. 4 it is possible to predict that each subsequent step will decrease the total efficiency. It is also predictable, that the less efficient step will mostly affect the final result. Consequently, establishing individual contributions of subsequent steps will enable looking for those components of production system that require major improvements. In presented cases, as the most energy consuming appear operations like ploughing, mechanical planting or harvesting. The operations like: transportation of goods to the fields, watering, transportation of crops, etc. will be the subject of subsequent works. It also seems that improvement in technology of energetic exploitation of biomass may be the important step onto achieving higher energetic efficiency of the biomass derived fuels. It might be expected that direct combustion is not mostly effective use of willow biomass – what possibly can be improved by changing the technology of obtaining other than solid fuels from this biomass.

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