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Evaluation of sustainability aspect – energy balance of briquettes made of hemp biomass cultivated in Moldova

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Abstract. Biomass is currently a significant source of energy mainly for its availability and high potential. Energy crops suitable for energy purposes must have a positive energy balance within the whole production cycle. Industrial hemp (*Cannabis sativa L.*) has a high yield in a short period of time and reaches a gross calorific value similar to that of wood. Two hemp cultivars were experimentally sown in the Republic of Moldova in order to determine the yield and energy balance for utilization of solid fuels in the form of briquettes. Briquettes were considered to be used in small – scale boilers for heating purposes with a thermal efficiency of 80%. Hemp harvested as a green plant in autumn was left under a roof for losing moisture, to keep yield as high as possible and left the field for another crop in rotation system. The energy balance included all forms of inputs – energy of human labor, energy in fuels, in seeds and in the machines during the technological process according to common practises in Moldova. Energy Return on Energy Invested (EROEI), due to the large share of manual labor and agricultural practices without using of fertilizers, exceeded the value of 12.6. This means that it is classified as very suitable for energy purposes. Hemp appears to be a promising energy crop in temperate climate and it is able to contribute solving the energy situation in Moldova.

Key words: energy yield**,** energy balance, Energy Return on Energy Invested (EROEI), energy inputs, energy outputs.

INTRODUCTION

Moldova is currently a priority country of the Czech Republic in the framework of Development Cooperation. One of the areas of assistance is also focused on energy. The Republic of Moldova has very insignificant reserves of solid fossil fuels, petroleum and gas. This has led to a high dependence on energy imports from Russia reaching 96% of total energy consumption in 2010 (Karakosta & Dimopoulou, 2011). To ensure sufficient amount of energy supplies for future generations and less dependency on foreign imports, we must find a proper alternative to fossil fuels. The solution can be found through growing energy crops.

The efforts of most industrialized countries around the world to use fossil fuels more efficiently as well as to replace them with renewable sources of energy have attracted scientific research towards testing energy crops whose potential can be ranked higher than other renewable sources of energy (Prade et al., 2011). Most of the research published in the available literature focuses primarily on the evaluation of the potential of the energy crop according to the following criteria: energy balance, tonnage value and productivity as well as environmental impact (Prade et al., 2012; Kreuger et al., 2011; Gill et al., 2011).

Hemp (Cannabis sativa) is a plant that has been prohibited for years in relation to the psychoactive effect of some of its secondary metabolites – terpenoids (Sladký, 2004). However, it has been experiencing a worldwide revival in the last 10 years (Prade et al., 2011). This crop and most of the industrial situations involving it is currently grown mainly for the production of its very tough fibers that are unique in composition as well (Li et al., 2012). Such a situation is, from an energy point of view, not endowed to many crops. Hemp can also be used as a feedstock for the production of solid biofuels – briquettes and pellets (Prade et al., 2011) as well as a source of biomass for biogas generators (Kreuger et al., 2011). Prade et al. (2012) evaluated the physical and chemical properties of solid biofuels. They mentioned that these attributes influence suitability and competitiveness among solid biofuels. However, the above mentioned physical properties (particle size, bulk density, angle of repose and bridging tendency) can be changed by specific treatment processes (grinding, milling or compaction), but its chemical properties (content of major alkali and earth alkali metals) are hard to change once the crop has been harvested (Prade et al., 2011). Furthermore, because of the high concentration of cellulosic fibers thus glucose, hemp could be a suitable second generation crop for the production of cellulosic ethanol (Tutt & Olt, 2011).

Finally, adding to the potential of hemp on the energy market, seeds can also be used for energy production since the oil they contain could be converted into biodiesel (Gill et al., 2011). Available literature resources mainly discuss the optimization, oil characteristics and fuel property analysis made of these oils and their blends (Gill et al., 2011).

Industrial hemp is well known for its high productivity as well as gross calorific value, which can be compared to wood (Prade et al., 2011). The uniqueness of this plant lies in its ability to yield more than 24 tons of green biomass per hectare (corresponding to 10.9 t ha^{-1} of dry biomass) within 140 days (Kolarikova et al., 2013).

Prade (2012) and his team calculated the energy balance and output-to –input ratio for hemp production for CHP (combined heat-electricity), from spring-harvested baled hemp; heat from spring-harvested briquetted hemp and vehicle fuel from autumn-harvested hemp processed into biogas in an anaerobic digestion process. They took into consideration Swedish conditions. Net energy yield of CHP and heat production from the hemp biomass were above average. Both other conversion possibilities suffered from high energy inputs and lower conversion efficiency. According to Prade hemp competes with perennial crops (willow) in the production of solid biofuels (Prade et al., 2012).

The high energy potential of hemp and lack of information about its cultivation, harvest and environmental suitability has led to further research to obtain new information.

The main objective of this work is to do a system analysis of energy effectiveness (EROEI) of hemp biomass from the autumn harvest for the production of solid biofuel-briquettes and its use in small- scale boilers to obtain heat in the conditions of the Republic of Moldova.

MATERIAL AND METHODS

Definition of system boundaries

To calculate the energy balance, a model situation was chosen. Taken into account were aspects of the current Moldovan agriculture i.e. large share of manual labour and non mineral fertilizers. The model included the situation of the farmer, who farms on 4 ha of land useing classic crop rotation, which includeshemp. The Produced bio-fuel - briquettes will produce energy in the form of heat for the personal use of the farmer.

The system boundaries include soil preparation, to processing into the form of briquettes, transporting to the farmer's house and combusting in the small scale boiler for heating purposes. Technological processes include - stubble treatment, ploughing, seedbed preparation, sowing, harvesting (mowing, sheaves), transport and briquetting (when moisture content reaches 15%).

Hemp harvested as a green plant in autumn was left under a roof for losing moisture, to keep yield as high as possible and left the field for another crop in the rotation system.

Determination of energy output and losses

Biomass yield (BY)

A variety of hemp of Polish origin Bialobrzeskie and French Ferimon was cultivated in Chisinau (Republic of Moldova) in 2013 in order to obtain biomass for the energy yield evaluation from its autumn harvest. Hemp was grown on a trial plot of 100 m^2(50 m^2 each) with a seed rate of 60 kg ha^{-1} and the biomass yields of the small-scale samples (determined by collecting and weighing all plants) were extrapolated to a biomass yield per hectare (BY).

Samples experiments

The plants used for sampling were subjected to the following experiments during which determined: moisture content (MC), gross calorific value (GCV) and dry matter yield (DM) according to EU norms.

Harvestable biomass

To account for losses during harvest, hemp DM yield was reduced by 10% for autumn harvest.

Biomass energy yield (BEY)

The biomass gross energy yield (BEY) per hectare describes the total mass of energy stored in biomass (potential energy yield). It was calculated by multiplying the dry matter (DM) yield by corresponding gross calorific value (GCV), i.e.:

$$BEY = GCV \cdot DM [\mathrm{GJha^{-1}}] \quad (1)$$

Useful heat calculation (Energy output $-E_O$)

According to lower calorific value (formula 2) of briquettes made of hemp and taking into consideration losses during combustion process (20%) it was possible to calculate useful heat for household use in small scale boilers (efficiency 80%)

$$LCV = GCV - 24.42 \cdot (w + 8.94 \cdot H_a) \quad (2)$$

where: w – moisture content in briquettes [%]; H_a – content of hydrogen in sample [%].

Energy inputs calculation

The amount of energy inputs (Ei) was determined as the conversion of spent labour and materials (hours of human labour, kWh, kg, etc.) in the energy equivalent (Table 1 and 2).

Direct energy inputs include that of human labour (E_1) and energy in fuels (E_2). Indirect energy inputs consist of energy embedded in machines (E_3), in seeds (E_4), and in fertilizers (E_5) see formula

$$E_I = E_1 + E_2 + E_3 + E_4 \text{ [GJ ha}^{-1}\text{]} \quad (3)$$

$$E_1 = S_{hl} \cdot e_{hl} \text{ [GJha}^{-1}\text{]} \quad (4)$$

where: S_{hl} – spent human labour per hectare [hha^{-1}]; e_{hl}– energy equivalent of human labour [MJ h^{-1}].

$$E_2 = S_f * e_{ff} + S_e \cdot e_e \text{ [GJ ha}^{-1}\text{]} \quad (5)$$

where: S_f – fuel consumption [l ha^{-1}]; e_{ff} – energy equivalent of fuels [MJ l^{-1}]; S_e –spent electricity per hectare [kWh ha^{-1}]; e_e – energy equivalent of electricity [MJ kWh^{-1}].

$$E_3 = W \cdot K_e \cdot T_s \cdot K_{rm} / T_{wh} \text{ [GJ ha}^{-1}\text{]} \quad (6)$$

where: W – weight of machine[kg]; K_e – conversion equivalent [MJ kg^{-1}]; T_s – time spent on operation [h]; K_{rm} – repairing and maintenance coefficient; T_{wh} – total number of working hours per machine's service life [h].

$$E_4 = S_s \cdot e_s \text{[GJ ha}^{-1}\text{]} \quad (7)$$

where: S_s – seeding rate[kg ha^{-1}]; e_s – energy equivalent [MJ kg^{-1}].

Table 1. Energy conversion equivalents

Item	Unit	Energy equivalent	Source
Human labour	1 h	2.3 MJ h^{-1}	Preininger (2009)
Diesel	1 l	35.8 MJ l^{-1}	Špička, Jelínek (2008)
Electricity	1kWh	3.6 MJ (kWh)$^{-1}$	Preininger (1987)
Steel	1 kg	25 MJ kg^{-1}	Hill et al. (2006)
Seeds	1 kg	22.9 MJ kg^{-1}	Abrham et al.(2009)

Machines and equipment used in Technological process are as follows with technical specification in table 2.

- Stubble treatment (carrier–Privatroto 430 +Tractor 81 kW BELARUS)
- Ploughing (4 furrow plough – Overum + Tractor)
- Seedbed preparation (combined cultivator Pracant + Tractor)
- Sowing (Amazone AD +Tractor)
- Harvesting (hand tools + manual work 250hours per hectar)
- Transport (tractor +trailer)
- Grinding (hammer mill 9FQ-40C, power 7.5 kW)
- Briquetting (BRIK-STAR 50–12, power 4.5 kW)

Table 2. Machines and equipment specification

Machine/ equipment	Weight [kg]	Conversioneq uivalent[a]	Mantenance coefficient[b]	Lifetime [years] [c]	Annualuse [h] [d]	Indirect energy [MJ h^{-1}] [e]	Spent time in operation [h][f]	Spent fuel in operation [l] [g]
TractorBelarus	4,295	95.7	2	12	1,800	38.06	n.a.	n.a.
Privatroto 430	1,750	99.2	1.7	10	750	39.34	0.35	9.1
Overum	1,110	99.2	1.7	10	500	37.43	1.43	19.1
Pracant	2,480	99.2	1.7	10	250	167.29	0.58	7.9
Amazone AD	1,850	95.4	2.1	10	350	105.89	0.83	11.2
Trailer NS 9	3,400	95.4	1.3	10	600	70.28	1.4	13.4
Hamermill	180	37.5*	2	10	720	1.88	28.46	213**
BrikStar50–12	790	37.5*	1.7	10	720	6.99	284.6	1,537**

[a]Source: Špička&Jelínek (2008)
*own calculation according to Hill et al. (2006) on the basis of energy needed for steel production (25 MJ kg^{-1}) increased by 50%
[b]Source Kavka et al. (2008)
[c], [d], [f], [g]Source: Abrham et al. (2009), Kavka et al. (2008)
[e]indirect energy in machine /equipment in MJ per hour – own calculation
**kWh

Energy profit, EROEI determination

The energy profit was calculated as the difference between the energy outputs (Eo) and energy inputs (Ei).The energy output represents the energy derived as useful heat from the conversion process, and energy inputs as a total sum of direct and indirect energy for biomass production.

The parameter EROEI or energy efficiency is a ratio of energy yield and energy inputs:

$$EROEI = (Eo) / (E_I) \quad (8)$$

RESULTS AND DISCUSSION

Energy outputs as results of field and laboratory measurements as shown in Table 3. Energy inputs results are in Table 4.

Table 3. Moisture content, biomass yield, dry matter, lower calorific value, Energy in Harvested Biomass, harvest losses, energy in harvestable biomass, combustion heat losses, useful heat

	Bialobrzeskie	Ferimon
BY [tha^{-1}]	28.9	31.1
MC [%]	58.3	61.2
DM [tha^{-1}]	12.05	12.07
LCV [GJt^{-1}]	17.7	17.1
Energy in harvested biomass [$GJha^{-1}$]	213.3	206.4
Harvest losses [%]	10	10
Energy in Harvestable biomass	191.9	185.7
Combustion losses [%]	20	20
Useful heat [GJ t^{-1}]	**153.5**	**148.6**

Table 4. Energy inputs for commodity balance of hemp [MJ]

	Direct energy		Indirect energy		
	Human labour	Fuel consumption	Energy in machines	Energy in seeds	Sum
Stubble treatment	0.81	325.78	27.09		353.68
Ploughing	3.30	683.78	107.95		795.03
Seedbed preparation	1.33	282.82	119.09		403.24
Sowing	1.91	400.96	119.48	1,374	1,896.35
Harvesting	575.00				575.00
Transport	3.22	479.72	151.67		634.61
Grinding	65.46	833.22	1.88		900.56
Briquetting	654.58	5,532.62	6.99		6,194.19
Total	1,305.61	8,538.9	534.15	1,374	**11,752.66**

Energy profit and EROEI are shown in Table 5.

Table 5. Energy profit, EROEI

Cultivar	Energy profit	EROEI
Bialobrzeskie	141.7 GJ	13.1
Ferimon	136.9 GJ	12.6

The share of energy inputs is as follows: energy in fuels (72.7%), energy in seeds (11.7%), energy of human labour (11.1%), and energy in machines (4.5%).

The highly demanded operation is biomass briquetting, which spent more than 5.5 GJ of energy in the form of electricity, which is 65% of total energy in fuels.

A similar experiment on energy balance of hemp cultivars was done in the Czech Republic. The EROEI was determined to be 7.1 for Bialobrzeskie and 7.2 for Ferimon (Kolarikova et al., 2013). The big difference is caused by the elimination of mineral fertilizers, and a high share of manual labor at harvest, which are both common practices of Moldovan agriculture.

Prade et al. also evaluated hemp briquettes for heating in household boilers, however he considered as the best practise harvest in the spring, when yield is lower, but moisture content also decreases. His result 5.1 is quite low due to differences in the technological processes used (Prade et al., 2012).

High hemp DM yield (12t ha^{-1}), GCV similar to wood and ability to suppress weeds determine this crop among the most suitable in moderate climate. Drawbacks are seen in quite problematic mechanization of harvest due to high tenacity of fibre and some restrictions for cannabis cultivation -varieties used shall have a THC content not exceeding 0.2%, only certified seeds of certain varieties can be used, and areas growing hemp require administrative approval.

CONCLUSION

The energy balance is a fundamental element to indicate how much energy is produced by the crop per unit of energy input; it can reveal existing reserves and optimize energy inputs in the manufacturing process. The inventory analysis serves as well as the environmental impact evaluation (LCA) and possibility of CO_2 (greenhouse gases) reduction.Industrial hemp has good energy output-to-input ratios.

Targeted scientific research in yield improvement may determine this crop among the best energy crops for the whole temperate climate; it can be a good solution in improving the energy situation in Moldova.

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