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Energijska analiza pridelave oljne ogrščice za potrebe proizvodnje biodizla na Hrvaškem

An Energy Analysis of Rapeseed Production for Biodiesel in Croatia

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Preden smo na Hrvaškem začeli s izdelavo biodizla iz olja ogrščice, smo izvedli energijsko analizo pridelave tega pridelka. Podatke, potrebne za energijsko analizo, smo v obdobju 2001 do 2003 zbirali na podlagi raziskav, izvedenih na kmetijah v Slavoniji, ki je glavno kmetijsko področje na Hrvaškem. Za izračun dovedene in odvedene energije smo rezultate raziskave uporabili skupaj z energijskimi vrednostmi iz primerjalne literature. Povprečen pridelek oljne ogrščice je bil 3195 kg/ha, njena povprečna vsebnost olja pa 42,5%. Če upoštevamo, da smo oljno ogrščico uporabili za izdelavo biodizla in za krmo živali, je znesek celotne odvedene energije znašal 74,01 GJ/ha. Celotna dovedena energija, potrebna za pridelavo oljne ogrščice, je bila 23,44 GJ/ha, pri čemer je bilo največ te energije namenjene porabi gnojil in goriva. Energijsko razmerje pri pridelavi oljne ogrščice je bilo 3,16, čisti energijski prirastek je bil 50,56 GJ/ha, in energijska donosnost je bila 49,23 L/GJ. Predlagali smo tudi nekatere možnosti varčevanja z energijo v postopku pridelave oljne ogrščice.

(Ključne besede: oljna ogrščica, analize energijske, varčevanje z energijo, biodizel)

Before starting with biodiesel production from rapeseed oil in Croatia, an energy analysis of the production was made. The data for the energy analysis were gathered from investigations on farms in the Slavonia region, the main arable production area in Croatia, in the period 2001 to 2003. For the calculation of energy outputs and inputs, the results of this investigation were used together with energy values from the literature. The average rapeseed yield and oil content was 3195 kg/ha and 42.5%, respectively. Considering rapeseed oil for biodiesel and meal for animal feed, the total energy outputs were 74.01 GJ/ha. Total energy inputs for the rapeseed production were 23.44 GJ/ha, and the major energy inputs were fertilizers and fuel. The energy ratio of the rapeseed production was 3.16, the net energy gain was 50.56 GJ/ha, and the energy productivity was 49.23 L/GJ. Some possibilities for energy saving in rapeseed production were also suggested.

(Keywords: rapeseed, energy analysis, energy saving, biodiesel)

0 UVOD

Zaradi omejenih virov fosilnih goriv in problemov z emisijami toplogrednih plinov v ozračje postajajo dandanes nadomestna goriva za dizelske motorje vse bolj pomembna. Biodizel je nadomestno tekoče gorivo narejeno iz obnovljivih bioloških virov, kot na primer rastlinska olja. Do prvih pobud za rabo biodizla je prišlo leta 1981 v Južni Afriki in leta 1982 v Avstriji, Nemčiji in na Novi Zelandiji. Že leta 1985 so v majhnem poskusnem obratu v Avstriji poskusno naredili biodizel iz olja ogrščice, leta 1990 pa je prva kmetijska zadruga pričela s pridelavo oljne ogrščice

0 INTRODUCTION

Alternative fuels for diesel engines are becoming increasingly important today due to the limited resources of fossil fuels and problems with the emission of greenhouse gases into the atmosphere. Biodiesel is an alternative liquid fuel, which is made from renewable biological sources such as plant oils. The first biodiesel initiatives were reported in 1981 in South Africa and then in 1982 in Austria, Germany and New Zealand. As early as 1985, a small pilot plant in Austria tested the production of biodiesel from rapeseed oil, and in 1990 the first farm-v tržne namene. Naslednji pomembni korak je bila uveljavitev prvega standarda glede goriv za biodizel, ON C 1190, ki ga je leta 1991 potrdil avstrijski inštitut za standardizacijo in s tem zagotovil visoko kakovost tako narejenega goriva. Velik korak naprej je bil narejen leta 1996, ko so se v Franciji in Nemčiji pojavili veliki industrijski obrati in ko je bil ustanovljen Evropski odbor za biodizel, strokovna organizacija, ki vključuje vse večje izdelovalce biodizla [1]. Poleg omenjenih držav se biodizel gospodarsko uporablja kot nadomestno gorivo tudi v drugih evropskih državah, na primer v Belgiji, na Češkem, Madžarskem, v Italiji in na Švedskem [2]. Čeprav sicer večina sodobnih raziskav na področju uporabe nadomestkov dizelskih goriv poteka v razvitih državah, pa so potrebe po teh nadomestkih in možnosti za njihovo izdelavo precej večje v državah v razvoju [3]. Podobno kakor druge evropske države, Hrvaška nima ustreznih zalog virov fosilnih goriv, kar vodi v odvisnost od uvoza nafte, potrebne za zadovoljitev potreb po bencinu in dizelskem gorivu na področju prevoza. Zadovoljiva ponudba biodizla bi zato pripomogla k zmanjšanju tovrstne odvisnosti. Hkrati pridelovanje oljčnic velja za eno najboljših izbir v kmetijstvu, saj se je pridelava za prehrambne namene zmanjšala v skladu z evropsko kmetijsko politiko. Ta okoliščina omogoča razvoj novih panog, na primer agroenergijske industrije, s tem pa tudi zaposlovanje in pokrajinski razvoj [4].

V Evropi je najpomembnejša surovina za izdelavo biodizla oljna ogrščica, tej sledita sončnica in soja [5]. Glede na vir [1] je oljna ogrščica odlična za pridelavo v evropskem podnebju, biodizelsko gorivo, pridobljeno iz te rastline, pa se zelo približa značilnostim običajnega dizelskega goriva. Poleg tega nove različice oljne ogrščice z dvojno ničlo (00) vsebujejo manj ko 0,1% eruka kisline in 8 do 12 mol/g glukosinolata, zaradi česar sta izboljšana kakovost olja in krme [6]. Leta 2001 smo na Hrvaškem začeli projekt izdelave biodizla iz olja ogrščice, saj lahko uporaba biodizla kot nadomestnega goriva Hrvaški prinese gospodarske, okoljevarstvene in energijske koristi. Zaradi majhnih gospodarskih donosov glavnih poljščin na Hrvaškem, koruze in pšenice, so mnogi kmetje pokazali zanimanje za pridelavo oljne ogrščice. Eden napomembnejših pogojev za odločitev, ali je pridelek oljne ogrščice primeren za proizvodnjo biodizla, je zahteva, da, v primerjavi z energijo, ki smo jo porabili za pridelek, omogoča pozitivni energijski donos, tj. da s pridelavo

ers' cooperative started with commercial production. Another important step was establishing the first fuel standard for biodiesel, ON C 1190, in 1991 by the Austrian Standardisation Institute, so ensuring the high quality of this fuel. A big step forward was made in 1996 with start of large industrial-scale plants in France and Germany, and also with the foundation of the European Biodiesel Board as a professional organization for all major biodiesel producers [1]. In addition to the above-mentioned countries, biodiesel has been in commercial use as an alternative fuel in other European countries, like Belgium, Czech Republic, Hungary, Italy and Sweden [2]. Although much of the recent research and development in the production and use of diesel-fuel substitutes has been carried out in developed countries, the need for such substitutes and the potential for their production are much greater in developing countries [3]. Croatia, like many other European countries, does not have adequate reserves of fossil-fuel resources, which implies a dependency on petroleum imports in order to provide for the demands for petrol and diesel fuel in the transport sector. The satisfaction of this demand with biodiesel would contribute to reducing this dependency. On the other hand, oil crops have been considered as one of the best alternatives in the agricultural sector, whose production for food purposes has been limited by the PAC, thus allowing the development of new industries such as the agroenergy industry, which facilitates employment opportunities and regional development [4].

The most important raw material for biodiesel production in Europe is rapeseed, followed by sunflower and soybean [5]. According to [1], rapeseed oil is an ideal raw material for the European climate, and biodiesel fuel produced from this plant oil comes very close to the properties of conventional diesel fuel. In addition, the new double-zero (00) rapeseed varieties contain less than 0.1% erucic acid and 8 to 12 mol/g glucosinolate, which results in good oil and meal quality [6]. In 2001 Croatia started a project for biodiesel production from rapeseed oil, since using biodiesel as an alternative fuel can have economic, environmental and energy benefits for Croatia. Due to the small economic returns of the main arable crops in Croatia, maize and wheat, many farmers showed an interest in rapeseed production. One of most important requirements for an oilseed crop to be considered for biodiesel production is that it provides a positive energy return compared with the energy used for ustvarimo več energije kakor je porabimo ([7] in [8]). Preden smo na Hrvaškem pričeli z izdelavo biodizla iz oljne ogrščice, smo opravili energijsko analizo pridelave oljne ogrščice na Hrvaškem. Na podlagi podatkov iz primerjalne literature smo izrabili tudi nekaj možnosti za prihranek energije.

1 METODOLOGIJA ENERGIJSKE ANALIZE

Obstaja več metodologij energijske analize, ki se precej razlikujejo glede na svoja izhodišča in postopke. V tem prispevku poročamo o uporabi energijske analize, ki jo je leta 1974 predlagala Mednarodna zveza inštitutov za sodobne raziskave, pojasnila pa sta jo Ortiz-Canavate in Hernanz [9]. V tem postopku energijske analize za vsak dejavnik pridelovalnega postopka ugotovimo potrebno količino neobnovljive energije. Celotno energijo postopka ugotovimo s seštevkom delnih vnosov energije, ki so vezani na posamezne korake v postopku, ne da bi jim pri tem določili kakovostni faktor. Celotno energijo na pridelovalno enoto (hektar) ugotovimo s seštevkom delnih energij posameznih vnosov, ki se nanašajo na določeno pridelovalno enoto. Energija je lahko dovedena neposredno in posredno. Neposredno dovedena energija ($EI_{neposredna}$) vključuje energijo dizelskega goriva, porabljenega pri postopku pridelave oljne ogrščice. Posredno dovedena energija ($EI_{posredna}$) pa vključuje energijo porabljeno za izdelavo kmetijske mehanizacije, gnojil, pesticidov in semen, pa tudi energijo, potrebno za delo kmetovalcev. Namakanja nismo upoštevali, ker le-tega nismo uporabljali v poljedelstvu obravnavanega področja. Celotno dovedeno energijo ($EI_{celotna}$) zato laho izrazimo z enačbo:

production, i.e., that the production yields more energy than it spends ([7] and [8]). Before starting with biodiesel production from rapeseed oil in Croatia, an energy analysis of rapeseed production in Croatia was made. Some possibilities for energy saving were made based on the literature data.

1 METHODOLOGY OF THE ENERGY ANALYSIS

There are several methodologies for energy analysis; these are quite different in terms of their basis and approaches. In this paper, the energy analysis suggested in 1974 by the International Federation of Institutes for Advanced Studies and explained by Ortiz-Canavate and Hernanz [9], was applied. In this procedure, the energy analysis relies on assigning non-renewable energy amounts to each factor in the production. The total energy in a process is established by adding the partial energies associated with each step, without assigning a quality factor. The total energy per production unit (hectare) is established by the addition of the partial energies of each input, referred to the unit of production. The energy inputs are classified as direct and indirect. Direct energy inputs (EI_{direct}) include the energy of the diesel fuel consumed in rapeseed production. Indirect energy inputs ($EI_{indirect}$) include the energy for the production of farm machinery, fertilizers, pesticides and seeds, and the energy for the labor of the agricultural workers. Irrigation was not considered, because irrigation was not applied in the arable production in this region. Thus, the total energy input (EI_{total}) can be expressed with:

$$EI_{celotna/total} = EI_{neposredna/direct} + EI_{posredna/indirect} \quad [MJ/ha] \qquad (1).$$

1.1 Neposredno dovedena energija

Neposredno dovedeno energijo na hektar smo določili z izmero traktorjeve porabe goriva, potrebnega za vsako opravljeno delo na polju, ali za potreben prevoz z uporabo prostorninskega sistema. Za izračun neposredno dovedene energije pri pridelavi oljne ogrščice smo upoštevali podatke o povprečni porabi dizelskega goriva za vsako opravljeno delo na polju in za vsak prevoz. Glede na vir [9] je energiji, potrebni za prevoz goriva do kmeta (9,1 MJ/L) treba dodati še kurilno vrednost dizelskega goriva in energijo, ki je potrebna za rafiniranje surove nafte (38,7 MJ/L). Tako je celoten

1.1 Direct energy inputs

The direct energy inputs per hectare were determined by measuring the tractor's fuel consumption for completing each field operation over the known area or transported distance by applying a volumetric system. For calculating the direct energy inputs in rapeseed production, the average diesel-fuel consumption data for each field operation and transportation was taken into account. According to [9], it is necessary to add the diesel fuel's heating value and the energy needed to refine the crude oil (38.7 MJ/L) to the energy required to transport it to the farmer (9.1 MJ/L). Therefore, the total energy strošek energije za porabo enega litra dizelskega goriva 47,8 MJ/L. Stroške maziva smo šteli med stroške vzdrževanja. Če je N celotno število opravljenih del pri pridelavi oljne ogrščice, in je E_n strošek energije na hektar za vsako od teh opravljenih del, lahko celotno neposredno dovedeno energijo izračunamo z enačbo:

cost to consume a liter of diesel fuel is 47.8 MJ/L. The lubricant costs were calculated as maintenance costs. If N is the total number of operations in rapeseed production, and E_n is the energy cost per hectare for each of these operations, the total direct energy inputs can be calculated with:

$$EI_{neposredna/direct} = \sum_{n=1}^{N} E_n \quad [MJ/ha] \qquad (2).$$

1.2 Posredno dovedena energija

Posredno dovedena energija za kmetijsko mehanizacijo vključuje energijo potrebno za pripravo surovin (jeklo in drugo) in za proizvodni postopek, energijo za prevoz mehanizacije do porabnika in energijo za vzdrževanje in popravila mehanizacije. Glede na vir [10] je srednja vrednost za prva dva koraka ocenjena na znesek 87,0 MJ/kg, za prevoz 8,8 MJ/kg in za vzdrževanje ter popravila 47,9 MJ/kg (skupaj 143,7 MJ/kg). Za ovrednotenje posredno dovedene energije, potrebne za delovanje mehanizacije na hektar, moramo poznati maso rabljene mehanizacije, njeno dobo trajanja in njen delovni čas na hektar. Energijske vrednosti gnojil, pesticidov in semena pomenijo energijo, potrebno za pridelavo, pakiranje in dostavo končnih izdelkov. Za izračun dovedene energije gnojil N, P_2O_5 in K_2O smo uporabili vrednosti 78,1 MJ/kg, 17,4 MJ/kg in 13,7 MJ/kg [11]. Delujoča sestavina uporabljenih pesticidov (devrinol in triflurolex) je bila trifluralin, ki potrebuje energijo v znesku 171,4 MJ/kg [12]. Znesek stroškov energije za semena oljne ogrščice, 200 MJ/kg, smo povzeli po viru [13]. Za potrebe naše raziskave smo posejali semena različice Bristol, čigar uporabljeni odmerek je bil 4,6 kg/ha. Energijo, potrebno za delo kmetovalcev, smo izračunali tako, da smo čas, potreben za posamezno opravilo, spremenili v stroške energije za vloženo delo, pri čemer je bil spreminjevalni količnik 2,3 MJ/h [14]. Delovno učinkovitost smo določili z izmero časa, potrebnega za vsako delo, opravljeno na obravnavanem področju, ali za prevoz na določeni razdalji. Tako lahko celotno posredno dovedeno energijo izrazimo z enačbo:

1.2 Indirect energy inputs

The indirect energy inputs for the farm machinery included the energy required to produce the raw materials (steel and others) and the manufacturing process, the energy for the transportation of the machinery to the consumer, and the energy for the machinery's maintenance and repairs. According to [10], the mean value for the first two steps was assumed to be 87.0 MJ/kg, for transportation, 8.8 MJ/kg, and for maintenance and repairs, 47.9 MJ/kg (total 143.7 MJ/kg). To evaluate the indirect energy inputs for machinery per hectare it is necessary to know the weight of the used machinery, its working life and the working time per hectare. The energy values for fertilizers, pesticides and seeds included the energy for production, packaging and distribution of the final products. When calculating the energy inputs for N, P_2O_5 and K_2O fertilizers, the values of 78.1 MJ/kg, 17.4 MJ/kg and 13.7 MJ/kg, respectively, were used [11]. The active ingredient of the applied pesticides (Devrinol and Triflurolex) was trifluralin, which required an energy of 171.4 MJ/kg [12]. The energy cost for rapeseed seeds of 200 MJ/kg was taken from [13]. In this investigation, the rapeseed variety Bristol was sowed with an application rate of 4.6 kg/ha. The energy for human labor was calculated by converting the time for each operation into labor energy costs, with a conversion factor of 2.3 MJ/h [14]. The work rate was determined by measuring the time to finish each field operation of a known area or transport distance. Thus, the total indirect energy inputs can be expressed as follows:

$$EI_{posredna/indirect} = E_{mehanizacija/machinery} + E_{gnojila/fertilizers} + E_{pesticidi/pesticides} + E_{semena/seeds} + E_{delo/labour} \quad [MJ/ha] \qquad (3).$$

1.3 Odvedena energija (EO)

Odvedeno energijo pri pridelavi oljne ogrščice smo ocenili z množenjem količin izdelkov, olja za biodizel in krme za živali, z njihovimi energijskimi

1.3 Energy outputs

The energy outputs for rapeseed production were estimated by multiplying the quantities of the products, the oil for the biodiesel and the meal for vrednostmi. Glede na vir [15] so energijske vrednosti olja, pridobljenega iz oljne ogrščice in krme, 37,6 MJ/kg in 15,0 MJ/kg. Če odpadke pridelka obravnavamo kot energijo biomase, je njihova energijska vrednost 12,5 MJ/kg. V postopku naše raziskave smo odvedeno energijo izračunali s seštevkom povprečnih količin pridelka oljne ogrščice, deležem olja v semenih in količino odpadkov pridelka:

the animal feed by their energy values. According to [15], the energy values of the rapeseed oil and the meal are 37.6 MJ/kg and 15.0 MJ/kg, respectively. If crop residues are taken as biomass energy, their energy value is 12.5 MJ/kg. The energy outputs during this investigation were calculated with an average rapeseed yield, oil content in the seed and quantity of crop residues:

$$EO_{celotna/total} = E_{olje/oil} + E_{krma/meal} (+ E_{odpadki/residues}) \quad [MJ/ha] \qquad (4).$$

1.4 Energijska izravnava

Da bi v tej raziskavi določili energijsko izravnavo pridelave oljne ogrščice, smo izračunali energijsko razmerje, čisti energijski prirastek in energijsko donosnost. Energijsko razmerje (ER) smo definirali kot razmerje med kurilno vrednostjo dobljenih izdelkov in vso energijo, dovedeno v postopku pridelave:

1.4 Energy balance

In this analysis, for determining the energy balance of the rapeseed production, the energy ratio, the net energy gain and the energy productivity were calculated. The energy ratio (ER) is defined as the ratio between the calorific heat of the output products and all the energy inputs that take part in the production processes:

$$ER = EO_{celotna/total} / EI_{celotna/total} \qquad (5).$$

Čisti energijski prirastek (NEG) pomeni razliko med celotno odvedeno energijo in celotno dovedeno energijo, ki se nanaša na enoto pridelave, tj. 1 hektar:

The net energy gain (NEG) is the difference between the total energy outputs and the total energy inputs, related to the unit of production, i.e. 1 hectare:

$$NEG = EO_{celotna/total} - EI_{celotna/total} \quad [MJ/ha] \text{ ali/or } [GJ/ha] \qquad (6).$$

Energijska donosnost (EP) je merilo količine izdelka (v tem primeru olja ogrščice; Q_{olje}) pridobljenega na enoto dovedene energije in pomeni kurilno vrednost končnega izdelka:

The energy productivity (EP) is a measure of the quantity of a product (in this case rapeseed oil, Q_{oil}) obtained per unit of input energy, and this is the calorific value of the final product:

$$EP = Q_{olje/oil} / EI_{celotna/total} \quad [L/GJ] \qquad (7).$$

1.5 Poskusna polja in mehanizacija

Podatke, potrebne za energijsko analizo, smo v obdobju 2001 do 2003 zbirali z raziskovanjem na desetih izbranih kmetijah z značilno pridelavo oljne ogrščice v Slavoniji, ki je glavna obdelovalna površina na Hrvaškem. Vse te kmetije so izvajale enoten način pridelovanja. Povprečna velikost polj, ki smo jih zajeli v analizo, je bila 5,2 ha, kar je za to področje običajno. Povprečna razdalja od kmečkega poslopja do polja je bila 3,6 km, povprečna razdalja med poljem in skladiščem pa je bila 21,8 km. Preglednica 1 prikazuje mehanizacijo in pripomočke, ki so jih kmetovalci uporabljali v času naše raziskave.

1.5 Experimental fields and machinery

The data for the energy analysis were gathered by investigations on ten selected farms with typical rapeseed production in the Slavonia region, the main arable production area in Croatia, in the period 2001 to 2003. An identical production system was applied in all of the farms. The average size of the fields considered in the analysis was 5.2 ha, which is representative for this region. The average distance from the farmyard to the field was 3.6 km, while from the field to the storage facility the average distance was 21.8 km. The machines and the implements included in this investigation are presented in Table 1.

Preglednica 1. *Stroji in pripomočki za delo na polju in za transport*
Table 1. *Machine and implements for field operations and transport*

Opravila Operation	Mehanizacija Machinery
vlečenje in vožnja pulling and driving	traktor – moč motorja 55 kW tractor – 55 kW engine power
oranje ploughing	rigolni plug - 3 brazde mouldboard plough - 3 furrows
priprava semenskih gred seedbed preparation	kombajn za obdelovanje semenske grede - 3 m seedbed combine implement - 3 m
uporaba gnojil fertilizer application	centrifugalni razdeljevalnik gnojil - 620 l centrifugal fertilizer distributor - 620 l
uporaba pesticidov pesticide application	razpršilnik - 600 l field sprayer - 600 l
vnos pesticidov pesticide incorporation	kultivator - 3,2 m field cultivator - 3.2 m
setev sowing	sejalni stroj - 3 m planter - 3 m
žetev harvesting	žetveni kombajn - 4 m combine harvester - 4 m
prevoz transport	prikolica – 3000 kg trailer – 3000 kg

2 REZULTATI IN RAZPRAVA

Neposredno dovedena energija pri pridelavi oljne ogrščice je znašala 5346,43 MJ/ha (2), kar pomeni 22,8% celotne dovedene energije. Za opravila na polju je bilo porabljenih 80,6% omenjene dovedene energije, 19,4% energije pa za prevoz. Pri delih na polju je bilo največ energije porabljene za oranje, in sicer 1419,66 MJ/ha ali 33,0% (preglednica 2), poraba energije za obdelovanje zemlje (oranje in priprava semenskih gred) pa je znašala 49,1% celotne energije, potrebne za opravila na polju. Ti rezultati so podobni podatkom iz vira [16], po katerem je 55 do 65 odstotokov neposredno porabljene energije na polju povezanih z obdelovanjem zemlje. Kakor poroča vir [17], sta oranje in z njim povezana priprava semenskih gred energijsko izrazito zahtevni opravili, ki terjata največjo dovedeno energijo. Le-to lahko zmanjšamo z uporabo manj zahtevnega obdelovalnega sistema, na primer najmanjšega obdelovanja.

Druga največja poraba energije za delo na polju je povezana z žetvijo, za katero so kmetovalci potrebovali 1042,04 MJ/ha energije (24,2%). Z boljšo izrabo časa lahko bistveno povečamo energijsko donosnost žetve in zmanjšamo stroške energije. Glede na vir [18] lahko izrabo časa definiramo kot zmožnost, da neko dejavnost izvedemo ob času, ko pričakujemo optimalno kakovost in kolikost pridelka.

2 RESULTS AND DISCUSSION

The direct inputs in the rapeseed production were 5346.43 MJ/ha (Eq. 2), and this represented 22.8% of the total energy inputs. From this input, 80.6% of the energy was spent in field operations and 19.4% in transport. The greatest energy consumer of field operations was ploughing, with 1419.66 MJ/ha or 33.0% (Table 2), while soil tillage (ploughing and seedbed preparation) consumed 49.1% of the total energy requirement for the field operations. These results are close to the data of [16], who reported that 55-65% of the direct field energy consumption should be accounted for by the soil tillage. According to [17], ploughing and the associated seedbed preparation were very energy-intensive operations and required the highest energy inputs. These can be reduced by adopting less-intensive tillage systems, such as a minimum tillage system.

The second-ranking energy consumer in the field operation was harvesting, with 1042.04 MJ/ha (24.2%). The energy productivity of harvesting can be substantially increased, and the energy costs decreased by an improvement in timeliness. According to [18], timeliness can be defined as the ability to perform an activity at such a time when the quality and quantity of the product are optimized.

Preglednica 2. *Neposredno dovedena energija za dela na polju pri pridelavi oljne ogrščice*
Table 2. *Direct energy inputs for field operations in rapeseed production*

Opravila na polju Field operation	Delovna učinkovitost Work rate ha/h	Poraba goriva Fuel consumption L/ha	Dovedena energija Energy input MJ/ha
oranje ploughing	0,32	29,7	1419,66
priprava semenskih gred seedbed preparation	2,17	12,3	587,94
uporaba gnojil-3 x fertilizer application-3 times	4,80	8,7	415,86
uporaba pesticidov -2 x pesticide application-2 times	4,32	5,6	267,68
vnos pesticidov pesticide incorporation	2,82	8,1	387,18
setev sowing	1,08	3,9	186,42
žetev harvesting	1,20	21,8	1042,04
skupaj total		90,1	4306,78

Izračun stroškov energije, potrebne za prevoz, vezan na povprečno veliko polje (5,2 ha), je temeljil na desetih vožnjah traktorja z ustreznimi kmetijskimi orodji, eni vožnji žetvenega kombajna od kmečkega poslopja do polja in nazaj, ene vožnje traktorja s prikolico za potrebe prevoza materiala na polje in šest voženj traktorja s prikolico za potrebe prevoza oljne ogrščice od polja do skladišča. Za potrebe prevoza je znašala celotna dovedena energija na hektar 1039,65 MJ/ha ali 19,4% neposredno dovedene energije za potrebe pridelave oljne ogrščice (preglednica 3).

Calculation of the transportation energy costs for an average field (5.2 ha) was based on ten movements of the tractor with implements and one movement of a combine harvester from the farmyard to the field and back, one movement of the tractor with a trailer for the transportation of the input materials to the field and six movements of the rapeseed yield by tractor with the trailer from the field to the storage facility. The total energy input in transport per hectare was 1039.65 MJ/ha, 19.4% of the direct energy inputs in the rapeseed production (Table 3).

Preglednica 3. *Neposredno dovedena energija za potrebe prevoza za povrečno polje na hektar*
Table 3. *Direct energy inputs in the transport for an average field and per hectare*

Mehanizacija Machinery	Celotna razdalja Total distance km	Povprečna hitrost Average speed km/h	Celotna poraba goriva Total fuel consumption L	Celotna dovedena energija Total energy input MJ	Dovedena energija na hektar Energy input per hectare MJ/ha
traktor + orodje tractor + implement	72,0	16,5	22,7	1085,06	208,67
traktor + prikolica tractor + trailer	268,8	19,2	82,6	3948,28	759,28
žetveni kombajn combine harvester	7,2	10,6	7,8	372,84	71,70
skupaj total			113,1	5406,18	1039,65

Poznamo ukrepe, s katerimi lahko prihranimo energijo, potrebno za kmetijski prevoz: primerna izbira traktorja in prikolice, njuno pravilno vzdrževanje, primeren način vožnje in dobro načrtovanje, s katerim lahko zmanjšamo število posameznih voženj. Pomembni so tudi še naslednji dejavniki: uporaba koncentriranih gnojil in pesticidov, odstranitev vlage iz materiala, ki ga prevažamo, odstranitev odpadkov, ki jih ni treba prevažati [19].

Posredno dovedeno energijo potrebno za mehanizacijo smo izračunali iz teže vse uporabljene mehanizacije, njene dobe trajanja in delovnega časa na hektar (preglednica 4), in je znašala 5,2% celotne dovedene energije. Največ dovedene energije je bilo potrebne za žetveni kombajn (41,8%) in za traktor (37,4%), medtem ko so vsi preostali stroji porabili le 20,8% energije za mehanizacijo. Uporaba velikih orodij je do neke mere pripomogla k večji izrabi goriva in manjšemu naporu kmetovalcev, vseeno pa so se stroški energije v tem primeru povečali [20]. Količino dovedene energije za potrebe kmetijske mehanizacije je zato mogoče zmanjšati le s primernim vzdrževanjem, s katerim dosežemo daljšo dobo trajanja strojev in povečamo površino, ki jo stroji letno obdelajo.

Preglednica 5 prikazuje vrednosti dovedene energije za potrebe gnojil, pesticidov in semen. Največ

Some measures to save energy in agricultural transportation could include the proper choice of tractor and trailer, their proper maintenance, good driving habits and good planning to reduce the number of trips. This is also important in relation to energy savings in transport, the use of concentrated fertilizers and pesticides, the removal of moisture from commodities and the elimination of residues that do not need to be transported [19].

The indirect energy input for machinery was calculated from the weight of the used machinery, its working life and the working time per hectare (Table 4), and it was found to be 5.2% of the total energy input. The largest energy input was for the combine harvester (41.8%) and the tractor (37.4%), while all the other machines used only 20.8% of the energy for the machinery. Using larger equipment provides a degree of improved fuel efficiency and reduced labor input, but in general, energy costs increase [20]. So, the energy input for farm machinery can be reduced by proper maintenance, for a longer working life of the machines, and a greater acreage on which it is used annually.

The energy inputs for fertilizers, pesticides and seeds are presented in Table 5. The major

Preglednica 4. *Dovedena energija za potrebe kmetijske mehanizacije*
Table 4. *Energy inputs for farm machinery*

Mehanizacija Machinery	Teža Weight kg	Doba trajanja Working life h	Dovedena energija Energy input MJ/h	Obratovalni čas Working time h/ha	Dovedena energija Energy input MJ/ha
traktor tractor	3980	12000	47,66	9,50	452,77
rigolni plug mouldboard plough	450	2000	32,33	3,13	101,19
kombajn za obdelovanje grede seedbed implement	980	2000	70,41	0,46	32,39
centrifugalni razdeljevalnik centrifugal distributor	250	1500	23,95	0,63	15,09
razpršilnik field sprayer	325	1500	31,14	0,46	14,32
kultivator field cultivator	375	2000	26,94	0,36	9,70
sejalni stroj planter	435	1500	41,67	0,93	38,75
žetveni kombajn combine harvester	11000	3000	526,90	0,96	505,82
prikolica trailer	1250	12000	14,97	2,69	40,27
skupaj total					1210,30

Preglednica 5. *Dovedena energija za potrebe gnojil, pesticidov in semen*
Table 5. *Energy inputs for fertilizers, pesticides and seeds*

Material	Uporabljena količina Application rate kg/h	Energijska vrednost Energy value MJ/kg	Dovedena energija Energy input MJ/ha
gnojila / fertilizers			
N gnojilo N fertilizer	138	78,1	10777,80
P_2O_5 gnojilo P_2O_5 fertilizer	117	17,4	2035,80
K_2O gnojilo K_2O fertilizer	176	13,7	2411,20
skupaj / total			15224,80
pesticidi / pesticides			
Devrinol	2,7	171,4	462,78
Triflurolex	1,5	171,4	257,10
skupaj / total			719,88
semena / seeds			
različica Bristol Bristol variety	4,6	200,0	920,00

posredno dovedene energije je bilo porabljene za gnojila, tj. 15224,80 MJ/ha (64,9% celotne dovedene energije) in največji delež te energije je bil potreben za dušikovo gnojilo (70,8% celotne energije za gnojila in 46,0% celotne dovedene energije). Glede na vir [20] je skoraj tretjina vse energije, porabljene v kmetijstvu, namenjena dušikovemu gnojilu. Menimo, da ni mogoče bistveno zmanjšati rabo gnojil, ker bi to vodilo do zmanjšanega pridelka [8]. Stroške energije za potrebe mineralnih gnojil bi lahko zmanjšali s povečano uporabo komposta ter trave in detelje pri kolobarjenju posevkov [21].

Vrednost dovedene energije, potrebne za pesticide, je znašala 719,88 MJ/ha, kar pomeni 3,1% celotne dovedene energije. Celotna energija, potrebna za pesticide, je manjša od drugih vrednosti dovedene energije, je pa vloga pesticidov zelo pomembna, saj bi bil pridelek močno poškodovan, če ne bi pravilno izvajali nadzora nad plevelom, škodljivci in boleznimi. Zato pri načrtovanju zaščite pridelkov zmanjšanje energije ne sme biti glavno vodilo, saj so okoljski in gospodarski vidiki v tem primeru bolj pomembni [22].

Dovedena energija, potrebna za sejanje semen, je bila 920 MJ/ha (uporabljena količina je bila 4,6 kg/h), kar je 3,9% celotne dovedene energije. V tem primeru ne moremo pričakovati kakršnegakoli znatnega zmanjšanja stroškov energije, saj je bila pri prejšnjih različicah oljne ogrščice uporabljena količina precej večja, 8 do 10 kg/h [23].

Energija, potrebna za delo kmetovalcev, pomeni neznaten del dovedene energije z deležem, ki je bil manjši od 0,1% celotne dovedene energije (preglednica 6).

indirect energy input was for fertilizers, 15224.80 MJ/ha (64.9% of total energy inputs), and the greatest part of this input was for nitrogen fertilizer (70.8% of fertilizers and 46.0% of total energy inputs). According to [20], nearly one-third of all the energy used in agriculture is for nitrogen fertilizer. However, a significant reduction in the use of fertilizers is not considered feasible as it would decrease production yields [8]. Reducing energy costs for mineral fertilizers could be possible with the increased utilization of manure and grass-clover crops as part of crop rotation [21].

The energy input for pesticides was 719.88 MJ/ha, which was 3.1% of the total energy input. The overall energy required for pesticides is lower than other inputs, although it is of great significance because the yield can be seriously affected if the control of weeds, pests and disease is not performed properly. Therefore, energy reduction is not the main factor to be taken into account in planning crop protection, because environmental and economic considerations are more important [22].

The energy input for seeds was 920 MJ/ha (the application rate was 4.6 kg/h), 3.9% of the total energy input. In this input, no significant reduction of energy costs could be expected, because earlier rapeseed varieties had much greater application rates, 8 to 10 kg/h [23].

Labor was an insignificant energy input, with less than 0.1% of the total (Table 6). The greatest part of labor was taken up by ploughing

Preglednica 6. *Dovedena energija za potrebe dela kmetovalcev pri pridelavi oljne ogrščice*
Table 6. *Energy inputs for labor in rapeseed production*

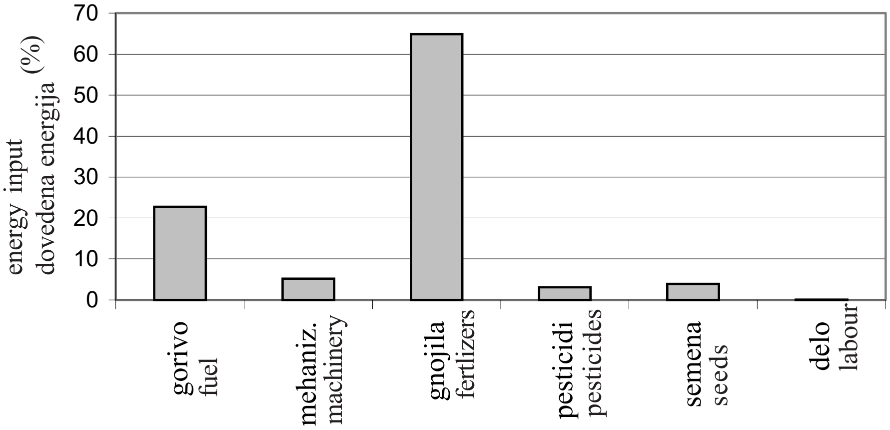
Opravila Operation	Delovni čas Working time h/ha	Dovedena energija Energy input MJ/ha
oranje ploughing	3,13	7,20
priprava semenskih gred seedbed preparation	0,46	1,06
uporaba gnojil-3 x fertilizer application-3 times	0,63	1,45
uporaba pesticidov -2 x pesticide application-2 times	0,46	1,06
vnos pesticidov pesticide incorporation	0,36	0,83
setev sowing	0,93	2,14
žetev harvesting	0,96	2,21
prevoz transport	2,69	6,18
skupaj total	9,62	22,13

Največ energije je bilo potrebne za oranje (32,5%) in prevoz (27,9%). Celotna posredno dovedena energija pri pridelavi oljne ogrščice je znašala 18.097,11 MJ/ha (enačba 3). Znesek celotne dovedene energije pri pridelavi oljne ogrščice pa je tako znašal 23.443,54 MJ/ha (enačba 1). Slika 1 kaže deleže posameznih vnosov energije.

Preglednica 7 prikazuje vso odvedeno energijo pri pridelavi oljne ogrščice. Povprečen pridelek vseh kmetij, dosežen v raziskovalnem obdobju, je bil 3.195 kg/ha (s 7,0% deležem vlage), kar je zelo dobro, saj je bil v istem obdobju povprečni pridelek oljne ogrščice na Hrvaškem 2.140 kg/ha [24].

(32.5%) and transport (27.9%). The total indirect energy input in rapeseed production was 18097.11 MJ/ha (Eq. 3). So, the total energy input in rapeseed production was 23443.54 MJ/ha (Eq. 1). Figure 1 shows the percentage of all the energy inputs.

The energy outputs in rapeseed production are presented in Table 7. The average yield of all the farms in the investigated period was 3195 kg/ha (with a 7.0% moisture content), which was very good, because the average yield of rapeseed in Croatia in the same period was 2140 kg/ha [24]. Some [25]



Sl. 1. *Dovedena energija pri pridelavi oljne ogrščice*
Fig. 1. *Energy inputs in rapeseed production*

Preglednica 7. *Odvedena energija pri pridelavi oljne ogrščice*
Table 7. *Energy outputs in rapeseed production*

Pridelek Item	Donos Yield kg/ha	Energijska vrednost Energy value MJ/kg	Odvedena energija Energy output MJ/ha
semena / seeds	3195		
olje / oil	1154	37,6	43390,40
krma / meal	2041	15,0	30615,00
skupaj / total			74005,40
odpadki / crop residues	5130	12,5	64125,00

Nekateri [25] menijo, da je povečanje pridelka mogoče, če uporabljamo nove hibride oljne ogrščice, ki so zdaj že na voljo. Povprečni delež olja v semenih je bil 42,5%, pri 85% ekstrakciji olja je ta pridelek vseboval 1.154 kg olja in 2.041 kg krme. Pri takšnem pridelku je celotna odvedena energija znašala 74.005,40 MJ/ha (4). Če odpadke pridelka oljne ogrščice obravnavamo kot energijo biomase, je njihova odvedena energija znašala 64.125 MJ/ha.

Če upoštevamo oboje, olje ogrščice, namenjeno proizvodnji biodizla, in krmo za živali, je energijsko razmerje pri pridelavi oljne ogrščice bilo 74.005,40/ 23.443,54 = 3,16 (5). Neto energijski prirastek pri pridelavi oljne ogrščice je bil 74.005,40 - 23.443,54 = 50.561,86 MJ/ha ali 50,56 GJ/ha (6). Energijska donosnost pri pridelavi oljne ogrščice za potrebe biodizla je bila 1.154/ 23,44 = 49,23 L/GJ (7). Te vrednosti energijske izravnave so zelo podobne evropskim povprečnim vrednostim [15], ki kažejo na energijsko razmerje 3,15 in neto energijski prirastek 49,27 GJ/ha pri pridelavi oljne ogrščice, pri čemer običajno v izračunu niso upoštevani odpadki pridelka. Vir [26] je poročal o neto energijskem prirastku 43,4 GJ/ha ter o razmerju med dovedeno in odvedeno energijo 2,8, ugotovljenem pri pridelavi oljne ogrščice, iz navedenega je sklepal, da v prihodnje biogoriva lahko obravnavamo kot pomembne vire obnovljive energije. V primerjavi z drugimi postopki proizvodnje goriva iz obnovljivih kmetijskih virov, oljna ogrščica ponuja dobro razmerje med dovedeno in odvedeno energijo in precejšen energijski donos. Glede na vir [27] je učinkovita raba energije tudi eden od pogojev za razvoj trajnostnega kmetijstva, saj omogoča denarne prihranke, ohranjanje fosilnih virov in zmanjšano onesnaževanje.

suggested that an increase in yield seems possible by using new rapeseed hybrids, which are now available. The average oil content in the seed was 42.5%, and with an extraction rate of 85%, this yield is made up of 1154 kg of oil and 2041 kg of meal. According to this yield, the total energy output was 74005.40 MJ/ha (Eq. 4). If we consider rapeseed crop residues as the biomass energy, their energy output was 64125 MJ/ha.

Considering the rapeseed oil for biodiesel and the meal for animal feed, the energy ratio of the rapeseed production was 74005.40/23443.54 = 3.16 (Eq 5). The net energy gain of the rapeseed production was 74005.40 - 23443.54 = 50561.86 MJ/ha, or 50.56 GJ/ha (Eq. 6). The energy productivity of the production of rapeseed oil for biodiesel was 1154/23.44 = 49.23 L/GJ (Eq. 7). These values of energy balance are very close to the average values for Europe [15]. They showed an energy ratio of 3.15 and a net energy gain of 49.27 GJ/ha in rapeseed production, normally without using crop residues in the calculation. Source [26] reported a net energy gain of 43.4 GJ/ha, and an energy output/input ratio of 2.8 in the production of rapeseed oil, and concluded that biofuels can be considered as an important source of renewable energy in the future. In comparison with other processes for fuel production from renewable agricultural resources, rapeseed oil gives a good output/input energy ratio and a substantial net energy gain. According to [27], efficient energy use is also one of the conditions for sustainable agriculture because it allows financial savings, the preservation of fossil-fuel resources and a reduction in air pollution.

3 SKLEP

Oljno ogrščico imamo lahko za primeren vir priprave biodizla na Hrvaškem, saj v primerjavi z energijo, potrebno za njeno pridelavo, omogoča

3 CONCLUSION

Rapeseed can be considered for biodiesel production in Croatia because it provides a positive energy return compared with the energy used to energijski donos. Ko smo raziskovali možnosti za uporabo oljne ogrščice za izdelavo biodizla in za krmo živali, je bilo energijsko razmerje pri pridelavi oljne ogrščice 3,16, neto energijski domos 50,56 GJ/ha in energijska donosnost 49,23 L/GJ. Večina dovedene energije je bila potrebna za rabo gnojil, 64,9%, ter za porabo goriva, 22,8%. Hkrati smo ugotovili, da je bil za delo kmetovalcev potreben le neznaten delež energije, tj. manj ko 0,1% celotne dovedene energije. Ker bi zmanjšanje uporabe gnojil povzročilo tudi zmanjšan pridelek, je treba najprej iskati možnosti varčevanja z dovedeno energijo pri porabi goriva, potrebnega za opravila na poljih, predvsem pri obdelovanju zemlje, in pri prevozu. Pridelava oljne ogrščice za proizvodnjo biodizla je hrvaškim kmetovalcem dobra zamenjava in lahko Hrvaški prinese gospodarske, okoljevarstvene in energijske koristi.

produce it. Considering rapeseed oil for biodiesel and meal for animal feed, the energy ratio of the rapeseed production was 3.16, the net energy gain was 50.56 GJ/ha, and the energy productivity was 49.23 L/GJ. The major energy inputs were fertilizers, with 64.9%, and fuel consumption, with 22.8% of the total energy input. On the other hand, labor was an insignificant energy input, with less than 0.1% of the total. Because the reduction of fertilizers would decrease production yields, the reduction of energy input might first be possible with regard to fuel consumption for field operations, especially in soil tillage and transport. The production of rapeseed oil for biodiesel can be a good alternative for Croatian farmers and can have economic, environmental and energy benefits for Croatia.

4 VIRI
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