

Article

Not peer-reviewed version

---

# The energy and environmental evaluation of maize, hemp and faba bean multi-crops

---

[Kęstutis Romaneckas](#)\*, [Austėja Švereikaitė](#), [Rasa Kimbirauskienė](#), [Aušra Sinkevičienė](#), [Jovita Balandaitė](#)

Posted Date: 24 August 2023

doi: 10.20944/preprints202308.1680.v1

Keywords: Zea mays L.; Cannabis sativa L.; Vicia faba L.; multi-cultivations; energy indices; CO2 eq



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article

# The energy and Environmental Evaluation of Maize, Hemp and Faba Bean Multi-Crops

Kęstutis Romaneckas \*, Austėja Švereikaitė, Rasa Kimbirauskienė, Aušra Sinkevičienė and Jovita Balandaite

Department of Agroecosystems and Soil Sciences, Agriculture Academy, Vytautas Magnus

University, Studentu Str. 11, Akademija LT-53361, Kaunas distr., Lithuania; jovita.balandaite@vdu.lt (J.B.); austėja.svereikaite@stud.vdu.lt (A.Š.); rasa.kimbirauskiene@vdu.lt (R.K.); ausra.sinkevicienne@vdu.lt (A.S.)

\* Correspondence: kestitis.romaneckas@vdu.lt; Tel.: +370-656-300-44

**Abstract:** Agriculture uses a lot of fuel, fertilizers, pesticides and other substances, while emitting large amounts of GHGs. It is important to optimize these inputs and outputs. One such way is increasing crop biodiversity. For this reason, single crops and mixtures of maize, hemp and faba bean as binary and ternary crops were investigated at the Experimental Station of Vytautas Magnus University, Lithuania. Results showed that consumption of diesel fuel was by the 31–46% higher than in single and 22–35% higher than in binary cultivations was found in a ternary crop. This influenced on the highest energy input or near twice higher than in maize and hemp single crops and maize+hemp binary crop, but similar with binary crops with faba bean. Despite this, the productivity of the trinary crop and, at the same time, the energy output were 2–5 times higher than in other treatments. This compensated for higher energy inputs and the energy efficiency ratio. In ternary crop, energy productivity was from 1.1 to 2.8 times higher and net energy was by 1.9–5.3 times higher than in other tested cultivations. The highest total GHG emissions were obtained in binary maize+hemp and maize+faba bean cultivations (1729.84 and 2067.33 CO<sub>2eq</sub> ha<sup>-1</sup>). Ternary cultivation with the highest energy inputs initiated average GHG emission—1541.90 kg ha<sup>-1</sup> CO<sub>2eq</sub>. For higher efficiency, ternary crop could be sown and harvested in one machine pass. Faba beans should be included in the ternary crops, as their biomass takes a significant part of the total biomass produced. We recommend to review the inter-cropped faba bean seeding rates as faba bean seeds have a high energy input equivalent.

**Keywords:** *Zea mays* L.; *Cannabis sativa* L.; *Vicia faba* L.; multi-cultivations; energy indices; CO<sub>2eq</sub>

## 1. Introduction

Currently, high population growth and high demand for food and energy, especially produced from renewable resources (for example, biomass) [1].

Maize is a crop with a high potential for biomass production. Today, maize is one of the most important and productive crops in the world, with more than 206 million hectares being cultivated in 2021. In the USA, ethanol extracted from maize is mixed with standard fuel and the final product contains 10% of ethanol. They can be used for the production of feed, biofuels, synthetic plastics, chemical compounds, etc. [2,3]. The aim is to reduce the use of fossil fuels and regulate greenhouse gas emissions [4]. However, this fuel does not provide a significant amount of energy compared to the energy produced from sugar cane [5].

Faba beans are widely grown around the World. According to FAO data, faba beans were grown over 2.7 million hectares worldwide in 2021, and over 473 thousand hectares in Europe. The faba beans are mainly used for food, animal feed and soil improvement, but they can be used for energy purposes by converting biomass into pellets and using them as medium to low-power boilers [6].

Industrial hemp—it is great technical crop. Their ability to produce high biomass yields with relatively low water content is one of the main advantages. Industrial hemp is valuable for its high energy and biomass yield per hectare [7]. It is claimed that hemp can be used for energy production as a fuel source that does not emit sulphur either by direct combustion or by liquefying fuels such as

bioethanol. Hemp oil is produced as a renewable biofuel because it emits less carbon monoxide when burned, thus helping to reduce global warming. It is important to emphasize that biomass by-products (straw and shivers) are a good raw material for energy production [8].

Multi-crops are a type of crop cultivations, where several species of plants are grown at the same place and time. Multi-crops ensure sustainable farming and increase crop productivity per unit area [9]. Multi-crops can increase biodiversity, reduce the damage caused by diseases, pests and weeds, reduce the need for mineral fertilizers and maintain soil fertility and quality, easier for plants to grow under adverse conditions [10]. Biomass plants are classified as renewable sources and their cultivation is very courageous, as the European Union wants to increase the energy supply from alternative sources by 2030 (up to 45%). However, despite the enormous hidden potential in this area, the cultivation of inter-crops has still not been sufficiently studied [11]. It is important to understand that the number of plants that can be cultivated as multi-crops is quite large and all crops have a different function and their benefits are not the same. In order to achieve the maximum harvest result, the advantages of each multilayer plant must be exploited [12].

Agro-technological operations have a significant impact on energy consumption and environmental pollution. Tillage technologies are one of the most important, but at the same time the most energy-intensive and expensive technological operations [13]. Reversible tillage technologies consume between 29 and 59% of total diesel fuel in technological process [14,15].

Fertilizers production and use account for the majority of energy expenditure (about 50%) in field crop production in Europe [16]. The production of nitrogen fertilizers is a particularly energy-intensive process, compared to the production of phosphorus and potassium fertilizers, about 10 times more energy is consumed [17]. Ghazvineh et al. [18] found that in maize cultivation, the total energy consumption and output were 50.485 and 134.946 MJ ha<sup>-1</sup>, respectively. Nitrogen fertilizers, electricity and diesel fuel consume the largest part of energy with 35.25 and 20 percent, respectively. In barley production systems, the total energy input and output was 12416.62 and 43656.25 MJha<sup>-1</sup>. The most energy consumed was diesel fuel energy (52.4%), nitrogen fertilizers (16.2%) and seed (23%). 3.51 and 0.11 KgMJ<sup>-1</sup> in energy efficiency and energy productivity of this agroecosystem. In wheat systems, total energy input was 14255.05 MJha<sup>-1</sup>, total energy output—56161.7 MJha<sup>-1</sup>. The biggest part of wheat made up the total energy input nitrogen fertilizers (31.8%), seed (27.2%) and diesel fuel energy (31.6%). In hemp systems, it was 17,945 MJha<sup>-1</sup> for the total energy input.

There is still no formal agreement on a methodology for calculating greenhouse gas (GHG) emissions from crop production systems. The authors conclude that further research and development is still needed to improve crop production sustainability [19]. It is argued that the large number of units used to measure agricultural inputs makes it very difficult to compare carbon inputs. Points out that it is useful to convert different units of measurement into carbon dioxide emissions for agricultural activities [20].

Agriculture's direct contribution to GHG are estimated to be 10–15% of total anthropogenic GHG emissions which non-CO<sub>2</sub> anthropogenic GHG emissions consist of 48%. Sustainable agriculture, which reduces greenhouse gas (GHG) emissions, can contribute to climate change mitigation [21]. Also in organic agriculture, in contrast to traditional farming, is associated with a lower average of GHG emissions per hectare [22]. Bručienė et al. [23] pointed that in organic agriculture the most important factor in controlling GHG emissions is reducing the use of organic fertilizers and diesel fuel.

The aim of our study was to evaluate the biomass production capacities of differently biodiversed multi-crops, to analyse the possible for these technologies machinery, to evaluate the inputs of energy for main materials, fuels, working time and biomass energy outputs, to ascertain the impact of technologies on the GHG emissions according CO<sub>2</sub> equivalent. We hypothesize that cultivation of a ternary crop will not only produce more plant biomass, but will also use energy more efficiently, and GHG emissions will not be the highest.

## 2. Materials and Methods

### 2.1. Experimental Site

A short-term stationary field experiment was performed in 2020–2022 at the Vytautas Magnus University, Agriculture Academy, Experimental station (54°52' N, 23°49' E). In this study, data of crops biomass from 2020 is presented because the yield was the highest and the most suitable for fuel production in comparison with continue cropping in 2021 and 2022.

The soil of the experimental field is a deeper gleyic saturated loam (45.6% sand, 41.7% silt, 12.7% clay) Planosol (Endohypogleyic-Eutric, *Plu-gln-w* [24]. Soil pH<sub>HCl</sub> varies from 7.3 to 7.8; total nitrogen content, 0.08 to 0.13%; humus, 1.5 to 1.7%; available phosphorus, 189 to 280 mg·kg<sup>-1</sup>; available potassium, 97 to 118 mg·kg<sup>-1</sup>; available sulphur, 1.2 to 2.6 mg·kg<sup>-1</sup>; and exchangeable magnesium, 436 to 790 mg kg<sup>-1</sup>.

Lithuania is in a zone of surplus moisture. In the experimental site, the annual average precipitation rate varies from 600 to 650 mm or approx. 300–400 mm of precipitation per vegetative season. According to the climatic norm, the coldest month is January, and the warmest and the most humid is July. In nova days, January became much soft, negatives temperatures are recorded less often. In July, droughts occur more and more often, and the peak of precipitation moves to the beginning of August. In 2020 vegetative season, average air temperatures were the same as long-term average, but rainfall was 10 times less. May was colder, but with surplus humidity (Table 1). June was warmer than usually, but precipitation rate was approximately 30% higher than long-term climatic rate.

**Table 1.** Average air temperatures and precipitation rates. Kaunas Meteorological Station, 2020.

Months	Average Air Temperatures °C		Precipitation Rates mm	
	Monthly	Long-Term	Monthly	Long-Term
April	6.9	6.9	4.0	41.3
May	10.5	13.2	94.4	61.7
June	19.0	16.1	99.3	76.9
July	17.4	18.7	60.4	96.6
August	18.7	17.3	92.8	88.9

July was colder than average and slightly arid, but August was warmer and little more humid. In summary, it can be said that the vegetation conditions of the year were favourable for crop development, as moisture was usually sufficient.

### 2.2. Treatments and Agronomic Practice

Maize (*Zea mays* L., Pioneer hybrid P8105), hemp (*Cannabis sativa* L., cultivar Austa SK) and faba bean (*Vicia faba* L., cultivar Vertigo) were grown in the experiment as three types of cultivations: single, binary and ternary (Table 2).

**Table 2.** Crop bio-diversity [6].

Treatments	Cultivation	Abbreviation
single crop	maize	MA
	hemp	HE
	faba bean	FB
binary crop	maize + hemp	MA+HE
	maize + faba bean	MA+FB
	hemp + faba bean	HE+FB
ternary crop	maize + hemp + faba bean	MA+HE+FB

An experiment was performed with three replications. 21 experimental plots (the size was 8 m<sup>2</sup>). In 2019, the pre-crop of multi-cultivations was oat. In 2021–2022, cultivations were grown continuously.

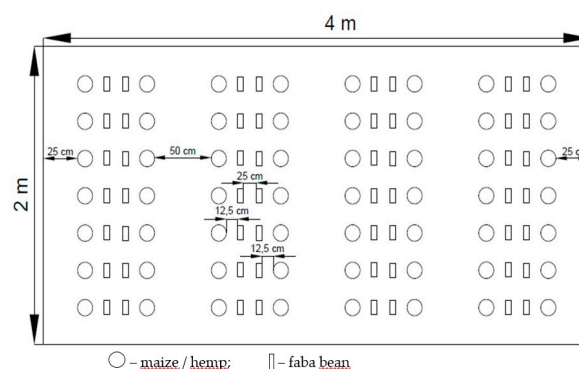
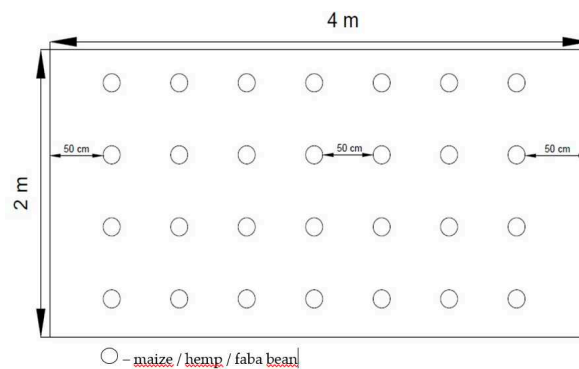
In 2019 autumn, disc-cultivated and ploughed (Table 3). In spring 2020, and cultivated in spring before sowing. In April, before seeding, the soil of experiment was shallowly tilled. Before the sprouting of crop, plots were fertilized with NPK 15:15:15 (300 kg·ha<sup>-1</sup>). There were used no more fertilizers.

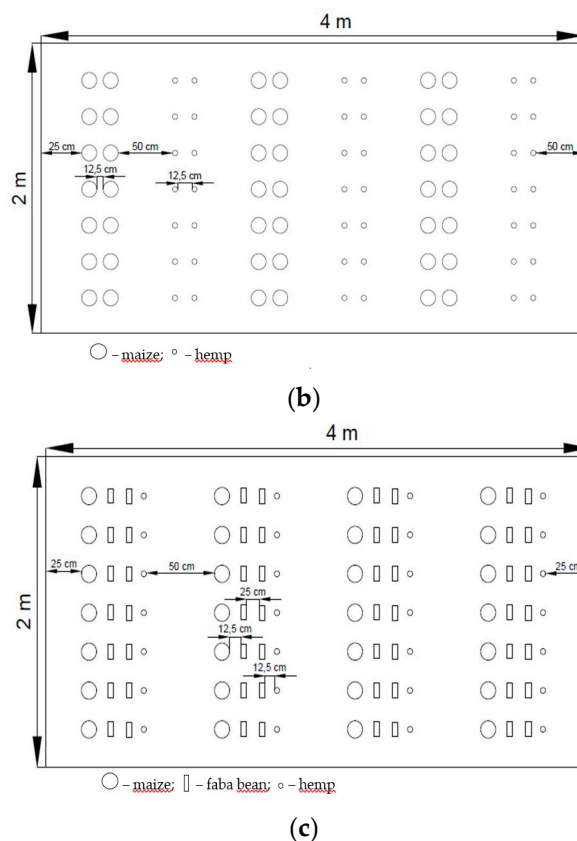
**Table 3.** Single and multi-cropping technological operations.

Technological operation (machinery/depth/material rate)/Treatments	M	H	FB	M+H	M+FB	H+FB	M+H+FB
Stubble cultivation (depth 12–15 cm)	o	o	o	o	o	o	o
Deep ploughing	o	o	o	o	o	o	o
Pre-seeding cultivation	o	o	o	o	o	o	o
Fertilization (N <sub>45</sub> P <sub>45</sub> K <sub>45</sub> kg ha <sup>-1</sup> )	o	o	o	o	o	o	o
One-pass conventional seeding of single crops	o	o	o	-	-	-	-
One-pass double seeding for binary crops	-	-	-	o	o	o	-
Two-passes ternary seeding	-	-	-	-	-	-	o
Inter-row loosening (2–3 cm depth)	oo	oo	oo	oo	oo	oo	o
One-pass biomass harvesting (low harvester load)	o	-	o	-	o	-	-
One-pass biomass harvesting (high harvester load)	-	o	-	o	-	o	-
Two-passes biomass harvesting (high harvester load)	-	-	-	-	-	-	o

Notes: M—maize, H—hemp, FB—faba bean, M+H—maize + hemp, M+FB—maize + faba bean, H + FB—hemp + faba bean, M + H + FB—maize + hemp + faba bean. o—operation performed once, oo—the operation was performed twice.

The experiment more closely followed the model conditions, so the crops were sown manually according to predetermined schemes. Sowing schemes are shown in Figure 1.





**Figure 1.** The seeding schemes of single (a), binary (b) and ternary (c) cultivations [6].

According to the schemes of seeding, the seed rates are presented in Table 4. The idea of experiment was to increase usual seeding rates for more rapid weed control and higher potential of biomass production. For better balance of energy inputs, seeding rates could be decreased, especially faba bean.

**Table 4.** Seeding rates ( $\text{kg ha}^{-1}$ ) of differently biodiversed cultivations.

Crop/Treatments	M	H	FB	M+H	M+FB	H+FB	M+H+FB
Maize yield	63.5	-	-	68.8	90.7	-	36.2
Hemp yield	-	22.3	-	14.9	-	21.0	13.7
Faba bean yield	-	-	362.9	-	397.9	369.4	375.8

For the energy and environmental evaluation, we selected machinery that are mostly used in agriculture in Lithuania. The inter-rows of crops were loosened 1–2 times. No pesticides were used. In experiment, crops biomass production was harvested by hands after a short 103-days vegetative season. At that time, faba bean have been reached full maturity. The biomass of maize and hemp had not yet reached its maximum, but there is a lack of plant biomass for fuel production in Lithuania in August.

In our calculations of energy and environmental evaluation of multi-cropping agrotechnologies, we used the data normative of agricultural machinery from Lithuanian Institute of Economics and Rural Development [25,26]. For calculations we used field size as 2–10 ha. Tractors power varied from 45–102 kW, power of biomass harvester was 250 kW (Table 5). The data of mechanical seeders are given in the calculations, when about  $200 \text{ kg ha}^{-1}$  of seeds are sown. Double sowing is carried out with a combined sowing machine, in which separate seed boxes or the sowing unit of the one next to it could be installed. For sowing in two passes, we have provided both of the previously mentioned seeders. Of course, a ternary crop seeder can be made to seed such a crop in one pass. Then the energy and environmental calculations would change.

**Table 5.** Technical indicators of single and multi-cropping operations.

Technological operation	Machinery power (kW)	Working width (m)	Field capacity (ha h <sup>-1</sup> )	Working time (h ha <sup>-1</sup> )	Fuel consumption (L ha <sup>-1</sup> )
Stubble cultivation-discing	102	4.00	2.21	0.45	8.2
Deep ploughing	102	1.75	0.80	1.25	24.1
Pre-sowing cultivation	102	7.00	4.56	0.22	6.4
One-pass conventional seeding (single crop)	45	3.00	1.41	0.71	4.0
One-pass double seeding (binary crop)	67	3.00	1.31	0.76	9.8
Two-passes seeding (ternary crop)	45 and 67	3.00	0.68	1.47	13.8
Fertilization	67	14.00	16.55	0.06	0.6
Inter-row loosening	54	3.00	1.56	0.64	4.10
One-pass biomass harvesting (low harvester load)	250	3.00	1.82	0.55	19.19
One-pass biomass harvesting (high harvester load)	250	3.00	1.37	0.73	27.55
Two-passes biomass harvesting	250	3.00	0.68	1.47	46.74

We chose 6-furrow biomass harvesters. Single and binary crops without hemp are classified as low harvester load. For difficult conditions, we classified single and binary crops with hemp. Biomass harvesting in two passes is provided in ternary crops, in which the upper juicier part of the biomass is cut first, and the more woody lower part is cut in the second pass.

### 2.3. Methodology

For crop biomass productivity assessment, plants were cut in a row of 1 m length with at least in 5 spots per plot. Samples for each species of plant were taken separately, so a total of 36 samples were formed. Biomass was dried at a temperature of 105 °C to absolutely dry humidity. The results of dried biomass are presented in this study.

A biomass chemical composition was tested in the laboratories of Lithuanian Research Centre for Agriculture and Forestry in Kaunas, Lithuania (Table 6). We would like to show that biomass of crops is rich in elements important for biofuel production and plant nutrition (as pellets or ash). We took advantage of these features by registering patents for the production of solid biofuel from faba bean residues and ternary crop biomass at the Lithuanian National Patent Office [27,28].

**Table 6.** Biomass chemical composition.

Biomass chemical composition	M	H	FB	M+H	M+FB	H+FB	M+H+FB
pH	6.51	7.07	6.63	6.66	6.43	7.09	6.87
Total nitrogen %	0.92	0.64	2.12	0.84	1.48	1.22	0.98
Available phosphorus %	0.20	0.16	0.38	0.20	0.32	0.28	0.22
Available potassium %	1.20	0.76	0.78	0.98	1.04	0.98	0.87

Note: M—maize, H—hemp, FB—faba bean, M+H—maize + hemp, M+FB—maize + faba bean, H + FB—hemp + faba bean, M + H + FB—maize + hemp + faba bean.

Equivalents of energy inputs and outputs in single and multi-crops biomass production are presented in Table 7.

**Table 7.** Energy equivalents in crops biomass production systems.

Indices	Energy equivalent	Reference
<b>Inputs:</b>		
Human labour (MJ h <sup>-1</sup> )	1.96	[29]
Diesel fuel (MJ L <sup>-1</sup> )	56.3	[29]
Agricultural machinery (MJ h <sup>-1</sup> )	357.2	[30]
Seed of maize (MJ kg <sup>-1</sup> )	16.6	[29]
Seed of hemp (MJ kg <sup>-1</sup> )	25.0	Todde et al., 2022 [31]

Seed of faba bean (MJ kg <sup>-1</sup> )	21.0	Kazemi et al., 2015 [32]
N (MJ kg <sup>-1</sup> )	60.6	[29]
P <sub>2</sub> O <sub>5</sub> (MJ kg <sup>-1</sup> )	11.1	[29]
K <sub>2</sub> O (MJ kg <sup>-1</sup> )	6.7	[29]
<b>Outputs:</b>		
Maize biomass (MJ kg <sup>-1</sup> dry matter)	17.7	[33]
Hemp biomass (MJ kg <sup>-1</sup> dry matter)	16.6	[34]
Faba bean biomass (MJ kg <sup>-1</sup> dry matter)	17.0	[35]

The energy ratio (energy use efficiency), energy productivity, net energy were calculated based on the energy equivalents of technological inputs and outputs [30,36]:

$$\text{Energy output (MJ ha}^{-1}\text{)} = \text{Dried biomass yield (kg ha}^{-1}\text{)} \cdot \text{Energy equivalent (MJ kg}^{-1}\text{)} \quad (1)$$

$$\text{Energy efficiency ratio} = \text{Energy output (MJ ha}^{-1}\text{)} / \text{Energy input (MJ ha}^{-1}\text{)} \quad (2)$$

$$\text{Energy productivity (kg MJ}^{-1}\text{)} = \text{Biomass yield (kg ha}^{-1}\text{)} / \text{Energy input (MJ ha}^{-1}\text{)} \quad (3)$$

$$\text{Net energy} = \text{Energy output (MJ ha}^{-1}\text{)} - \text{Energy input (MJ ha}^{-1}\text{)} \quad (4)$$

All agricultural technological operations, machinery and materials can be evaluated as environmental impact by CO<sub>2</sub> equivalent (Table 8).

**Table 8.** CO<sub>2</sub> equivalents in crops biomass production systems (according Šarauskis et al. [30]).

Inputs	CO <sub>2</sub> equivalent	Reference
Diesel fuel (kg CO <sub>2eq</sub> l <sup>-1</sup> )	2.76	[37]
Agricultural machinery (kg CO <sub>2eq</sub> MJ <sup>-1</sup> )	0.071	[38]
Seed of maize (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	15.3	[39]
Seed of hemp (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	18.7	[40]
Seed of faba bean (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	0.99	[41]
N (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	1.30	[20]
P <sub>2</sub> O <sub>5</sub> (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	0.20	[20]
K <sub>2</sub> O (kg CO <sub>2eq</sub> kg <sup>-1</sup> )	0.15	[20]

In our study, we calculated the conditional GHG emission of fuel, machinery, sowing material and mineral fertilizers according to equation 5 [23]:

$$\text{GHG emission (kg CO} _{2eq} \text{ ha}^{-1}\text{)} = \text{Agro-technological inputs} \cdot \text{CO} _{2} \text{ equivalents (kg CO} _{2eq} \text{ unit}^{-1}\text{)} \quad (5)$$

An experimental data were analysed using one-factor analysis of variance (ANOVA) from the statistical software SELEKCIJA (vers. 5.00, author dr. Pavelas Tarakanovas, Lithuanian Institute of Agriculture, Akademija, Kedainiu distr., Lithuania). The significance of differences between treatments was estimated by the least significant difference (LSD) test. Lower-case letters mean significant differences between treatments at  $p \leq 0.05$ .

### 3. Results and Discussion

#### 3.1. Energy Inputs

Energy is an important driver of development, but it is particularly influential in the agricultural sector, as agriculture is both a consumer and a producer of energy [42]. Complex mechanized technological processes such as tillage, sowing or harvesting are widely used in agriculture and have a significant impact on energy consumption [30].

An energy input-output analysis was performed to compare the efficiency of maize, hemp, faba bean production under different multi-cropping systems. The energy inputs for maize, hemp, faba bean multi-crops were calculated based on the mechanized operations and agricultural machinery used, working time, fuel consumption, the sowing of seeds and the application of fertilization. After the maize, hemp, faba bean crop biomass production, energy outputs were determined and recalculated per hectare. Energy inputs and outputs were assessed separately for each maize, hemp and faba bean production treatment (Table 9).

**Table 9.** Energy inputs of technological operations and materials in crop biomass production systems, MJ ha<sup>-1</sup>.

Inputs	M	H	FB	M+H	M+FB	H+FB	M+H+FB
Human labour	8.8	9.2	8.8	9.4	9.0	9.4	11.0
Diesel fuel	3980.4	4447.7	3980.4	4774.2	4307.0	4774.2	5815.8
Agricultural machinery	1607.4	1678.8	1607.4	1714.6	1643.1	1714.6	2000.3
Seed of maize	1054.1	-	-	1142.1	1505.6	-	600.9
Seed of hemp	-	512.9	-	342.7	-	483.0	315.1
Seed of faba bean	-	-	7620.9	-	8355.9	7757.4	7891.8
N	2727.0	2727.0	2727.0	2727.0	2727.0	2727.0	2727.0
P <sub>2</sub> O <sub>5</sub>	499.5	499.5	499.5	499.5	499.5	499.5	499.5
K <sub>2</sub> O	301.5	301.5	301.5	301.5	301.5	301.5	301.5
<b>Total energy input</b>	<b>10178.7</b>	<b>10176.6</b>	<b>16745.5</b>	<b>11511.0</b>	<b>19348.6</b>	<b>18266.6</b>	<b>20162.9</b>

Note: M—maize, H—hemp, FB—faba bean, M+H—maize + hemp, M+FB—maize + faba bean, H + FB—hemp + faba bean, M + H + FB—maize + hemp + faba bean.

Analysing the indicators of multi-cropping and other technological operations presented in Table 9, it was found that the lowest labour capacity was for the maize single crop (8.8 MJ ha<sup>-1</sup>) and faba bean (8.8 MJ ha<sup>-1</sup>). The highest capacity was for the ternary crop (11.0 MJ ha<sup>-1</sup>) because of wider agro-technological operations.

Biodiesel has been gaining growing importance in terms of environment and energy. Other researchers have obtained opposite trends in the high labour and fuel costs of growing bean crops [30]. Biodiesel can be produced of processed vegetable oils from different feedstock like sunflower oil [43], rapeseed oil [44,45], soybean oil [46,47], palm oil [48] and hemp (Table 9).

In our experiment, the highest fuel consumption is obtained when growing ternary crop (5815.8 MJ ha<sup>-1</sup>), and the lowest—in single maize (3980.4 MJ ha<sup>-1</sup>) and faba bean (3980.4 MJ ha<sup>-1</sup>). Ali et al. [49] stated that the most energy consumption of diesel fuel accounted for about 54% of the total energy used for single faba bean cultivation.

Similar trends have been identified in agricultural machinery as well as in diesel fuel. The most intensive use of agricultural technique was found in the ternary (M+H+FB) crop (2000.3 MJ ha<sup>-1</sup>). Compared to other crops, it was by 14.3 to 19.6% higher (Table 9).

Maize (600.9 MJ ha<sup>-1</sup>) and hemp (315.1 MJ ha<sup>-1</sup>) seeds were the lowest in the ternary crop (M+H+FB) compared to other crops. The highest amount of energy from seed of maize (1505.6 MJ ha<sup>-1</sup>) was determined in the binary (M+FP) crop, and seed of hemp (512.9 MJ ha<sup>-1</sup>), in the single (H) crop. Seed of faba bean (8355.9 MJ ha<sup>-1</sup>) had the highest amount of energy input in the binary (M+FB) crop, and the lowest (7620.9 MJ ha<sup>-1</sup>)—in the single (FB) crop compared to other crops.

Fertilizer use has increased exponentially worldwide over the past few decades. The intensive use of mineral fertilizers and the use of conventional methods of fertilization have a negative impact on the soil, the environment and human health [50]. In our experiment, the highest amount of energy input (2727.0 MJ ha<sup>-1</sup>) was determined for N fertilizer, while the lowest (301.5 MJ ha<sup>-1</sup>) was calculated for K<sub>2</sub>O fertilizer (Table 9).

The total energy consumption is the highest (20162.9 MJ ha<sup>-1</sup>) in the ternary crop (M+H+FB), and the lowest (10176.6 MJ ha<sup>-1</sup>) in the single crop (H) (Table 9). In ternary crop (M+H+FB) the most energy was used, because more human labour is added, more diesel fuel is consumed and agricultural

machinery is used several times. This is because single crop require much less energy than other multi-cultivations [51].

### 3.2. Biomass Yields

Maize and hemp biomass is the main resources for biofuel production [52–54]. The highest biomass of maize was grown in single cultivation—4461 kg ha<sup>-1</sup> and the lowest one—in ternary crop (1358 kg ha<sup>-1</sup>) (Table 10) because maize crop density in ternary crop was more than twice less (about 134 thousand plants per ha) according to the seeding scheme. Maize with faba bean inter-crop produced second higher yield of biomass—3519 kg ha<sup>-1</sup>. According findings of other scientists, maize mix with *Fabaceae* crops warranted higher maize yields [55], but we found the converse conclusions [56].

**Table 10.** Single and multi-crops dried biomass yields.

Biomass yields and composition	M	H	FB	M+H	M+FB	H+FB	M+H+FB
Total yield kg ha <sup>-1</sup>	4461c	9038bc	9811bc	12197b	7787bc	10974b	22928a
Proportion of biomass components	-	-	-	1:4.1	1:1.2	1:0.2	1:5.3:10.6
<b>Yields of separate components kg ha<sup>-1</sup>:</b>							
Maize yield	-	-	-	2373	3519	-	1358
Hemp yield	-	-	-	9824	-	8710	7239
Faba bean yield	-	-	-	-	4268	2264	14331

Notes: M—maize, H—hemp, FB—faba bean, M+H—maize + hemp, M+FB—maize + faba bean, H + FB—hemp + faba bean, M + H + FB—maize + hemp + faba bean. Different letters (a, b, c) mean significant difference between treatments at  $p \leq 0.05$ .

The highest dried hemp biomass was in the binary hemp and maize crop (9824 kg ha<sup>-1</sup>) and the lowest one was in the ternary crop (7239 kg ha<sup>-1</sup>).

Faba bean as companion of maize and hemp in ternary crop showed the best results (14331 kg ha<sup>-1</sup> of dried biomass) although the density of the faba bean crop in the crops of different diversification varied little—from 560 to 614 thousand plants per hectare. In addition, the hemp and maize crops densities were the lowest one in ternary cultivation. Faba bean less interact with rarer crops. Similarly, Ewansiha et al. [57] concluded that reducing the maize shade increases the productivity of inter-crops.

The significantly highest total dried biomass of crops was found of ternary crop—22,928 kg ha<sup>-1</sup> or 2–5 times higher than it other tested single and binary cultivations (Table 10)

### 3.3. Fuel Consumption and Energy Indices

Diesel fuel consumption, energy input, energy output, energy efficiency, energy productivity, net energy of the various mechanised technological operations for tillage, sowing, fertilising and harvesting are presented in Table 11.

**Table 11.** Fuel consumption and energy indices of single and multi-crops biomass production systems.

Treatments	Diesel fuel consumption L ha <sup>-1</sup>	Energy input MJ ha <sup>-1</sup>	Energy output MJ ha <sup>-1</sup>	Energy efficiency ratio	Energy productivity MJ ha <sup>-1</sup>	Net energy MJ ha <sup>-1</sup>
M	70.7	10178.7	78959.7	7.76	0.44	68781.0
H	79.0	10176.6	150030.8	14.74	0.89	139854.2
FB	70.7	16745.5	166787.0	9.96	0.59	150041.5
M+H	84.8	11511.0	205080.5	17.82	1.06	193569.5
M+FB	76.5	19348.6	134842.3	6.97	0.40	115493.7
H+FB	84.8	18266.6	183074.0	10.02	0.60	164807.4



P <sub>2</sub> O <sub>5</sub> (kg CO <sub>2eq</sub> ha <sup>-1</sup> )	9.0	9.0	9.0	9.0	9.0	9.0	9.0
K <sub>2</sub> O (kg CO <sub>2eq</sub> ha <sup>-1</sup> )	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Total GHG emission (kg CO <sub>2eq</sub> ha <sup>-1</sup> )	<b>1241.32</b>	<b>709.63</b>	<b>629.02</b>	<b>1729.84</b>	<b>2067.33</b>	<b>1067.04</b>	<b>1541.90</b>

Note: M—maize, H—hemp, FB—faba bean, M+H—maize + hemp, M+FB—maize + faba bean, H + FB—hemp + faba bean, M + H + FB—maize + hemp + faba bean .

The highest amount of CO<sub>2eq</sub> ha<sup>-1</sup> from diesel fuel was obtained in the cultivation of ternary M+H+FB crop (285.1 kg CO<sub>2eq</sub> ha<sup>-1</sup>), and the lowest in single maize (M) and faba bean FB—195.1 kg CO<sub>2eq</sub> ha<sup>-1</sup> because diesel consumption was 1.2 to 1.5 times higher. Pishgar-Komleh et al. [61] estimated that the total GHG emissions from cucumber production were 82,724 kg CO<sub>2eq</sub> ha<sup>-1</sup>, with the highest emissions from diesel (61%), electricity (19%), and manure (14%).

The same trends remained in agricultural machinery. In the ternary crop, CO<sub>2eq</sub> of agricultural machinery was to be 1.3 times higher compared to other cultivations. Seeds of maize (553.9 kg CO<sub>2eq</sub> ha<sup>-1</sup>) and hemp (256.2 CO<sub>2eq</sub> ha<sup>-1</sup>) had the lowest emissions in the ternary M+H+FB crop compared to other crops. Maize seeds (1387.7 CO<sub>2eq</sub> kg<sup>-1</sup>) had the highest amount of CO<sub>2eq</sub> in the binary M+FP crop, and hemp seeds (417.0 kg CO<sub>2eq</sub> ha<sup>-1</sup>)—in the single hemp crop. Seeds of faba bean (393.9 kg CO<sub>2eq</sub> kg<sup>-1</sup>) had the highest amount of CO<sub>2eq</sub> in the binary (M+FB) crop, and the lowest (359.3 kg CO<sub>2eq</sub> ha<sup>-1</sup>)—in the faba bean single crop compared to other crops.

The same amount of fertilizers was used. So the CO<sub>2eq</sub> was the same in all tested cultivations. Higher fertilizer rates are associated with higher greenhouse gas emissions [70]. In our study, we found that N fertilizer released the highest amount of 58.5 kg CO<sub>2eq</sub> ha<sup>-1</sup>, and K<sub>2</sub>O fertilizer released the lowest amount of 6.85 kg CO<sub>2eq</sub> kg<sup>-1</sup>. In terms of GHG emission CO<sub>2eq</sub> ha<sup>-1</sup>, the best indicators were shown by the single faba bean crop. Faba beans also play an important role in crop rotation due to the ability to biologically capture nitrogen (N). Therefore, beans are classified as efficient nitrogen sources [71].

The lowest total GHG emissions were calculated in single faba bean and single hemp crops (629.02 and 709.63 CO<sub>2eq</sub> ha<sup>-1</sup>) (Table 12). The highest ones were obtained in binary M+H and M+FB cultivations (1729.84 and 2067.33 CO<sub>2eq</sub> ha<sup>-1</sup>). Carraretto et al. [40] having assessed the technological operations of mechanized maize cultivation technologies on the basis we would come to the conclusion that the emissions of CO<sub>2</sub> into the environment related with all technologies would be reduced about five times. Alimagham et al. [68] investigated the GHG emissions of faba bean. Cultivation and found that the total GHG emissions ranged from 1265.1 kg CO<sub>2eq</sub> ha<sup>-1</sup> to 2969.2 kg CO<sub>2eq</sub> ha<sup>-1</sup>. In our experiment, ternary cultivation with the highest energy inputs conducted average CO<sub>2eq</sub>—1541.90 kg ha<sup>-1</sup>.

#### 4. Conclusions

The highest consumption of diesel fuel was found in a ternary crop (103.3 L ha<sup>-1</sup>) or 31–46% higher than in single cultivations and 22–35% higher than in binary cultivations because of double crop sowing and harvesting operations. For this reason, the energy input was the highest in the ternary crop or near twice higher than in M, H, M+H crops, but similar with M+FB and H+FB. Despite this, the productivity of the ternary crop and, at the same time, the energy output were 2–5 times higher than in other treatments. This compensated for higher energy inputs and the energy efficiency ratio of ternary crop reached 19.23. In ternary crop, energy productivity was from 1.1 to 2.8 times higher and net energy was by 1.9–5.3 times higher than in other tested cultivations.

The highest total GHG emissions were obtained in binary M+H and M+FB cultivations (1729.84 and 2067.33 CO<sub>2eq</sub> ha<sup>-1</sup>). As we expected, ternary cultivation with the highest energy inputs initiated average GHG emission—1541.90 kg ha<sup>-1</sup> CO<sub>2eq</sub>.

In general, this study showed that the multi-cropping in agriculture can be an effective method to warrant high biomass production level, to optimize efficiency of energy consumption, while GHG emissions remains average. In order to make the cultivations of multi-crops even more efficient, it is necessary to improve the sowing and harvesting systems so that the ternary crop can be sown and harvested in one machine pass. In addition, faba beans should be included in the ternary crops, as

their biomass takes a significant part of the total biomass produced. Also to review the intercropped faba bean seeding rates as faba bean seeds have a high energy equivalent.

**Author Contributions:** Conceptualization, K.R.; methodology, K.R. and J.B.; software, A.Š., J.B. and K.R.; validation, J.B., K.R.; formal analysis, J.B., A.Š., R.K., A.S. and K.R.; investigation, J.B., A.Š., K.R., A.S. and R.K.; resources, J.B., K.R., A.R., A.S. and A.Š.; data curation, J.B., K.R. and A.Š.; writing—original draft preparation, K.R., R.K.; A.S. and; writing—review and editing, K.R., R.K., and A.S.; visualization, K.R., A.Š. and J.B.; supervision, K.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Most of the data generated or analysed during this study are included in the present article. In Balandaitė, J.; Romaneckas, K.; Švereikaitė, A.; Kimbirauskienė, R.; Sinkevičienė, A.; Romaneckas, A. The Biomass Productivity of Maize, Hemp and Faba Bean Multi-Crops. *Agronomy* **2022**, *12*, 3193. <https://doi.org/10.3390/agronomy12123193>, some productivity indices of the experiment are demonstrated.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Ioelovich, M. Energetic Potential of Plant Biomass and Its Use. *Int. J. Sustain. Energy* **2013**, *2*(2), 26–29.
2. García-Lara, S.; Serna-Saldivar, S.O. Chemistry and Technology. *Corn* **2019**, 1–18.
3. Abukhadra, M.R.; Adlii, A.; Jumah, M.N.B.; Othman, S.; Alruhaimi, R.S.; Salama, Y.F.; Allam, A.A. Sustainable conversion of waste corn oil into biofuel over different forms of synthetic muscovite based K<sup>+</sup>/Na<sup>+</sup> sodalite as basic catalysts; characterization and mechanism. *Materials Research Express* **2021**, *6*, 1–13.
4. Yang, K.; Ryu, K.; Dechant, B.; Berry, J.; Hwang, Y.; Jiang, C.; Kang, M.; Kim, J.; Kimm, H.; Kornfeld, X.; Yang, X. Sun-induced chlorophyll fluorescence is more strongly related to absorbed light than to photosynthesis at half-hourly resolution in a rice paddy. *Remote Sensing of Environment* **2018**, *216*, 658–673.
5. Saghaian, S.; Nemati, M.; Walters, C.; Chen, B. Asymmetric Price Volatility Transmission between U.S. Biofuel, Corn, and Oil Markets. *Journal of Agricultural and Resource Economics* **2018**, *43*, 46–60.
6. Romaneckas, K.; Balandaitė, J.; Sinkevičienė, A.; Kimbirauskienė, R.; Jasinskas, A.; Ginelevičius, U.; Romaneckas, A.; Petlickaitė, R. Short-Term Impact of Multi-Cropping on Some Soil Physical Properties and Respiration. *Agronomy* **2022**, *12*, 2–17.
7. Frankowski, J.; Sieracka, D. Possibilities for Using Waste Hemp Straw for Solid Biofuel Production. *Environ. Sci. Proc.* **2021**, *9*(1), 1–18.
8. Crini, G.; Lichtfouse, E.; Chanet, G.; Morin-Crini, N. Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agrochemistry, energy production and environment: a review. *Environmental Chemistry Letters* **2020**, *18*, 1451–1476.
9. Haberl, H.; Erb, K.H.; Krausmann, F.; Bondeau, A.; Lauk, C.; Muler, C.; Plutzer, C.; Steinberger, J.K. Global bioenergy potentials from agricultural land in 2050: Sensitivity to climate change, diets and yields. *Biomass bioenergy* **2011**, *35*(12), 4753–4769.
10. Blanco-Canqui, H.; Ruis, S. J. Cover crop impacts on soil physical properties: A review. *Soil Science Society of America Journal* **2020**, *84*, 1527–1576.
11. Francis, C.A.; Porter, P. Multicropping. *Crop Systems* **2016**, *3*, 29–33.
12. Beaumelle, L.; Auriol, A.; Grasset, M.; Pavy, A.; Thiéry, D.; Rusch, A. Benefits of increased cover crop diversity for predators and biological pest control depend on the landscape context. *Ecol. Solut. Evid.* **2021**, *2*, 1–12.
13. Failla, S.; Ingraio, C.; Arcidiacono, C. Energy consumption of rainfed durum wheat cultivation in a Mediterranean area using three different soil management systems. *Energy* **2020**, *195*, 1–13.
14. Šarauski, E.; Buragienė, S.; Masolionytė, L.; Romaneckas, K.; Avižienytė, D.; Sakalauskas, A. Energy balance, costs and CO<sub>2</sub> analysis of tillage technologies in maize cultivation. *Energy* **2014**, *69*, 227–235.
15. Akbarnia, A.; Farhani, F. Study of fuel consumption in three tillage methods. *Research in Agricultural Engineering* **2014**, *60*, 142–147.
16. Paris, B.; Vadorou, F.; Balafoutis, A.T.; Vaiopoulos, K.; Kyriakarakos, G.; Manolagos, D.; Papadakis, G. Energy use in open-field agriculture in the EU: A critical review recommending energy efficiency measures and renewable energy sources adoption. *Renewable and Sustainable Energy Reviews* **2022**, *158*, 1–17.

17. Pelletier, N.; Audsley, E.; Brodt, S.; Garnett, T.; Henriksson, P.; Kendall, A.; Kramer, K.J.; Murphy, D.; Nemecek, T.; Troell, M. Energy intensity of agriculture and food systems. *Annual review of environment and resources* 2011, 36, 223–246.
18. Ghazvineh, S.; Yousefi, M. Evaluation of consumed energy and greenhouse gas emission from agroecosystems in Kermanshah province. *Technical Journal of Engineering and Applied Sciences* 2013, 3, 349–354.
19. Trimpler, K.; Stockfisch, N.; Märlander, B. The relevance of N fertilization for the amount of total greenhouse gas emissions in sugar beet cultivation. *European Journal of Agronomy* 2016, 81, 64–71.
20. Lal, R. Carbon emission from farm operations. *Environ. Int.* 2004, 30(7), 981–990.
21. Mangalassery, S.; Sjögersten, S.; Sparkes, D.; Mooney, S. Examining the potential for climate change mitigation from zero tillage. *J. Agric. Sci.* 2015, 153, 1151–1173.
22. Adewale, C.; Reganold, J.P.; Higgins, S.; Evans, R.D.; Carpenter-Boggs, L. Improving carbon footprinting of agricultural systems: boundaries, tiers, and organic farming. *Environmental Impact Assessment Review* 2018, 71, 41–48.
23. Bručienė, I.; Aleliūnas, D.; Šarauskis E.; Romanekas, K. Influence of Mechanical and Intelligent Robotic Weed Control Methods on Energy Efficiency and Environment in Organic Sugar Beet Production. *Agriculture* 2021, 11, 2–17.
24. IUSS working group WRB. *World Reference Base for Soil Resources*, 3rd ed.; *World Soil Resources Reports No.106*; FAO: Rome, Italy, 2014. Available on line: <http://www.fao.org/3/i3794en/I3794en.pdf> (accessed on 18 October 2022).
25. Pagrindinio žemės dirbimo darbai/Primary tillage works. In *Mechanizuotų žemės ūkio paslaugų įkainiai. Rates for mechanized agricultural services*; Srebutėnienė, I., Eds.; Lietuvos agrarinės ekonomikos institutas: Vilnius, Lithuania, 2017. Available online: [https://zum.lrv.lt/uploads/zum/documents/files/IKAINIAI\\_2017\\_I\\_dalis.pdf](https://zum.lrv.lt/uploads/zum/documents/files/IKAINIAI_2017_I_dalis.pdf) (accessed on 2023 August 2023) (in Lithuanian).
26. Pasėlių priežiūra ir šienapjūtės darbai/Crop care and mowing work. In *Mechanizuotų žemės ūkio paslaugų įkainiai. Rates for mechanized agricultural services*; Srebutėnienė, I.; Stalgienė, A., Eds.; Lietuvos agrarinės ekonomikos institutas: Vilnius, Lithuania, 2017 (in Lithuanian).
27. Patent LT6701B. Faba Bean Waste Biofuel Pellets And/Or Sorbent, Fertilizer. Available online: <https://search.vpb.lt/pdb/patent/dossier/5140/text> (accessed on 21 August 2023).
28. Patent LT6998B. Corn, Hemp And Bean Multi-Crop Biomass Pellets And/Or Fertilizer. Available online: <https://search.vpb.lt/pdb/patent/dossier/48325/text> (accessed on 21 August 2023).
29. Lal, B.; Gautam, P.; Nayak, A.K.; Panda, B.B.; Bihari, P.; Tripathi, R.; Shahid, M.; Guru, P.K.; Chatterjee, D.; Kumar, U.; Meena, B.P. Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system. *J. Clean. Prod.* 2019, 226(8), 15–30.
30. Šarauskis, E.; Romanekas, K.; Jasinskas, A.; Kimbirauskienė, R.; Naujokienė, V. Improving energy efficiency and environmental mitigation through tillage management in faba bean production. *Energy* 2020, 209, 1–9.
31. Todde, G.; Carboni, G.; Marras, S.; Caria, M.; Sirca, C. Industrial hemp (*Cannabis sativa* L.) for phytoremediation: Energy and environmental life cycle assessment of using contaminated biomass as an energy resource. *Sustain. Energy Technol. Assess.* 2022, 52(A), 102081. doi.org/10.1016/j.seta.2022.102081.
32. Kazemi, H.; Shahbyki, M.; Baghbani, S. Energy analysis for faba bean production: a case study in Golestan province, Iran. *Sustain. Prod. Cons.* 2015, 3, 15–20.
33. Amir, S. Hemp as a biomass crop. Technical Article, April 2023. Available online: <https://www.biomassconnect.org/wp-content/uploads/2023/04/Hemp-as-Biomass-Crop.pdf> (accessed on 21 August 2023).
34. Kraszkievicz, A.; Kachel, M.; Parafiniuk, S.; Zając, G.; Niedziółka, I.; Sprawka, M. Assessment of the Possibility of Using Hemp Biomass (*Cannabis Sativa* L.) for Energy Purposes: A Case Study. *Appl. Sci.* 2019, 9, 4437.
35. Jasinskas, A.; Minajeva, A.; Šarauskis, E.; Romanekas, K.; Kimbirauskienė, R.; Pedišius, N. Recycling and utilisation of faba bean harvesting and threshing waste for bioenergy. *Renew. Energ.* 2020, 162, 257–266.
36. Tabar, I.B.; Keyhani, A.; Rafiee, S. Energy balance in Iran's agronomy (1990-2006). *Renew. Sustain. Energy. Rev.* 2010, 14(2), 849-55.
37. Moghimi, M.R.; Pooya, M.; Mohammadi, A. Study on energy balance, energy forms and greenhouse gas emission for wheat production in Gorve city, Kordestan province of Iran *Eur. J. Exp. Biol.* 2014. 4(3), 234–239.
38. Pishgar-Komleh, S.H.; Ghahderijani, M.; Sefeedpari, P. Energy consumption and CO2 emissions analysis of potato production based on different farm size levels in Iran. *J. Clean. Prod.* 2012, 33, 183–191.
39. Singh, S.; Mittal, J.P.; Verma, S.R. Energy requirements for production of major crops in India. *Agric. Mech. Asia Africa Latin. Am.* 1997, 28(4), 13–17.

40. Campiglia, E.; Gobbi, L.; Marucci, A.; Rapa, M.; Ruggieri, R.; Vinci, G. Hemp Seed Production: Environmental Impacts of Cannabis sativa L. Agronomic Practices by Life Cycle Assessment (LCA) and Carbon Footprint Methodologies. *Sustainability* 2020, 12, 65–70.
41. Reckmann, K.; Blank, R.; Traulsen, I. Krieter, J. Comparative life cycle assessment (LCA) of pork using different protein sources in pig feed. *Arch. Anim. Breed.* 2016, 59(1), 27–36.
42. Imran, M.; Özçatalbaş, O.; Bashir, M.K. Estimation of energy efficiency and greenhouse gas emission of cotton crop in South Punjab, Pakistan. *J. Saudi Soc. Agric. Sci.* 2020, 19, 216–224.
43. Tomic, M.; Savin, L.; Micic, R.; Simikic, M.; Furman, T. Possibility of using biodiesel from sunflower oil as an additive for the improvement of lubrication properties of low-sulfur diesel fuel. *Energy* 2014, 65, 101–108.
44. Labeckas, G.; Slavinskas, S. Comparative performance of direct injection diesel engine operating on ethanol, petrol and rapeseed oil blends. *Energy Convers Manag.* 2009, 50(3), 792–801.
45. Labeckas, G.; Slavinskas, S. Performance of direct-injection off-road diesel engine on rapeseed oil. *Renew Energ.* 2006, 31(6), 849–863.
46. Bueno, A.V.; Velásquez, J.A.; Milanez, L.F. Heat release and engine performance effects of soybean oil ethyl ester blending into diesel fuel. *Energy* 2011, 36(6), 3907–3916.
47. Carraretto, C.; Macor, A.; Mirandola, A.; Stoppato, A.; Tonon, S. Biodiesel as alternative fuel: Experimental analysis and energetic evaluations. *Energy* 2004, 29, 2195–2211.
48. Silalertruksa, T.; Gheewala, S.H. Environmental sustainability assessment of palm biodiesel production in Thailand. *Energy* 2012, 43(1), 306–314.
49. Ali, A.S.; Tedone, L.; Verdini, L.; Mastro, G. Implications of No-tillage system in faba bean production: energy analysis and potential agronomic benefits *Open. Agric. Journal.* 2018, 12(1), 270–285.
50. Kazlauskas, M.; Bručienė, I.; Jasinskas, A.; Šarauskis, E. Comparative Analysis of Energy and GHG Emissions Using Fixed and Variable Fertilization Rates. *Agronomy* 2021, 1(11), 1–19.
51. Mandal, K.G.; Saha, K.P.; Ghosh, P.K.; Hati, K.M.; Bandyopadhyay, K.K. (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass and Bioenergy* 2002, 23(5), 337–345.
52. Torney, F.; Moeller, L.; Scarpa, A.; Wang, K. Genetic engineering approaches to improve bioethanol production from maize. *Curr. Opin. Biotechnol.* 2007, 18(3), 193–199.
53. Prade, T.; Svensson, S. E.; Andersson, A.; Mattsson, J. E. Biomass and energy yield of industrial hemp for biogas and solid fuel. *Biomass & Bioenergy.* 2011, 35(7), 3040–3049.
54. Prade, T.; Svensson, S. E.; Mattsson, J. E. Energy balances for biogas and solid biofuel production from industrial hemp. *Biomass & Bioenergy.* 2012, 40(7), 36–52.
55. Akinnifesi, F.K.; Makumba, W.; Kwesiga, F.R. Sustainable maize production using gliricidia/maize intercropping in Southern Malawi. *Exp. Agric.* 2006, 42, 441–457.
56. Tsubo, M.; Walker, S.; Ogindo, H.O. A simulation model of cereal-legume intercropping system of semi-arid regions. *Field Crops Res.* 2005, 93, 23–33.
57. Ewansiha, S.U.; Kamara, A.Y.; Chiezey, U.F.; Onyibe, J.E. Performance of cowpea grown as an intercrop with maize of different populations. *Afr. Crop Sci. J.* 2015, 23(2), 113–22.
58. IPCC. Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014. Available online: <https://www.ipcc.ch/report/ar5/wg3/> (accessed on 2 October 2020).
59. Kizilaslan, H. Input-output energy analysis of cherries production in Tokat Province of Turkey. *Appl. Energy* 2009, 86, 1354–1358.
60. Rafiee, S.; Hashem, S.; Avval, M.; Mohammadi, A. Modeling and sensitivity analysis of energy inputs for apple production in Iran. *Energy* 2010, 35, 3301–3306.
61. Pishgar-Komleh, S.H.; Omid, M.; Heidari, M.D. On the study of energy use and GHG (greenhouse gas) emissions in greenhouse cucumber production in Yazd province. *Energy* 2013, 59, 63–71.
62. Glantz, M.H.; Gommers, R.; Ramasamy, S. Coping with a changing climate: considerations for adaptation and mitigation in agriculture. *Environment and Natural Resources Management Series, Monitoring and Assessment-Food and Agriculture Organization of the United Nations* 2009, 15, 33–57.
63. Šarauskis, E.; Masilionytė, L.; Juknevičius, D.; Buragienė, S.; Kriauciūnienė, Z. Energy use efficiency, GHG emissions, and cost-effectiveness of organic and sustainable fertilisation. *Energy* 2019, 172, 1151–1160.
64. Hoffman, E.; Cavigelli, M.A.; Camargo, G.; Ryan, M.; Ackroyd, V.J.; Richard, T.L.; Mirsky, S. Energy use and greenhouse gas emissions in organic and conventional grain crop production: accounting for nutrient inflows. *Agric. Syst.* 2018, 162, 89–96.
65. Streimikienė, D.; Klevas, V.; Bubelienė, J. Use of EU structural funds for sustainable energy development in new EU member states. *Renewable Sustain. Energy Rev.* 2007, 11, 1167–1187.
66. FAO. Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks. Available online: <https://www.fao.org/3/i3671e/i3671e.pdf> (accessed on 21 August 2023).

67. Lu, X.; Lu, X.; Cui, Y.; Liao, Y. Tillage and crop straw methods affect energy use efficiency, economics and greenhouse gas emissions in rainfed winter wheat field of Loess Plateau in China *Acta Agric Scand Sect B Soil. Plant Sci.* 2018, 68(6), 562–574.
68. Alimagham, S.M.; Soltani, A.; Zeinali, E.; Kazemi, H. Energy flow analysis and estimation of greenhouse gases (GHG) emissions in different scenarios of soybean production (Case study: gorgan region, Iran). *J. Clean Prod.* 2017, 149, 621–628.
69. Šarauskis, E.; Romaneckas, K.; Kumhála, F.; Kriaučiūnienė Z. Energy use and carbon emission of conventional and organic sugar beet farming. *J. Clean Prod.* 2018, 201, 428–438.
70. Diacono, M.; Rubino, P.; Montemurro, F. Precision nitrogen management of wheat. *Agron. Sustain. Dev.* 2013, 33, 219–241.
71. Etemadi, E.; Hashemi, M.; Barker, A.V.; Zandvakili, O.R.; Liu, X. Agronomy, nutritional value, and medicinal application of faba bean (*Vicia faba* L.). *Horticult Plant J.* 2019, 5(4), 170–182.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.