Czech University of Life Sciences Prague

Faculty of Tropical AgriSciences

Department of Sustainable Technologies in Tropics and Subtropics

Dissertation thesis

Evaluation of solid biofuels made of hemp *(Cannabis sativa L.)* from two different localities – Prague and Chisinau (Moldova)

Author: Ing. Michel KOLAŘÍKOVÁ
Supervisor: prof. Ing. Bohumil HAVRLAND, CSc.
doc. Ing. Jan BANOUT, Ph.D.

Supervisor specialist: Ing. Tatiana Ivanova, Ph.D.

Declaration

Hereby I declare that I have elaborated the doctoral dissertation thesis independently, only with the help of expert consultations and with the use of credible sources of information which I am stating in the text and then mentioning in the references.

I agree entirely that my Thesis can be saved in the library of the Czech University of Life Sciences Prague and can be available for study purposes.

Prague, August 15, 2017

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Ing. Michel Kolaříková

Abstract

The main reason for use of renewable energy resources in energy sector lies in trying to replace non-renewable fossil fuels, reduce their consumption and further decrease anthropogenic emissions of greenhouse gases. Biomass is currently a significant source of energy mainly for its availability and high potential. Industrial hemp (*Cannabis sativa L.*) has a high yield in a short period of time and reaches a Gross calorific value similar to that of wood. Two hemp cultivars were experimentally sown in the Czech Republic and Republic of Moldova in order to determine the biomass yield from autumn and spring harvests for utilization in the form of solid fuels - briquettes. Based on inventory analysis of relevant processes, Energy balance was developed. Technological process was considered from cultivation until distribution of the final energy product. Hemp harvested as a green plant in autumn was left under a roof for losing moisture, to keep yield as high as possible and left the field for another crop in rotation system. Spring harvested biomass was left in the field till the moisture content reached 15%. Briquettes were considered to be used in small – scale boilers for heating purposes with a thermal efficiency of 80%. Autumn and spring harvests in the Republic of Moldova and in the Czech Republic, referenced as Scenarios 1,2,3,4, respectively, have produced 142.5 GJ ha^{-1}; 102.3 GJ ha^{-1}; 115.2 GJ ha^{-1} and 88 GJ ha^{-1} of useful heat for household heating, respectively. Energy inputs included energy of human labor, energy in fuels, in seeds, in the machines and in fertilizers with total value 16.6 GJ ha^{-1}; 15.8 GJ ha^{-1}; 19.3 GJ ha^{-1} and 18.8 GJ ha^{-1} in respective order for Scenarios from 1 to 4, according to common farmers in both countries. Energy return on energy invested was calculated for Scenario 1: 8.56, Scenario 2: 6.49, Scenario 3: 5.96 and Scenario 4: 4.67. From the point of view of the energy balance, the Scenario 1 - Heat from the autumn-harvested briquetted hemp in the Republic of Moldova was found as the most advantageous. Based on values from inventory analysis, Life Cycle Assessment (LCA) was developed. LCA is used to evaluate the environmental benefits on global warming, acidification and photochemical oxidation potentials of heat energy produced by briquetted hemp biomass, when compared with coal. The results show that in both impact categories, coal-based heating represents greater environmental burden. Dominant impacted categories are global warming potential (94% higher impact on environment), human toxicity potential (91%), photochemical ozone creation (89%), acidification (81%) and the fossil fuel depletion. Due to positive results of energy balance and environmental impact, we can state, that hemp appears to be a promising energy crop in humid and temperate climates and it is able to contribute solving the energy situation, especially of small scale farmers in Moldova.

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List of Abbreviations

AD – Anaerobic Digestion
AP – Acidification Potential
BEY – Biomass Energy Yield
BY – Biomass Yield
CH$_4$ - Methane
CO$_2$ – Carbon Dioxide
CR - Czech Republic
CULS – Czech University of Life Sciences
DM – Dry Matter
Ei - Energy Input
EJ – Exajoule =10^{18} J
Eo - Energy Output
EP – Eutrophication Potential
EROI (EROEI) – Energy Return on (Energy) Invested
EU – European Union
EU-27 – European Union - 27 member states
FAME – Fatty Acid Methyl Ester
FAO – Food and Agricultural Organization
PAR - Photosynthetically Active Radiation
FFA - Fatty Free Acid
GCV- Gross Calorific Value
GCVdb- Gross Calorific Value on dry basis
GCVwb- Gross Calorific Value on wet basis
GHG – Green house gasses
GJ - Giga Joule
GWP – Global Warming Potential
HFCs- Hydro Fluoro Carbons
HTP – Human Toxicity Potential
ISO -International Organization for Standardization
kW - kilowatt
kWh – kilowatt-hour
LCA – Life Cycle Assessment
LCIA – Life Cycle Impact Assessment
NCV - Net Calorific Value
NCV$_{db}$ – Net Calorific Value on dry basis
NCV$_{wb}$ –Net Calorific Value on wet basis
LULUCF – Land Use, Land Use Change and Forestry
MC- Moisture Content
ME – Ministry of Environment
MJ – Mega Joule
MLD - Moldova; Republic of Moldova
MPO – Ministerstvo Průmyslu a Obchodu (Ministry of Industry and Trade)
MZE – Ministerstvo Zemědělství (Ministry of Agriculture)
MZP – Ministerstvo Životního Prostředí (Ministry of Environment)
N - Nitrogen
N$_2$O – Nitrous Oxide
NEY – Net Energy Yield
NREAH – National Renewable Action Plan for the Republic of Moldova
ODP – Ozone Layer Depletion Potential
PES – Primary Energy Resources
PFCs – Per Fluorocarbons
POCP - Photochemical Ozone Creation Potential
RES - Renewable Energy Sources
SF$_6$ – Sulphur Hexafluoride)
SY – Seed yield
TETP – Terrestric Ecotoxicity Potential
THC- Tetrahydrocannabinol
TOE – Tonne of Oil Equivalent
UN - United Nations
UNDP – United Nations Development Programme
UNFCCC – United Nations Framework Convention on Climate Change
wt% - percentage per weight

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1. INTRODUCTION

In the 21st century, the modern world has to face great challenges in connection with the growing population, such as provision of drinking water and energy or food security (UNDP, 2015). At the same time, there is a thread of changing climate and it is necessary to keep it in mind while implementing any technologies securing basic human's needs. This is one of the reasons for researchers to focus on comparison of alternative energy sources produced from biomass and non-renewable one. The main reason for use of renewable energy resources in energy sector lies in trying to replace non-renewable fossil fuels, reduce their consumption and further decrease anthropogenic emissions of greenhouse gases. Obtaining and using of renewable energy is a chain of operations, each of which has a certain potential to participate in environmental damage. If renewable sources of energy are to contribute to addressing the potential shortage of non-renewable raw materials and to reduce the environmental impact, it is necessary to be able to assess the environmental interaction of all involved processes, including their possible secondary impacts (Kočí, 2012).

Thus this proposed Dissertation Thesis will focus on energetic and environment evaluation of biofuels; as such it is complex and composes of the main components: energy balance and environmental impact. The theoretical part is focused on literature review of scientific research information. Practical survey is especially oriented on hemp biomass grown in two different localities – in the Czech Republic compared with trial plots in Chisinau (Moldova), their monitoring at all the stages of a product's life "from-cradle-to-grave". The main output will give an answer about evaluation of solid biofuels made of hemp in the terms of sustainability.

The Czech Republic does not have many raw material resources, and this predetermines the potential for economic growth – most mineral materials are imported (SEK, 2014). The stocks of some mineral resources being found in the CZ territory have already been utilized to a high degree (SEK, 2014; ME, 2009). Republic of Moldova (MLD) has got very insignificant reserves of solid fuels, petroleum and gas, and a low hydroelectric potential. This has led to a high dependence on energy imports from Russia and Ukraine (reaching 96%) of total energy consumption (Soimu, 2014; Karakosta et al., 2011)

To ensure sufficient amount of energy supplies for future generations and Moldova´ less dependency on foreign imports (sometimes conditioned by political issues), we must find a proper alternative to fossil fuels. The solution can be found through growing energy crops for biomass and agricultural biomass wastes. Energy crops seem to be environment friendly, they are not difficult to cultivate, and their common feature is high biomass yield (BY) and high gross calorific value (GCV) which determine high potential of biomass energy yield (BEY) (Kolaříková et al., 2013; Prade et al., 2012). EC also have well defined composition in comparison to residue's biomass (Li et al., 2012).

The annual herbaceous crop *Cannabis sativa L.* is native in Western Asia and India (Petříková, 2006). Hemp cultivation was prohibited almost all over the world due to content of psychoactive substances THC [1](Robinson, 1995). Hemp is currently grown over the world mainly for its very resistant fibre, which is suitable to produce various products -paper, clothe, rope, etc. (Sladký, 2004). From energetic point of view - hemp stems are suitable to produce solid biofuels – briquettes and pellets (Prade et al., 2011); serve as source for biogas plant (to produce methane) (Krauger et.al, 2011a); stems due to lignocelluloses' composition are considered as second generation biofuel for bioethanol production (Tutt et al., 2011). Hemp seeds can be processed and modified into biodiesel (Gill et al., 2011). The uniqueness of the plant is in its ability to create over 24 ton of biomass per hectare during 140 days. Hemp DM yield (12 t ha^{-1}), GCV (18 GJ t $^{-1}$) similar to wood, low demands for pesticides and ability to suppress weeds determine this crop among the most suitable in moderate climate (Prade, 2014; Kolaříková et al., 2013) Drawbacks are seen in quite problematic harvest due to high tenacity of fibre and some restrictions for cannabis cultivation - varieties used shall have a THC content not exceeding 0.2%, only certified seeds of certain varieties can be used, and areas growing hemp require administrative approval (EU, 2003)

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[1] THC tetrahydrocannabinol- aromatic terpenoid, principal psychoactive substance produced naturally by plants.

2. LITERATURE REVIEW

2.1. Renewable energy

Renewable energy is energy obtained from naturally repetitive and persistent flows of energy occurring in the local environment (Twidell and Weir, 2015), energy that is derived from natural processes that are replenished at a higher rate than they are consumed. Solar, wind, geothermal, hydro, and biomass are common sources of renewable energy. Such energy may also be referred to as green energy or sustainable energy (REN21, 2014; IEA, 2013).

Renewable energy provided an estimated 19% of global final energy consumption in 2012, and continued to grow in 2013 (REN21, 2014). Share of renewable energy on global final consumption is shown in Figure 1.

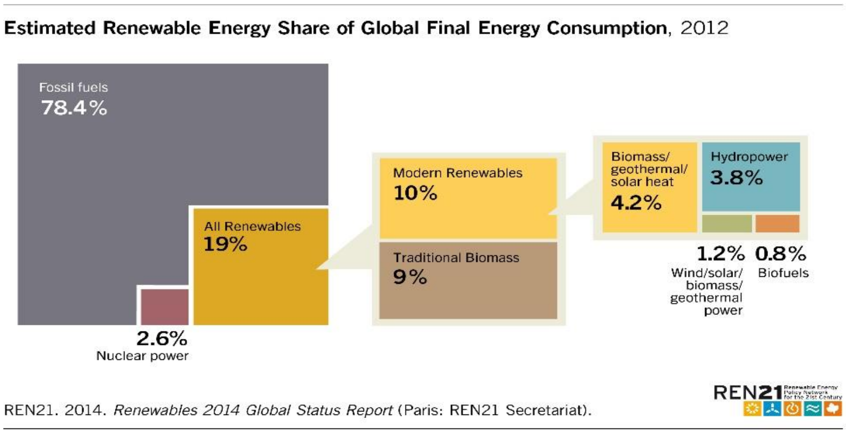

Figure 1: Estimated Renewable Energy Share of Global Final Energy Consumption
Source: REN21 (2014)

Of this total share in 2012 and 2013, traditional biomass, which currently is used primarily for cooking and heating in rural areas of developing countries, accounted for about 9%, and modern renewables increased their share to approximately 10%. However the number is still increasing, according to REN21 (2014), little less than half of global final energy consumption is from traditional biomass. There is debate about the sustainability of traditional biomass, and whether it should be considered renewable, or renewable only if it comes from a sustainable source.

Modern RES are occupied by hydropower (3.8%), biomass/ geothermal/ solar heat (4.2%), followed wind/solar/biomass/geothermal power (1.2%), and biofuels (0.8%) (REN21, 2014; EUROSTAT, 2014a, b; IEA, 2013). Useful heat energy from modern renewable sources accounted for an estimated 4.1% of total final energy use; hydropower made up about 3.7%; and an estimated 1.9% was provided by power from wind, solar, geothermal, and biomass, and biofuels (REN21, 2014).

There are two principal reasons why production of renewable energy is desirable:

The first reason is that renewable energy can be renewed. Renewability of energy supply is important, since the worldwide demand for energy (for food production, transportation or production of goods) is still increasing (Figure 2).

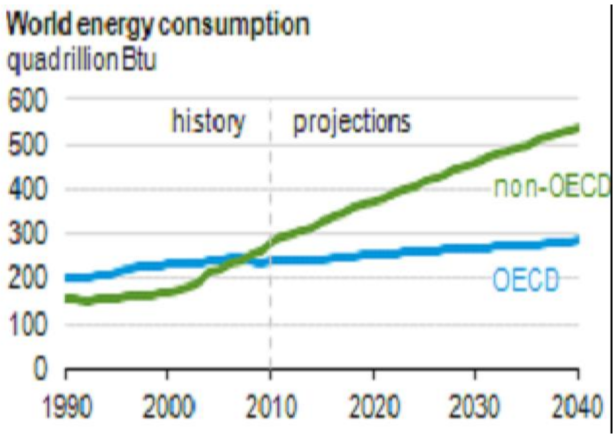

Figure 2: World energy consumption and prediction till 2040
Source: BP (2014)

The majority of global energy use is based on non-renewable resources (energy obtained from static stores of energy that remain underground unless released by human interaction). Such energy supplies are called finite supplies or brown energy. The biggest share of the supply is covered by mineral oil, followed by coal and natural gas (RES21, 2014; Twidell and Weir, 2015). Many of the current fossil fuel reserves under exploitation are dwindling (Prade et al., 2012). However, these reserves will not be exhausted at all for economic reasons. Besides easily extractable fossil fuel reserves, there are larger resources that are more difficult and costly to extract (Prade et al., 2012; Twidel and Weir, 2015).

Access to modern energy let people to live better lives—providing clean heat for cooking, lighting, cooling, water pumping, as well as basic processing and communications. Nevertheless there are still more than 1 billion people without access to modern energy services all over the world (RES21, 2014).

2.1.1. Renewable energy in the Czech Republic

The Czech Republic does not have many raw material resources; most mineral materials are imported (petroleum - 100% imports) (ME, 2013). The country's stocks of some mineral resources have been exhausted. According to Six National Communication of the Czech Republic under the United Nations Framework Convention on Climate Change of the Ministry of Environment (MZP, 2012), CR consumes more primary energy sources and electricity than necessary so that consumed energy is inadequately converted to added value (ME, 2009). The use of traditional sources of energy is cheap, and to some extent available. It does not depend on natural conditions and accumulates large amounts of energy per unit. Import of fossil fuels is closely related to dependence of unstable economies.

The significance of renewable energy sources in the Czech energy sector has been steadily growing. Before 2011, the largest sources of RES energy in the Czech Republic were hydropower plants, but these were overtaken in 2011 by photovoltaic power plants due to rapid increase in solar production compounded by lower production from hydro sources caused by lower precipitation that year (ME, 2013).

In 2012, the Act No. 165/2012 Coll., on supported energy sources was approved. It replaced the original Act and brought several changes relating to the use of RES (MZE, 2013). The total share of renewable energy in primary energy sources (PES) according to Ministry of industry and trade was 7% in 2013. This estimate refers to the energy content in the used fuel and it does not reflect the efficiency of the device (MPO, 2014). The share of renewable energy in 2013, the gross electricity production in total domestic electricity consumption reached 8.3% and their share in gross production of heat around 8%. The share of RES in final energy consumption according to international methodology of calculation was 10% (MZE, 2013; MPO, 2014).

Structure of electricity generation from RES in 2012 was as follows: photovoltaic sources (27%), hydropower (26.5%), biomass (22.5%), biogas (18%), wind (5%) and energy produced by incineration of solid municipal waste (1%) (ME, 2013).

Volume of heat generated using RES has been steadily growing over the long-term. In 2011, RES accounted for 8% of the heat produced. The largest volume is produced from biomass (83.8%), where the most important factor is use of wood in household sources (ME, 2013). Other sources contribute as follows: waste 5.7%, biogas 4.6%, heat pumps 4.9%, solar thermal collectors 1% (ME, 2013).

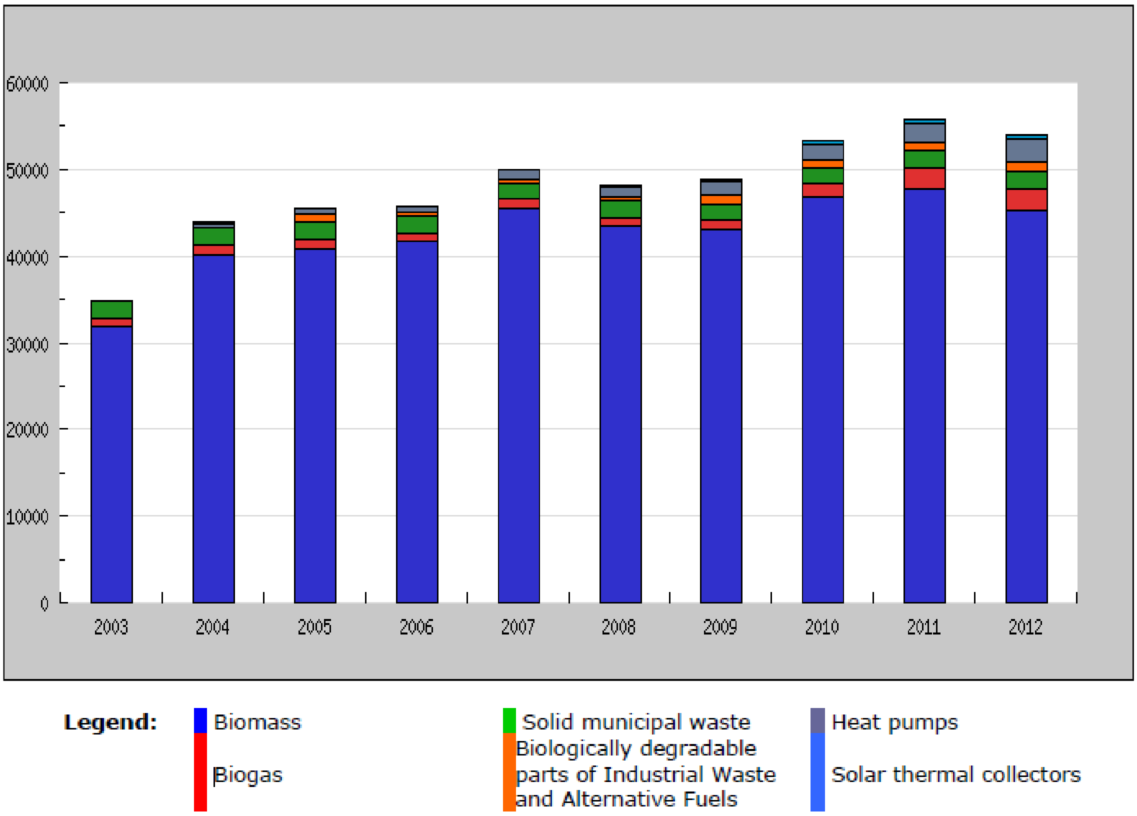

Figure 3: Heat production using RES and waste in the Czech Republic [GJ] in 2003 – 2012
Source: MPO (2014)

2.1.2. Renewable energy in the Republic of Moldova

The Republic of Moldova almost entirely depends on imported fuels; dependence on imports is estimated to be around 96%, however it has indeed great potential to produce energy from its own renewable sources (ENER21, 2014). In recent years, the Moldovan Parliament adopted a series of legislative acts in the energy field, including the Energy Strategy of the Republic of Moldova 2020, the law on the use of renewable energy (2007), and the law on energy efficiency (2010). According to the energy strategy of Moldova for 2020, the amount of energy produced from renewable sources should increase to 20% (NREAP, 2013). Studies have shown that the most reliable and affordable are alternative sources of energy such as those obtained from straw and other waste (NREAP, 2013).

The Republic of Moldova disposes the following forms of Renewable Resources: wind, solar, biomass and hydraulic.

According to National renewable action plan for Moldova (2013) RES used in Moldova in 2009 (when implementing State programme for exploitation of renewables) was 60 thousand TOE, 5.5% of the total energy consumption, which increased annually by a rate of 9.8%. Flowing strategy for RES structure is diversified as follows:

- Wind Energy, 25 thousand TOE, 5.0% of RES
- Solar Energy, 50 thousand TOE, 10.0% of RES
- Biomass Energy, 352 thousand TOE, 70.5% of RES
- Hydro Energy, 73 thousand TOE, 14.5% of RES

Theoretical and technical potential of different types of RES in Republic of Moldova is seen in the Table 1.

Table 1: The potential of different types of renewable energy in Republic of Moldova

Types of RES in the Republic of Moldova	Theoretical potential of RES (million TOE)	Technical potential of RES (million TOE)
Solar energy	12	1.2
Wind power	2.1	0.7
Biomass	1.0	0.5
Low grade heat sources	9.5	0.95
Water power	0.45	0.3
Total	25.05	3.65

Source: Doloscanu (2013)

The law of renewable energy form 2007 governs the legal framework for the renewable energy sector. Until 2020, Moldova aims to increase the share of alternative energies up to 20% of the total energy consumption (NREAP, 2013; Doloscanu, 2013). There is also an obligation of the country to the European Union to achieve these indicators by 2020.

Energy strategy’s fundamental principles of Republic of Moldova until 2020 are according to Doloscanu (2013) as follows:

- Design of energy supply systems towards customer´s needs
- Reasonable tariffs
- Improvement of Moldova’s role as important transit country (electricity, gas)

2.2. Protection of environment in the Czech Republic

By signing The Kyoto protocol[2] the Czech Republic has undertaken the task to reduce emissions of greenhouse gases[3] by 5.2% over the period of 2008-2012 (compared to 1990). Although the CR was successful in achieving targets for reducing emissions, when its goal for the share of energy produced from RES in the total consumption of primary energy sources in 2010 at 6% was fulfilled, more efficient scale – the amount of CO_2 per capita is still very high (ME, 2013; UN, 2010). Situation of carbon dioxide emissions per capita in part of Europe is seen on the Figure 4.

In 2011, the most important GHG in the Czech Republic was CO_2 contributing 85% to total national GHG emissions and removals expressed in CO_2 eq., followed by CH_4 8.2 % and N_2O 6.2 %. PFCs, HFCs and SF_6 contributed for 0.95 % to the overall GHG emissions in the country (ME, 2013).

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[2] The Kyoto protocol is a protocol to the United Nations Framework Convention on Climate Change with the aim to stabilize the concentration of GHG in the atmosphere. The Protocol was initially adopted on 11 December 1997 in Kyoto, Japan, and entered into force on 16 February 2005. As of September 2011, 191 states have signed and ratified the protocol.

[3] GHG (Greenhouse gases) – carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), hydro fluorocarbons (HFCs) and per fluorocarbons (PFC).

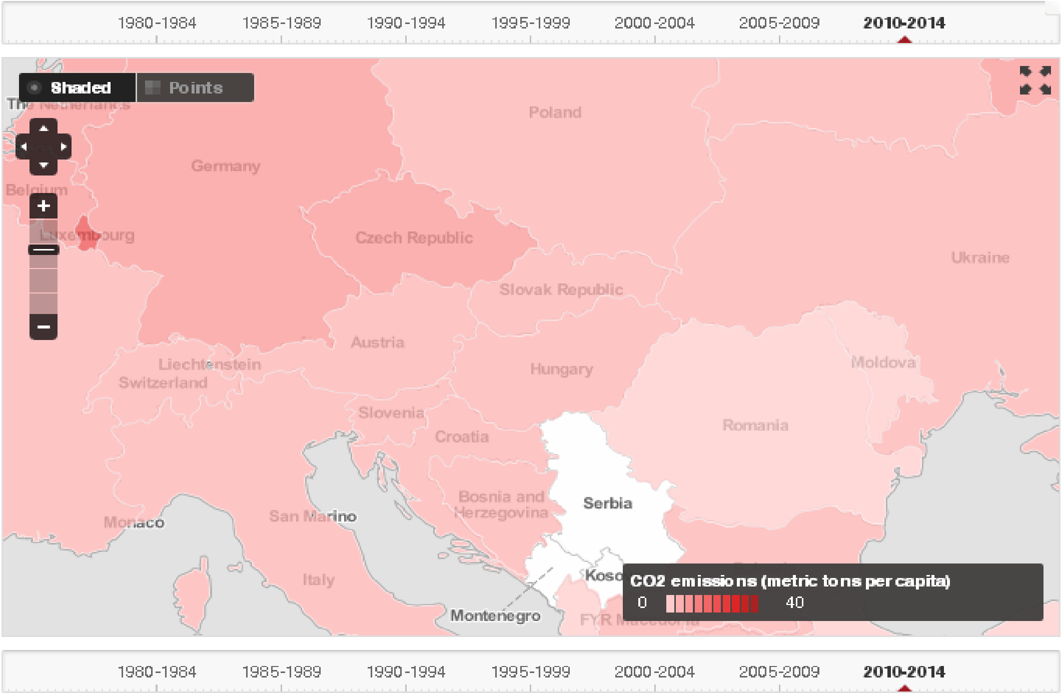

Figure 4: Carbon dioxide emissions (metric tons per capita)
Source: World Bank (2015)

CO_2 net emissions from LULUCF[4] totalled at -7.6 % from the overall CO_2 emissions. Over the period 1990 - 2011 CO_2 emissions and removals decreased by 31 %, CH_4 emissions decreased by 43% during the same period mainly due to lower emissions from Energy, agriculture and waste sectors (ME, 2013). N_2O emissions decreased by 42% over the same period due to emission reduction in agriculture and despite increases from the transport category. Emissions of HFCs and PFCs increased by orders of magnitude, whereas SF_6 emissions decreased significantly, resulting the overall F-gases trend at 15 times increase in CO_2 eq (ME, 2013).

The mitigation of global warming and its consequences could be possible through several different scenarios: by reducing energy intensity, by increasing energy effectiveness, by changing fuels with a lower production of carbon dioxide (change in the structure of energy resources (ME, 2009).

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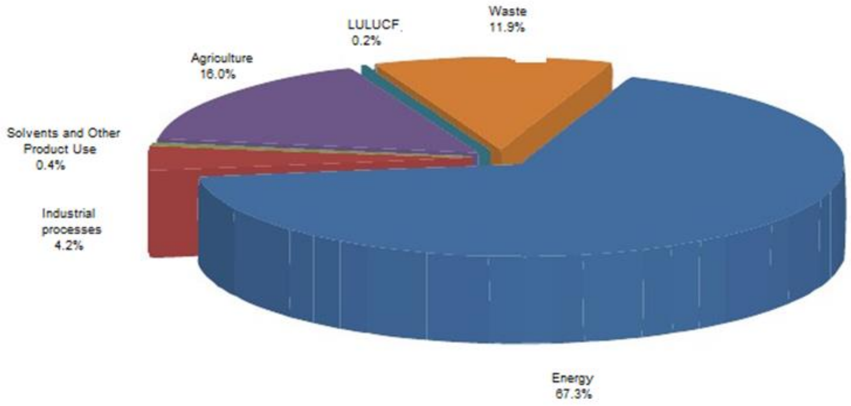
[4] LULUCF - Land Use, Land-Use Change and Forestry

2.3. Protection of environment in the Republic of Moldova

The Republic of Moldova signed the UNFCCC[5] on June 12, 1992 and ratified it on March 16, 1995 (UNDP, 2012). The Republic of Moldova ratified the Kyoto Protocol on February 13, 2003. As a non-Annex I Party, the Republic of Moldova has no commitments to reduce its GHG emissions under the Protocol.

The evolution of total direct greenhouse gas emissions expressed in CO_2 equivalent, revealed a decreasing trend in the Republic of Moldova, reducing by 72% (Brega et al., 2011). Emissions of CH_4 have decreased by 40%, while emissions of N_2O decreased by circa 58% (Brega et al., 2011). Halocarbons emissions (in particular HFCs, as no PFCs emission have been registered so far in the Republic of Moldova) and sulphur hexafluoride (SF_6) emissions commenced in 2000, considered as a reference year for F - gases in the Republic of Moldova (Brega et al., 2011; Pflieger, 2014).

Sectorial breakdown of the Republic of Moldova’s GHG emissions is shown in Figure 5. In 2010 approximately 67% of the total national direct GHG emissions originated from fossil fuel combustion, 16% from agriculture, almost 12% from wastes, followed by industrial process (4.2%), Solvents and other product use (0.4%) and LULUCF (0.2%)(UNDP, 2012).



Sectoral Breakdown of the Republic of Moldova's Total GHG Emissions, 2010

Figure 5: Sectoral breakdown of the Republic of Moldova´s total GHG Emissions
Source: Pflieger (2014)

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[5] The United Nations Framework Convention on Climate Change (UNFCCC) was adopted on May 9, 1992 at the UN Conference on Environment and Sustainable Development in Rio de Janeiro as a response of the international community to the global climate change phenomenon caused by the increased concentrations of greenhouse gases (GHG) in the atmosphere.

2.4. Biomass energy

This thesis deals with biomass utilization for commercial energy production which can be separated into two groups: 1. Residues

2. Biomass cultivated for sole purpose

All possible biomass conversion processes are shown in the Table 2.

Table 2: Biomass conversion processes

Process	Conditions	Energy carriers
Gasification	Thermal conversion/limited air/ oxygen supply	Syngas[6]
Pyrolysis	Thermal conversion/exclusion of air/oxygen	Char, pyrolysis, oil, syngas
Torre fraction	Thermal conversion/exclusion of air/oxygen	Char
Transesterification	Chemical conversion	Oils (FAME)
Fermentation	Biochemical conversion	Alcohols, acetone

Source: Prade (2011)

Overall, biomass still occupies the largest share of energy from renewable sources in the Czech Republic, although this share is declining - from 63.9% in 2011 to 62.4% in the following year. It is caused mainly by the growing share of biogas to 11.4% in 2012 (MZE, 2013).

Biomass in Moldova is represented by categories: wood, waste products of agriculture, waste of processing industry, and solid and liquid waste. A promising market in Moldova is using more efficient plants for biomass burning (Deloscanu, 2013).

In the republic of Moldova, there is experience with small scale biomass applications in rural areas, but none of large scale or more efficient use exist there. The main sources of biomass suitable for energy purposes are forestry, agriculture, food industry and housing services (NREAP, 2013).

According to Deloscanu (2013) Moldova has sufficient biomass resource to provide significant generation if utilized. There is a high potential for biomass to be included in social infrastructure and energy system development programs (especially cooperation with Ukraine).

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[6] Syngas consists mainly of hydrogen and carbon monoxide

Bioenergy seems to be a widespread source of RES worldwide. Strong requirements for sustainability and higher interest in production from biomass result in a demand for high-yielding energy crops with good conversion efficiencies (Prade, 2011).

2.5. Energy crops

Energy crops, according to an EU definition, are plants used to make biofuels or combusted to generate electricity or heat. According to carbohydrate content they can be also converted into biogas (e.g. maize). Energy crops are divided into two groups: woody (e.g. poplar, willow) and herbaceous (e.g. Miscanthus, hemp).

Growing herbal plants in the Czech Republic (for sole purpose of energy utilization) does not have tradition in our country (Sladký, 2004; Petříková, 2006). Most plants have been tested and verified, but a comprehensive guide does not exist. Petříková also recommended for cultivation in the Czech Republic mainly plants from the table 3 according to experimental researches' results.

Table 3: Energy crops suitable for CR

Lignocelluloses' plants	Woody plants (willow, poplar, alder, acacias)
	Cereals (whole plants)
	Grass (elephant grass, Reed canary grass, permanent grasslands)
	Other plants (hemp, sorghum, knotweed, rumex, mallow, hollyhock)
Oil plants	Oilseed rape, sunflower, flax
Starch – sugar plants	Potatoes, sugar beet, corn grain, Jerusalem artichoke, maize

Source: Petříková (2006)

2.6. Hemp *(Cannabis sativa L.)*

The Cannabis genus includes 3 species:

- *Cannabis sativa* (this thesis deals with this species)
- *Cannabis indica (*high content of THC, forbidden to grown)
- *Cannabis ruderalis* (weed)

Cannabis sativa L. is divided into 4 groups based on its geographical location (see Table 4).

Table 4: Division of *Cannabis sativa L*. based on geographical group

Geographic. group	Vegetation period (days)	Stalks	Leaves	Seeds	Location	Yield
Northern *(borealis)*	60 - 80	up to 0.8 m, poor in branches	small, 3 - 5 leaflets	small	north of Russia, Finland	low in fibre and seeds
Russian (*medioruthenica)*	90 - 120	up to 2 m, poor/rich in branches	medium size and wide, 3 - 9 leaflets	medium sized	Central and Eastern Europe	high in fibre, low in seeds
Southern (*australis*)	120 - 165	2 - 4 m, poor in branches	large, 9 - 13 leaflets	large, round shaped	warmer areas	medium in fibre, low in seeds
Hashish (*asiatica*)	130 - 150	1.1 - 1.15 m, rich in branches	very large and wide, 9 - 13 leaflets	small, oval shaped	India, Afghanistan North Africa	low in fibre, medium in seeds

Source: Šnobl et al. (2004)

The herbaceous crop *Cannabis sativa* (belongs to Cannabaceae family) has been grown for its fiber and seed for centuries. It originates in Western Asia and India (Sladký, 2004). The first appearance of hemp in the Czech Republic was found in archaeological excavations in Modlešice (close to Rakovník). The excavations demonstrated the use of hemp stalks to seal wooden troughs used to capture gold-bearing sand in the Celtic La Tene period from the 4th century BC (Petříková et al., 2006).

In 1937 in the U.S. cultivation of hemp was forbidden due to its psychotropic substances (THC) and later prohibition was spread to all countries. Prohibition is still in force in the U.S. and in Norway (Robinson, 1995).

Industrial hemp can be grown within the EU, but there are some restrictions for industrial hemp cultivation. In a case of production of hemp the varieties used shall have a tetrahydrocannabinol content not exceeding 0.2 %[7], only certified seeds of certain varieties can be used, and areas growing hemp require administrative approval (EU, 2003).

According to FAO, the area for total worldwide cultivation is 49, 518 ha (FAO, 2014). The world's leading producer of hemp is China, which grows industrial hemp for its fibers on about

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[7] According to the Czech Republic and EU regulations growers of industrial hemp in this country have to analyze plants samples under Custom Service supervision. Samples come from upper crop part and from various places of plot. There is also necessary to report on cannabis sawing, in the middle of growing season (when flowering), harvesting and processing.

16,500 ha. There is smaller production in Europe, Chile and the Democratic People's Republic of Korea. In the European Union hemp is grown on around 15 000 ha of land. Major producers are France, Germany and the United Kingdom (FAO, 2014).

2.6.1. Botanical description

Hemp is a thermophilous plant that can be grown at higher altitudes (up to 5000 m) with correspond yield. Cannabis is a dioecious crop; compared with the females, male plants are more slender and mature earlier. For industrial utilization monoecious varieties are preferred, due to their uniform ripening (Sladký, 2004). Hemp can grow up to 5 m in height. It is one of the most efficient plants known for its ability to utilize sunlight to photosynthesize (Hollebane, 1999).

2.6.2. Current research

Current research pays a special attention to utilize high biomass crops, especially for their fiber. Researchers also focuses on development of key cultivation techniques for hemp in different conditions (Amaducci et al., 2015), harvesting strategies (Pari et al., 2015), environmental aspects (Fernando et al., 2015) and value-added industrial products from hemp (Papadopoulou et al., 2015). Brand new research describes microbial diversity observed during hemp retting (Ribeiro et al., 2015).

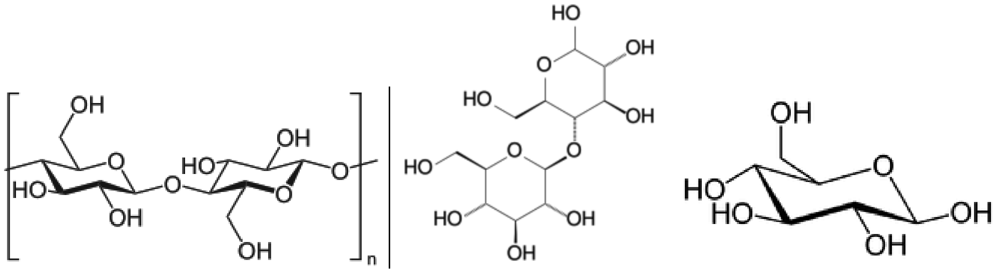
Experiments to use hemp for phytoremediation purposes were first done by Agritec, Czech company. Enhancing copper and lead bioaccumulation in rapeseed by adding hemp shives as soil natural amendments were tested in Romania with good results (Tanase et al., 2014)

2.6.3. Possible pathways for utilization of hemp energy

Based on literature resources, there are several possibilities how to use the hemp plant for energy purposes. The whole plant can be used as a source for solid biofuel. This kind of energy carrier can be transformed into heat or electricity production. The whole plant is also suitable material for biogas production (produces CH_4). Biogas can be used as vehicle fuel or for heating or electricity purposes. Hemp stems can be also used as source of bioethanol, which can be also transformed by additional processes (saccharicfication and fermentation) into fuel for vehicles. The last possible utilization is biodiesel production from hemp seeds (by transesterification) which is also possible to use for vehicles.

Hemp as source of bioethanol

Conversion of hemp into bioethanol is done by fermentation. Fermentation is a process where cellulose is broken down into fermentable glucose using an acid catalyst or cellulose enzyme complex. Scheme of the process is describe on Figure 6.



Cellulose -----------> cellobiose -------------> glukose

Figure 6: Degradation of cellulose into glucose
Source: Tutt and Olt (2011)

The industrial hemp (*Cannabis sativa L.)* hurds consist of 40%–48% cellulose, 18%–24% hemicellulose and 21%–24% lignin. The bast fibers contain higher amounts of cellulose (57%–77%) and content of hemicellulose (9%–14%) and lignin (5%–9%) is lower compared to woody core fibers (Gumuskaya, 2007).

Bioethanol is enjoying a rapid increase in production due to market demand (Tutt and Olt, 2011).

Table 5: Composition of selected plants

Sample	Ash %	Hemi cellulose %	Cellulose %	Lignin %
Energy grass	7.01	27.33	37.85	9.65
Miscanthus sacch.	5.37	30.15	42.00	7.00
Sunflower	9.78	5.18	34.06	7.72
Helianthus tuberoses	5.15	5.48	20.95	5.05
Hemp	5.25	10.60	53.86	8.76
Silage	-	25.96	39.27	9.02
Reed	-	31.50	49.40	8.74

Source: Tutt and Olt (2011)

Contemporary research is focused on suitable pre-treatment methods. Barta at al. (2010) used steam as an appropriate pre-treatment of hemp hurds that was investigated for sugar and ethanol production by enzymatic hydrolysis and simultaneous saccharification and fermentation.

Hemp as a biogas substrate

Biogas is a clean and efficient fuel. It is a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2) and hydrogen sulphide (H_2S). The chief constituent of biogas is methane (up to 75%) (Krauger et al., 2011a).

Energy crop suitability for biogasification must have a high biomass and biogas yield. Pakarinen, et al. (2010) pointed out the key role of lignin and polysaccharides (cellulose and hemicelluloses), their degradability and ability to hydrolyze. In the Table 6 is seen composition of hemp in comparing with lupine. Biomass yields of the Finland experiment were 14 t ha^{-1} DM (hemp) and 18 t ha^{-1} DM (lupine).

Table 6: Hemp composition in comparison with lupine

Crop/ component	Glucan non-	Glucan cellulose	Xylan	Arabian	Galactan	Mannan	al-A	Protein	Lignin
Hemp	4.3	33.8	4.8	1.3	1.7	1.6	5.3	9.1	1.4
Lupin	10.2	14.3	6.5	2.6	4.7	1.2	.9	16.9	6.2

Source: Pakarinen et al., 2010

In the Table 7 we can see how methane yield depends on time during anaerobic digestion. Methane production in 30 days averaged about 345 and 200 ml g^{-1} VS feed for hemp and lupine, respectively. The methane productions were 26.2 (hemp) and 58.3 (lupine) MWh ha^{-1} (Pakarinen et al., 2010).

Table 7: Methane yield of hemp

Days after sowing	63 days	83 days	119 days	146 days
Nm^3 CH_4 kg^{-1}	0.25	0.27	0.26	0.23
ton ha^{-1}	3.6	6.9	14.2	14.3
GJ CH_4 ha^{-1}	29	62	122	111

Source: Krauger et al. (2011)

Hemp as a solid fuel

There are several theoretical possibilities for the utilization of hemp as solid biofuel. Whole hemp plants can be harvested either as a green plants in the autumn, or as a plant with low water content in early spring. Prade (2011) mentioned, that digestate from biogas station also can be processed for solid fuel. Otherwise he refers high moister content therefore digestate is better as fertilizer (Prade, 2011).

Figure 7: Pellets, briquettes and hurd made of hemp,
Source: Široká (2006)

There is only one study focusing on line between moisture content and yield. Strašil (2005) compared plants from autumn and spring harvests. The table 8 below shows his experiment results (Strašil, 2005).

Table 8: Moisture and yield losses according to harvest time at selected crops (average for the period 2001-2004)

Crop	Autumn harvest		Spring harvest			
	Moisture (%)	DM yield (t ha^{-1})	Moisture (%)	DM yield (t ha^{-1})	Moisture loss (%)	Yield loss (%)
Sorghum "Hyso"	66	9.22	42	5.76	24	37.5
Reed can. grass	50	7.21	19	5.22	31	27.3
Miscanthus	50	15.57	25	12.11	25	22.3
Knotweed "Bohemika"	62	23.06	20	14.96	42	35.1
Hemp	**52**	**10.25**	**24**	**7.06**	**28**	**31.1**
Fescue grass	48	7.25	19	5.15	29	28.9
Jerusalem artichoke	57	9.56	19	5.16	24	46.1

Source: Strašil (2005)

Hemp as a source of biodiesel

Hemp biodiesel is an ester-based oxygenated fuel made of hemp oil. It comes from the pressing of the hemp seeds to extract the oil. Modification (through transesterification) makes biodiesel (FAME) able to be used directly in diesel engines. The figure 8 below shows the chemical reactions during the transesterification process.

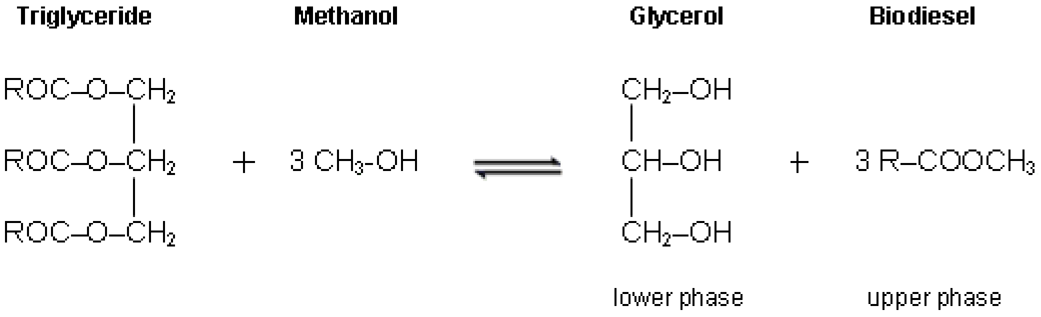


Figure 8: Scheme of transesterification process
Source: Gill et al., (2011)

Available sources mainly discuss the optimization, oil characterization and the fuel property analysis of these oils and their blends. Gill et al (2011) made a comparative analysis of hemp and *Jatropha* oils blends (both B10, B20)[8] used in diesel engines with the following conclusion: modifying through transesterification can improve fuel properties (slightly lower

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[8] B10, B20 means a blend of 10 (20) % biodiesel and 90(80) % petroleum diesel fuel

performance, higher smoke emission due to its higher viscosity). Ahmad et al. (2011) pointed out that the number of Free Fatty Acids (FFA) have a significant effect on glycerides transesterification; they make product separation and low yield biodiesel difficult to obtain. Optimum conditions for FAME were found; the optimum oil to methanol ratio is 1:6 at 60^o C.

2.7. Energy in agriculture

Agriculture is a sector that, on the one hand, consumes energy (fossil fuel, fertilizer, labor, etc.) and, on the other hand, transforms the kinetic energy of the sun (Strašil, 2005). Good knowledge of these bonds may lead to improved energy efficiency. Production energy in agriculture distinguishes this sector from other sectors that are only energy consumers (Picková, 2007). Špička (2008) in his research mentioned that it is necessary to address the energy balance in agriculture mainly because of the high energy intensity of agricultural production and the rising prices for energy. The agricultural sector is the largest consumer of water (70%, the majority for irrigation).

2.7.1. Energy inputs

Direct energy inputs

Direct energy consumption in the Czech agriculture varies from 45 to 50 billion GJ per year (Syrový, 1997) from of which 47% belongs to plant production, 37% to animal production and 16% to transport, storage and other activities.

Developing countries are based to a large extent on animal and human energy. Insufficient mechanical and electrical energy are available for agriculture, and hence the potential gains in agricultural productivity through the deployment of modern energy services are not being realized. It seems that both human and animal work will continue to be used as agricultural inputs for the future in developing countries. Efforts to support farming traditions include work on animal efficiency, which can be improved through modernization of equipment, better breeding and animal husbandry, feeding and veterinary care, and on improved designs of animal-drawn farm equipment (FAO, 2004).

Indirect energy

Energy in machines

A part of the calculation of indirect energy inputs is the energy embodied in machinery and equipment, or energy embodied during manufacturing. How Preininger expected the corresponding share of energy is continually insert into production process during lifetime of machinery (equipment). Hill et al. (2006) in his research on the “Energetic costs and benefits of biodiesel and ethanol biofuels”, they assumed its embodied energy that consist entirely of steel. It takes 25 MJ kg^{-1} to produce steel and an additional 50% energy is use for assembly.

Energy in products of chemical industry

Picková et al. (2007) mentioned that in crop production there are important energy inputs in the form of fertilizers (mainly nitrogenous) and plant protection agents; nevertheless argue that the consumption of mineral nitrogen decreases but plant protection agents increase. How Strašil et al. (2005) states to produce one ton of nitrogen requires energy 87.5 GJ, for comparing phosphate fertilizers need 17.75 GJ and potassium 9.6 GJ. According to report of Ministry of environment (ME, 2009) using fertilizers in the Czech Republic has been changing since 1990, when agriculture was transformed; there was a very substantial decrease in the consumption of mineral fertilizers and lime materials.

2.7.2. Energy outputs

Energy outputs are formed - by produced biomass and by irreversible energy losses. Preininger (1987) designated produced biomass as the sum of main and by-products, residues and root biomass. Irreversible loss of energy - the energy accumulated in the soil (from the non-harvested biomass) increase, according to author, entropy of the environment. The amount of biomass produced depends on the biological properties of cultivated crops, optimum conditions of directed technological processes (purposeful energy deposits).

The best method is to determine gross energy (calorific value) of dry matter unit. The value of the gross energy is relatively stable 17.58 GJ t^{-1} of dry matter (calorific value of cellulose (Preininger, 1987).

2.7.3. Energy balance

Balance is an objective measure of efficiency; quantification of inputs and outputs enable energy rationalization measures and evaluation of technologies for energy inputs (Preininger, 1987). The historical shift in the balance occurred when kinetic energy (power provided by animals and humans) was replaced by engines running off of fossil fuels (Picková et al., 2007). Energy balance was in equilibrium (energy was consumed as much as it was produced from the sun, water, wind and work of animals and humans) until non-renewable energy sources were discovered (Špička et al., 2008).

2.8. Life Cycle Assessment

Life Cycle Assessment (LCA) is an analytical tool based on the measurement of the technological, operational and environmental parameters of individual organizations or industries involved in the production, transport, operation or disposal of any material, equipment, fuel or energy carrier entering of any stage in the life-cycle. The LCA method is performed according to CSN EN ISO 14040[9] a CSN EN ISO 14044[10], it is a robust and transparent tool for quantification of concrete environmental impacts tied to individual input and output materials and energies. LCA is an internationally used method.

The essence of the LCA method is to determine the substance and energy flows in and out of the system under consideration (see Figure 9). Their quantity, composition, nature and seriousness for the environment are monitored. From these flows, then, the causes and consequences of the resulting changes in the environment are determined. Basic data are processed by inventory analysis. The pre-bounded part of the life cycle of the system under consideration is decomposed into unit processes, and flows are mapped between them. Following is the assessment of environmental impacts and final interpretation.

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[9] CSN EN ISO 14040 Environmental management – Life Cycle Assessment – Principles and Framework, 2006.

[10] CSN EN ISO 14044 Environmental management – Life Cycle Assessment - Requirements and guidelines, 2006.

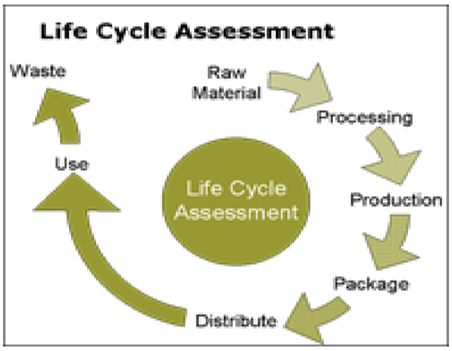

Figure 9: Life cycle assessment (LCA) scheme
Source: Baumann and Tillman (2004)

To achieve more sustainable production and consumption patterns, it must consider the environmental implications of the whole supply-chain of products, both goods and services, their use, and waste management, i.e. their entire life cycle from — cradle to grave.

The main reason for introducing renewable energy resources into energetic and transport sector is to substitute fossil fuels, decrease its consumption and limitation of anthropogenic emissions of greenhouse gasses.

2.8.1. LCA phases

Life cycle assessment has four phases, according to the ISO standards (ISO, 2006):

- Goal and scope definitions
- Inventory analysis
- Impact assessment
- Interpretation

2.8.2. Impact categories characterization

An important contribution to the use of the LCA method is to express potential environmental impacts not simply by listing the different emissions into individual environmental compartments, but by transferring these data to so-called results of impact category indicators. Following characterization of individual impact categories, which appears in this theses, was summarized from different literature resources and European norms (Kočí, 2012; Jakubes and Spitz, 2002; MZP, 2014).

Global warming potential and climate changes (GWP)

Greenhouse effect is a natural phenomenon of energy capture by greenhouse gases present in the atmosphere. GHG emissions cause ever more intensive energy retention in the atmosphere and enhancement of an otherwise natural greenhouse effect. Enhancement of the greenhouse effect is referred to as global warming. The effect of greenhouse effect is to increase global temperature and consequently climate change. Climate change is the observed change in weather at global, regional or local level. Major greenhouse gases include CO_2, methane CH_4, nitrous oxide N_2O, SF_6 (sulphur hexafluoride) and halogenated hydrocarbons such as freons and halons. The greatest absolute efficiency of greenhouse gases is water vapour. Due to its quantity in the atmosphere, its balance is not significantly influenced by humans and its total quantity is roughly constant. It has been observed that changes in concentrations of other greenhouse gases strongly correlate with changes in energy in the atmosphere.

Acidification potential (AP)

Acidification is the process of acidification of the soil or aquatic environment due to the increase in the concentration of hydrogen cations, H^+ protons. Acidification is caused by the release of acid-forming substances into the atmosphere, water and soil. Acid-forming substances are primarily those that dissociate by reaction with water and release the H + proton which carry acidic effects into the environment. Acid-forming substances, in the case of air emissions, get dry and wet deposition and collisions into other environmental compartments. Acidifiers act adversely on the biological tissues of plants, animals and bacteria and also disturb the materials. The main factor influencing acidification intensity is the amount of acid-generating emissions.

Eutrophication potential (EP)

Eutrophication is the process of nutrient enrichment. It is a problem of surface waters, soils and seas. The visible effect of eutrophication is the overgrowth of surface freshwater and seawater by aquatic cyanobacteria and algae, lack of oxygen in water, change in the species composition of ecosystems or degraded quality of surface water and drinking water sources.

Photochemical ozone creation potential (POCP)

The formation of tropospheric ozone, more commonly referred to as the formation of photo-oxidants, is a category of impact related to the adverse effect of ozone and other reactive substances in the ground level of the atmosphere. Ozone, a three-dimensional oxygen molecule, is a natural part of the Earth's atmosphere. Higher concentrations of tropospheric ozone are toxic to living organisms and oxidation reactions contribute to material disturbance. Ground-level ozone is formed by chemical reactions in the presence of solar radiation, nitrogen oxides and volatile organic compounds (VOC). As a result of human activity, the concentration of tropospheric ozone increased by 100%. The main cause of this is the growth of car traffic emitting a significant amount of nitrogen oxides.

Abiotic depletion (ADP elements, ADP fossils)

This category includes the impact of the product system on the irreversible use of non-renewable raw materials and on the consumption of renewable resources. This impact category is usually split into two, namely the loss of raw materials and the loss of energy (fossil) raw materials.

Ozone layer depletion potential (ODP)

This category describes the extent of the impact of emissions on the formation of so-called ozone hole to the stratosphere. The main cause of this problem is freons, stable halogenated hydrocarbons, which decompose and release chlorine or bromine under stratospheric conditions, the elements that catalyse the decomposition of stratospheric ozone.

Human toxicity potential (HTP), Terrestric ecotoxicity potential (TETP)

These categories characterize impacts on individual components of the environment of released substances that have the potential to cause toxic effects.

2.8.3. Research on LCA

Life cycle assessment methods were first developed in a study by Coca-Cola in 1969 (Baumann and Tillman, 2004), as a tool to establish whether glass or plastic bottles were environmentally preferable. In the following twenty years, more companies carried out their own studies of products, for example in manufacturing companies who wished to reduce the cost of production, or to eliminate waste. Life cycle assessment subsequently came to the fore as a tool for assessing the environmental impact of a process or of a product. During the 1990s, the life cycle assessment methodology was further refined, leading to the development of ISO standards 14040 to 14044, which set out the internationally recognised protocols for conducting LCAs (Finnveden, 2009).

LCA focused on RES and (hemp) biofuels

Renewable energy issues need to be viewed with regard to the whole life cycle and in the context of other energy sources. This is necessary to minimize the overall environmental impacts of energy sector. Market behaviour in this area can generate additional undesirable externalities with crossover to other sectors (Kočí, 2012). Achten and Verchot (2011) mentioned, that growing of large scale crops with the aim of producing biofuels have a number of undesirable environmental consequences: the release of carbon-bound in soils, even in tropical areas where crop cultivation seems to be beneficial (Achten and Vrchot 2008). Also, in India, a rapidly growing of *Jatropha Curcas*, which was perceived very optimistically in the view of fuel production, is not without problems (Achten and Mathijs, 2007). Alternative fertilization practices with lower impact on greenhouse gas emissions (Alluvione et al., 2010) may also offer some potential for environmental improvement.

Literary sources show that the assessment of environmental impacts and their potential links should be comprehensively. The benefits and shortcomings of individual renewable energy sources need to be assessed using different criteria.

The research of life cycle assessment (LCA) of biofuels is engaged in several research institutes in the world; such as LCA biodiesel from hemp seeds (O'Mahony, 2011), LCA hemp hurds (González-García et al., 2012), Life cycle environmental impacts of cornstalk briquette fuel in China (Wang et al., 2017) However according to Kočí (2012) these research results are hard to implement in condition of the Czech Republic. Kočí in his research made LCA of renewable energy sources in the Czech Republic with world indicators, but also mentioned the need to further research on this topic (Kočí, 2012).

3. OBJECTIVES

The main Thesis objective is “Evaluation of solid biofuels made of hemp biomass (spring and autumn harvest) from position of sustainability aspects including energy production per unit of area and impact on environment”.

The further formulated **specific objectives** should contribute to meeting the main objective. They are as follows:

1. As a verification of the standardized yield, to investigate potential hemp biomass yields per hectare at different localities
2. To determine advance energy balance of hemp used for solid biofuels for autumn and spring harvests for both localities, i.e. assessment of EROEI.
3. To design LCA of hemp solid fuels according to EU norm as the main parameter of sustainability.

General assumptions:
Production of biofuels made of hemp from trial plots in the Czech Republic and in the Republic of Moldova have positive energy balances.

Energy of briquetted hemp biomass has a more favorable impact on the environment than the use of traditional energy resources (coal).

4. MATERIAL AND METHODS

General conditions

This part of the thesis is based on trial experiments on hemp. Biomass was grown in two localities. Experimental plots of hemp were established on the territory of the Czech University of Life Sciences in Prague and Moldovan Botanical garden in Chisinau in the area of 99 m^2 each. For experiment French variety Ferimon and Bialobrzeskie – Polish variety were used. Both, according to previous experience have the highest yield, so it is the most appropriate for energy purposes (Kolaříková et al., 2013). Hemp was cultivated in both localities in order to obtain biomass for the energy yield evaluation from its autumn and spring harvests. Seed rate was 60 kg ha^{-1}, row spacing 12.5 cm, and sowing depth 3 cm.

Plants from the fields' trials were used for laboratory determination of moisture and hydrogen content, gross calorific values. Biomass from the field was harvested for biomass yield determining; according to which energy yield could be calculated. Hemp biomass was processed into solid biofuels (briquettes).

Normative parameters were done according to European norms:

- EN ISO 18134-3. 2015. Solid biofuels – Determination in moisture content – Oven dry method: Part 3: Moisture in general analysis sample. BSI Standards Publication, 14 pp.
- EN 14780. 2011. Solid biofuels – Sample preparation. BSI Standards Publication, 28 pp.
- EN 14918. 2009. Solid biofuels – Determination of calorific value. BSI Standards Publication, 64 pp.
- EN ISO 16948. 2015. Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen. BSI Standards Publication, 20 pp.

For both localities (Prague, Chisinau) half of this area was harvested in autumn (the growing season from May to October) and half in spring (May to February or March depending on the water content in the plants). Hemp harvested as a green plant in autumn was left under a roof for losing moisture (without additional input in the form of drying), to keep yield as high as possible and exempt the field for another crop in the rotation system. The regular analysis of samples for the determination of biomass moisture content was carried out until the required value (15% of moisture) was achieved; and then biomass was processed. The second (spring) part of experiment was monitored in the field by periodical sampling and, at about 15% moisture the biomass was harvested and immediately processed.

Aspects of the current Moldovan agriculture were taken into account, i.e. large share of manual labor as well as common agricultural practices for hemp cultivation in the Czech Republic. The produced biofuel - briquettes are considered to produce energy in the form of heat for the household use (small scale boiler).

4.1. Basic analysis and determination

4.1.1. Samples analysis

Samples for laboratory tests were taken from the fields for moisture content measurement and determination of gross calorific value (hereinafter GCV). All above-ground plant biomass was harvested and weight according to common agricultural practices to obtain data about biomass yield and energy yield. Standard methods were used for analysis of biomass samples.

4.1.2. Biomass Yield (BY) determination

The biomass yields of the small-scale samples, determined by collecting and weighing all plants of the trial plots (Figure 10) were extrapolated to a biomass yield per hectare.

Figure 10: Field of hemp in September 2013 in Botanical garden of Moldova (left side) and on the territory of the Czech University of Life Sciences (right side)
Source: Author (2013)

4.1.3. Moisture content (MC)

The main principle is: the representative sample of biofuel is dried at a temperature of 105 ^{o}C and the percentage moisture is calculated from the loss in the mass sample.

MC was determined as the total water; a controlled drying of a sample in the oven MEMMERT model 100-800 was used (see Figure 11).

Figure 11: Samples in laboratory oven MEMMERT model 100-800
Source: Medová (2015)

The samples of materials (1 whole plant of each variety to be eliminated differences among individual parts of the plant) were taken, put into beakers and weighed. Then the beakers with the samples were placed on the shelf of the oven and dried for 8 hours at 105 °C. After the drying the beakers with the dried materials were removed from the oven, and weighed. The weighing was carried out by laboratory balance KERN EW 3000 - 2M with preciseness up to 0.01 g. The following formula (1) is then used to calculate the material moisture content (MC):

$$\mathbf{MC = [(m_w - m_d)/\ m_w] * 100}\ [\%] \qquad (1)$$

where: m_w – total mass of wet material [g]
m_d – dry matter mass of the dried material [g]

4.1.4. Dry matter (DM)

Dry matter is defined according to the Norm as "material after removal of moisture under specific conditions". DM was obtained from the moisture content measures using the equation (2):

$$\mathbf{DM = (100 - MC)/\ 100 * BY}\ [\mathrm{t\ ha^{-1}}] \qquad (2)$$

where: MC – moisture content [%]
BY – biomass yield [t ha^{-1}]

4.1.5. Gross calorific value (GCV)

The energy content of biomass can be calculated by its calorific value (equation 3). The calorific value can be determined in a bomb calorimeter, resulting in the so called gross calorific value, which is a measure of the theoretical maximum energy to be derived from the biomass by any kind of thermal conversion.

$$\mathbf{GCV = (dTk * Tk - c) / m}\ [\mathrm{J\ g^{-1}}] \qquad (3)$$

where: dTk – temperature jump [^{0}C]
Tk – heat capacity of calorimeter [J $^0C^{-1}$]
c – external energy [J]
m – weight of material sample [g]

The laboratory measurement of the gross calorific values was carried out in the IKA C 6000 isoperibol oxygen bomb calorimeter (see Figure 12). Combustion processes take place in a calorimeter under defined conditions. For this purpose, the decomposition vessel is coated with a weighed out quantity of fuel sample, the fuel sample is ignited, and the increase in temperature of the calorimeter system is measured.

The specific gross calorific value of the sample is calculated from:

- the weight of the fuel sample
- the heat capacity (Tk value) of the calorimeter system
- the increase in temperature of the water (temperature jump) within the inner vessel of the measuring cell

Figure 12: Calorimeter IKA C6000
Source: Author

GCV measurement was done by author herself at the Bioenergy centre of Research Institute of Agriculture Engineering, p.r.i.

4.1.6. Biomass energy yield (BEY)

The biomass energy yield (BEY) per hectare describes the total amount of energy stored in biomass, i.e. the energy potential. It is calculated from the biomass dry matter yield per hectare and the corresponding gross calorific value on dry basis (GCV_{db}) of the biomass.

The quantity of dry matter produced by a biomass species per unit area of production determines the potential energy production capacity, or yield, of the available land area. Production is measured in DMt per ha and combined with the GCV of the biomass, the energy yield of the cultivated crop can be calculated as follows:

$$\mathbf{BEY= DM^{*}\, GCV_{db}}\ [\mathrm{GJ\ ha^{-1}}] \qquad (4)$$

where: DM – dry matter [t ha^{-1}]

GCV – gross calorific value [GJ t^{-1}]

4.1.6.1. Net calorific value determination (NCV)

According to Norm define as: “q_{net} – calculated value of the specific energy of combustion for unit mass of a fuel burned in oxygen at constant pressure under such conditions that all the water of the reaction product remain as water vapour (at 0.1 MPa) and the other products being as for the gross calorific value, all at the reference temperature” (EN ISO 16559:2014).

Determination of gross calorific value was carried out in a calorimeter, where the combustion of the sample in oxygen determines the heat that this reaction releases.

Determining of hydrogen content was done by author in the Bioenergy centre of Research Institute of Agriculture Engineering, p.r.i. Dried samples of biomass were ground in an IKA analytic mill. The ground samples were again dried to constant weight, after which they were subjected to chemical analyses. The content of hydrogen in the biomass of the analysed sample of hemp was determined in an Elementary Analyser LECO CHN628 (Fig. 13).

CHN628 uses the principle of the Dumas combustion method. The analyzed sample weighed into the capsule or foil is burned in the kiln. The resulting gases are then entrained in the oxygen stream into the secondary combustion tube for better oxidation and removal of undesirable particles. Gases also pass through a freeze unit that removes unwanted moisture.

The gas mixture is collected in ballast vessel where the gases are stabilized and homogenized. Only aliquots containing a representative sample are transferred from the detection system. Each element has a separate IR detection cell for detecting C, H, and TC for detecting N. Detection methods used:

- Carbon/ Hydrogen – Non-Dispersive Infrared (IR) absorption
- Nitrogen – Thermal Conductivity (TC Cell) Detector

Figure 13: Elementary Analyser LECO CHN628
Source: Author

Then NCV on dry basis was calculated from equations 5 as:

$$\mathbf{NCV = GCV - 24.42 * (W_a + 8.94 * H_a)}\ [J\ g^{-1}] \qquad (5)$$

where: GCV – gross calorific value [J g^{-1}]

24.42 – coefficient of 1% of water in the sample on temperature of 25°C (enthalpy difference between gaseous and liquid water at 25°C) [J g^{-1}]

W_a – moisture content in the sample [%]

8.94 – coefficient for the conversion of hydrogen to water (molar mass ratio between water H_2O and hydrogen H_2)

H_a – hydrogen content in the sample [%]

4.2. Energy balance

Determination of the energy balance for technological process of growing hemp for energy purposes was executed in the following steps:

- Determination of system boundaries
- Energy input calculation; adjustment for harvest losses
- Energy output determination
- Net energy yield and EROEI calculation

Baseline for Energy balance calculation was methodology of FMZVž No. 7/1987 titled "Energy evaluation of processes in crop production" (Preininger, 1987), which was adjusted.

4.2.1. Determination of system boundaries and scenarios:

This calculation was carried out from cultivation until distribution of the final energy product (system boundaries).

The produced bio-fuel i.e. briquettes produced energy in the form of heat for the personal use of the farmer. The system boundaries include soil preparation, biomass processing into the form of briquettes, briquettes´ transporting to the farmer's house and combusting in the small scale boiler for heating purposes.

To calculate the energy balance in Moldova, a model situation was chosen. Aspects of the current Moldovan agriculture were taken into account i.e. large share of manual labor (http://mecagro.md/en/).

For cultivation in the Czech Republic – technological process of hemp cultivation was adopted from Research Institute of Agricultural Engineering, p.r.i. (Abrham, 2009).

Detailed descriptions of the technological processes of both countries are included in Tables 12 and 13.

Considered scenarios:

1. Heat from autumn-harvested briquetted hemp (Republic of Moldova)
2. Heat from spring-harvested briquetted hemp (Republic of Moldova)
3. Heat from autumn-harvested briquetted hemp (Czech Republic)
4. Heat from spring-harvested briquetted hemp (Czech Republic)

- For 1. and 3.: Hemp harvested as a green plant in autumn was left under a roof for losing moisture, to keep yield as high as possible and remain the field for another crop in the rotation system
- For 2. and 4.: Hemp was left in the field untill moisture content reached 15%

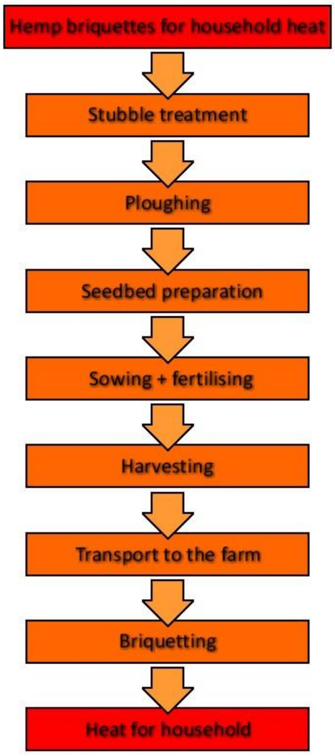

Figure 14: Schematic overview of the field and transport operations accounted for heat production from briquetted hemp biomass

Source: Author (2015)

All scenarios (for schematic overview see Fig. 14) describe the production of heat from combustion of autumn or spring-harvested, chopped and briquetted hemp. This scenario(s) illustrates the utilisation by combustion in small-scale boilers for household heating with efficiency of 80%.

4.2.2. Energy input calculation

The analyses of energy input were made on the basis of normalised biomass yields, general crop-specific cultivation recommendations (N-fertilisation level, use of pesticides, etc.) for each country and common agricultural practices. Energy equivalent are summarized in table 9.

Energy inputs (EI) taken into account are that of human labor (E1), energy in fuels (E2), energy embedded in machines (E3), in seeds (E4), and in fertilizers (E5) see formula 6.

$$\mathbf{EI = E1 + E2 + E3 + E4 + E5} \qquad [\mathrm{MJ\ ha^{-1}}] \qquad (6)$$

Energy of human labor (E1)

E1 was determined as the conversion of spent labor in the energy equivalent (formula 7). Data for the spent of labor in individual operations were taken from a database of Normative for Agriculture and Food Production (Kavka et al., 2008) as typical for each field operation. The energy equivalent of human labor is determined on the basis of energy consumption for food production in the country. For the recommended energy intake (14MJ day^{-1}) energy equivalent 0.583 MJ h^{-1} was taken into consideration.

$$\mathbf{E1 = S_{hl} * e_{hl}} \qquad [\mathrm{MJ\ ha^{-1}}] \qquad (7)$$

where: E1 – energy of human labor [MJ ha^{-1}]
S_{hl} – spent human labor [h ha^{-1}]
e_{hl} – energy equivalent of human labor [MJ h^{-1}]

Energy in fuels (E2)

The amount of energy in fuels (E2) was determined as the conversion of fuels (l, kWh) in the energy equivalent (see formula 8 and 9)

Indirect energy factor (IEF) for diesel was assumed to be 1.19 (15% for diesel production and 4% for lubricants used during machinery operation), resulting in 44.5 MJ of energy per liter diesel used. Data for consumption of diesel were taken from a database of Normative for Agriculture and food production (Kavka et al., 2008) as consumption per hour typical for each field operation and the associated effective capacity and frequency.

$$\mathbf{E21 = S_d * e_d} \qquad [\mathrm{MJ\ ha^{-1}}] \qquad (8)$$

where: E21– energy in diesel [MJ ha^{-1}]
S_d – spent diesel [l ha^{-1}]
e_d – energy equivalent of diesel [MJ l^{-1}]

Indirect energy factor for electricity was assumed to be 1.5 according to Špička (2013) based on the electricity mix.

$$\mathbf{E22 = S_{el} * e_{el}} \quad [\mathrm{MJ\ ha^{-1}}] \quad (9)$$

where: E22 – energy in electricity [MJ ha^{-1}]

S_{el} – spent electricity [kWh ha^{-1}]

$_{el}$ – energy equivalent of electricity [MJ kWh]

Energy embedded in machines (E3)

E3 was calculated as multiplying – weight of machine, conversion equivalent, time spent in operation and repairing and maintenance coefficient divided by total number of working hours per machine´s service life (see formula 10).

The annual use, the machinery's nominal lifetime repairing and maintenance coefficient and the weight of the machinery was taken from Kavka et al. (2008).

Energy equivalent of energy consumption for use of materials in production of machinery was assumed to be 17.5 MJ kg^{-1} for iron, 10 MJ kg^{-1} for cast iron, and 85 MJ kg^{-1} for tyres according to Gissén (Gissén et al., 2014). Embodied energy in machinery was calculated according to the assumption of 45% iron, 45% cast iron and 10% tyres. For machinery without tyres, an even blend of iron and cast iron was assumed (50% and 50 %).

$$\mathbf{E3 = T_s \cdot (\ m \cdot K_e \cdot K_{rm} / \ T_{wh})} \quad [\mathrm{MJ\ ha^{-1}}] \quad (10)$$

where: E3 – energy embedded in machines [MJ ha^{-1}]

m – weight of machine [kg]

K_e – conversion equivalent [MJ kg^{-1}]

T_s – time spent in operation [h ha^{-1}]

K_{rm} – repairing and maintenance coefficient

T_{wh} – total number of working hours per machine’s service life [h].

Energy in seeds (E4)

Energy for the production of seed material (energy equivalent) (E4) was calculated from the accumulated energy inputs for hemp crop, typical seed yields SY (7%) according to Preininger (1987) and assumed energy inputs for drying (Ed) and transport of the seeds (Et) according to Pinmentel (1992) – see formula 11.

$$\mathbf{E4= [(E1+ E2 + E3 + E4) * Sr * SY + Sr * Y* (Ed + Et)] / Y – Sr * SY} \quad [\mathrm{MJ\ ha^{-1}}] \quad (11)$$

where:

E4 – energy in seeds [MJ ha^{-1}]
E1 – energy of human labor [MJ ha^{-1}]
E2 - energy in fuels [MJ ha^{-1}]
E3 – energy embedded in machines [MJ ha^{-1}]
E5 – energy in fertilizers [MJ ha^{-1}]
Sr – seed rate [kg]
SY – seed yield [kg]
Ed –energy for seed drying [MJ kg^{-1}]
Et – energy for seed transport [MJ kg^{-1}]
Y – yield of hemp (typical) considered 12 000 kg [kg ha^{-1}]

Energy in fertilizers (E5)

The amount of energy in fertilizers (E5) was determined as the conversion of material (t) in the energy equivalent (see formula 12).

For industrial hemp grown for biomass in the Czech Republic, it is consider:

- F1=4.5 t farmyard manure, content of nutrients per ton (1.35 kg N, 1.2 kg P, 6 kg K)
- F2=250 kg superphosphate (19% of P2O5) + 0.1 t potassium salt (60% of K2O)
- F3=350 kg ammonium sulphate (21% of N)
- F4=250 kg LAV ammonium saltpetre with limestone (27% of N, 20% of CaO)

For industrial hemp grown for energy purposes in the Republic of Moldova, it is consider:

- F1=4.5 t farmyard manure, content of nutrients per ton (1.35 kg N, 1.2 kg P, 6 kg K)
- F2=250 kg superphosphate (19% of P2O5) + 0.1 t potassium salt (60% of K2O)
- F3=350 kg ammonium sulphate (21% of N)

N, P and K were accounted according to Gissén et al. (2014) as pure nutrition in fertilizers with energy equivalents (48.0 MJ kg^{-1}, 18.7 MJ kg^{-1} and 10.6 MJ kg^{-1}, respectively).

$$\mathbf{E5 = S_{fe} * e_{fe}} \qquad [\mathrm{MJ\ ha^{-1}}] \qquad (12)$$

where: E5 – energy in fertilizers [MJ ha^{-1}]
S_{fe} – spent fertilizers [kg ha^{-1}]
e_{fe} – energy equivalents [MJ kg^{-1}]

Energy inputs that were not accounted with are solar energy, transportation of building materials for storage areas and machinery, demolition of buildings and machinery and material recycling.

Table 9: Energy equivalents used in calculation

Item	Energy equivalent (Direct+ indirect energy)	Source
Human labor	0.583 MJ h^{-1}	FAO (2014), own calculation
Diesel	44.5 MJ l^{-1}	Špička (2008)
Electricity	5.4 MJ $(kWh)^{-1}$	Špička (2008)
Machinery	20.88 MJ kg^{-1}	Gissén (2014), own calculation
Machinery without tyres	13.75 MJ kg^{-1}	Gissén (2014), own calculation
Seed drying	0.83 MJ kg^{-1}	Pinmentel (1992)
Seed transport	1.15 MJ kg^{-1}	Pinmentel (1992)
P (P_2O_5)*	18.700 MJ kg^{-1}	Gissén (2014)
K (K_2O)*	10.600 MJ kg^{-1}	Gissén (2014)
Ca (CaO)*	2.800 MJ kg^{-1}	Špička (2008)
N (100%)*	48.000 MJ kg^{-1}	Gissén (2014)
Superphosphate (19% P_2O_5)	3.553 MJ kg-1	Own calculation
Limestone (87.5% CaO)	2.450 MJ kg^{-1}	Own calculation
Ammonium sulphate (21% N)	10.080 MJ kg^{-1}	Own calculation
Potassium salt (60% K_2O)	6.360 MJ kg^{-1}	Own calculation
Farmyard manure	0.151 MJ kg^{-1}	Own calculation

*pure nutrients

4.2.3. Adjustment for harvest losses

Biomass yield data from field trials in this study represent the amount of biomass standing in the field as crops. To account for losses during harvest, hemp DM yields were reduced by 10% and 25% (according to Prade, 2012)for autumn and spring harvest, respectively.

4.2.4. Energy outputs – useful heat calculation

The energy output (Eo) for the use of hemp biomass as solid biofuel was calculated from the Processed Biomass Yield (Dry matter yield recalculated to MC 15%) and the corresponding net calorific value. In the process there were taking into consideration losses during combustion process (20%).

4.2.5. Net energy yield, Energy return on energy invested (EROEI)

The net energy yield (NEY) was calculated by subtracting the sum of direct and indirect energy inputs from the energy output (see formula 13). The energy return on energy invested (EROEI) was calculated by dividing energy output by the accumulated energy inputs (formula 14)

$$\mathbf{NEY = Eo - Ei} \quad [\mathrm{GJ\ ha^{-1}}] \tag{13}$$

$$\mathbf{EROEI = Eo / Ei} \tag{14}$$

4.3. Environmental impact

LCA method used

Comprehensive evaluation of potential environmental impacts by Life Cycle Assessment (LCA) method standardized in international standards series ISO 14040 takes place in the following steps:

4.3.1. Definitions of scope of the LCA study

The scope definition consists of sets of two specifications:

- ✓ specification of technical parameters (definition of function, function unit and reference flow, determining of system boundaries, allocation procedures and selection of characterization model)
- ✓ specification of procedural steps related to the preparation of the study (determining the quality assurance procedures performed)

4.3.2. Definition of goals

- ✓ the objective of the study, its content, the significance of whom the study is intended and under what conditions its conclusions will be valid

4.3.3. LCI - Life cycle inventory analysis

- ✓ quantifying the number of elementary flows released during the product life cycle into the environment; defining processes entering the product system

Life cycle inventory analysis was done in the following steps:

- ✓ Set a flow chart (scheme) of the product system
- ✓ Data collection and calculation
- ✓ Setting of calculation procedures
- ✓ Verifying the accuracy of the data obtained
- ✓ Assignment of data production unit of the whole system
- ✓ Assign a recognition of the unit processes and
- ✓ Calculation of the eco-vector of the product system

4.3.4. LCIA - Life cycle impact assessment

The main objective of this phase was to convert individual quantities of elementary flows, to the values of impact category indicators describing the potential extent of impact on individual environmental problems. The LCIA aims to compare the environmental impacts of product systems measurably and compare their severity with new quantifiable variables designated as impact categories.

The transformation of environmental interactions of product systems expressed by eco-vectors for a clear set of specific environmental issues was considered:

- Global Warming Potential and Climate Change GWP[greenhouse gases, expressed in kilograms of CO_2 equivalent per MJ of fuel]
- Eutrophication Potential EP [PO_4^{3-} equivalent per unit of energy],
- Acidification Potential AP [SO_2 equivalents per unit of energy],
- Photochemical Ozone Creation Potential POCP [C_2H_2 equivalents per unit of energy],
- Abiotic Depletion Potential (ADP elements) [kg Sb-equiv.]
- Abiotic Depletion Potential (ADP fossil) [MJ]
- Ozone Layer Depletion Potential (ODP, steady state) [kg R11-equiv.]
- Terrestric Ecotoxicity Potential (TETP) [kg R11-equiv.]
- Freshwater Aquatic Ecotoxicity Potential (FAETP) [kg DCB-equiv.]
- Human Toxicity Potential (HTP) [kg DCB-equiv.]
- Marine Aquatic Ecotoxicity Potential (MAETP) [kg DCB-equiv.]

- ✓ *Characterization model of the impact category setting*

A defined procedure for expressing the influence of elementary flows on a particular impact category on whose development to the given elementary flows are involved.
Based on input information, the following LCA models of individual products were developed to serve as the basis for calculation of environmental indicators. The background of each of the illustrated process images is a dynamically interconnected database of environmental impacts that is used for the calculations.

Normalization

In order to compare the degree of importance of environmental impacts between the different impacts categories, the results of the impact on the individual impact categories should be normalized (a comparison of the statistical significance of interventions into different impact categories).

4.3.5. **Interpretation**

Life cycle analysis results were interpreted in accordance with objective and scope of study.

Life cycle assessment was elaborated in cooperation with the University of Chemistry and Technology in Prague, has manufacture the **LCA software.**

For calculation and product life cycle modelling, specialized software and inventory data from databases were used. In this study, the professional GaBi6 LCA software, created by Stuttgart's Thinkstep company, in collaboration with the Stuttgart Technical University[11], was used.

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[11] https://www.thinkstep.com/software/gabi-lca/

5. RESULTS AND DISCUSSION

5.1. Energy balance

The input–output methodology has been applied to characterize the energy balance of hemp briquettes intended for household heating.

Balance is an objective measure of efficiency; quantification of inputs and outputs enable energy rationalization measures and evaluation of technologies for energy inputs (Preininger, 1987).

5.1.1 Energy outputs

Energy outputs as results of field and laboratory measurements from Moldova experiment as shown in Table 10.

Table 10. Biomass yield, moisture content (MC), Gross calorific value (GCV), Dry matter (DM), Net calorific value (NCV), Energy in processed biomass, Harvest losses, Energy in harvestable biomass, Combustion heat losses, Useful heat from Moldova experiment

Variety	Time of harvest	Yield [t ha^{-1}]	MC [%]	GCV$_{db}$[1] [GJ t^{-1}]	DM [t ha^{-1}]	BY 15[2] [t ha^{-1}]	NCV$_{wb}$[3] [GJ t^{-1}]	Biomass energy yield[4] BEY [GJ ha^{-1}]	Energy in processed biomass[5] [GJ ha^{-1}]	Harvest losses %	Energy in harvestable biomass [GJ ha^{-1}]	Combustion losses [%]	Useful heat [GJ ha^{-1}]
Bialobrzeskie	autumn	28.9	58.3	18.10	12.05	14.18	13.73	218.11	194.69	10	175.22	20	140.18
Ferimon	autumn	31.1	61.2	18.60	12.07	14.20	14.16	224.50	201.07	10	180.96	20	144.77
Bialobrzeskie	spring	11.96	15.6	18.35	10.09	11.87	13.95	185.15	165.59	25	124.19	20	99.35
Ferimon	spring	12.33	15.8	18.84	10.38	12.21	14.36	195.56	175.34	25	131.51	20	105.21

Note:

[1] GCV$_{db}$ = Gross calorific value on dry basis - value for sample with moisture content 0%

[2] BY15 = Biomass yield recalculated for 15% moisture content (when biomass can be further processed)

[3] NCV$_{wb}$ = Lower calorific value on wet basis = taken into account gross calorific value on wet basis GCV$_{wb}$,moisture content 15%, and value of H content (with 15%MC)

[4] Biomass energy yield BEY–= maximal energy potential that can be derived by any conversion (DM multiplied by GCV$_{db}$)

[5] Energy in processed biomass= NCV$_{wb}$ multiplied by BY15

Energy outputs as results of field and laboratory measurements resulted from the Czech experiment as shown in Table 11.

Table 11. Biomass yield, moisture content (MC), Gross calorific value (GCV), Dry matter (DM), Net calorific value (NCV), Energy in processed biomass, Harvest losses, energy in harvestable biomass, combustion heat losses, useful heat from the Czech experiment

Variety	Time of harvest	Yield [t ha^{-1}]	MC [%]	GCV$_{db}$[1] [GJ t^{-1}]	DM [t ha^{-1}]	BY 15[2] [t ha^{-1}]	NCV$_{wb}$[3] [GJ t^{-1}]	Biomass energy yield[4] BEY [GJ ha^{-1}]	Energy in processed biomass[5] [GJ ha^{-1}]	Harvest losses %	Energy in harvestable biomass [GJ ha^{-1}]	Combustion losses %	Useful heat [GJ ha^{-1}]
Bialobrzeskie	autumn	22.1	56.8	17.61	9.55	11.24	13.32	168.18	149.72	10	134.75	20	107.80
Ferimon	autumn	26.5	59.8	17.93	10.65	12.53	13.59	190.95	170.28	10	153.25	20	122.60
Bialobrzeskie	spring	10.33	15.04	18.14	8.78	10.33	13.77	159.27	142.24	25	106.68	20	85.34
Ferimon	spring	11.08	16.19	18.21	9.29	10.93	13.83	169.18	151.16	25	113.37	20	90.70

Note:

[1] GCV$_{db}$ = Gross calorific value on dry basis - value for sample with moisture content 0%

[2] BY15 = Biomass yield recalculated for 15% moisture content (when biomass can be further processed)

[3] NCV$_{wb}$ = Lower calorific value on wet basis = taken into account gross calorific value on wet basis GCV$_{wb}$,moisture content 15%, real value of H content

[4] Biomass energy yield BEY– maximal energy potential that can be derived by any conversion (DM multiplied by GCV$_{db}$)

[5] Energy in processed biomass= NCV$_{wb}$ multiplied by BY15

Dry matter (DM) yield evaluation

Biomass yield of industrial hemp is the most important factor affecting better energy efficiency. During the growing season, the yields of *Cannabis sativa* var. Bialobrzeskie and Ferimon in the following locations: Czech University of Life Sciences Prague (Czech Republic) and Botanical Garden in Chisinau (Moldova) were evaluated and its comparison with DM yield from available literature resources was done.

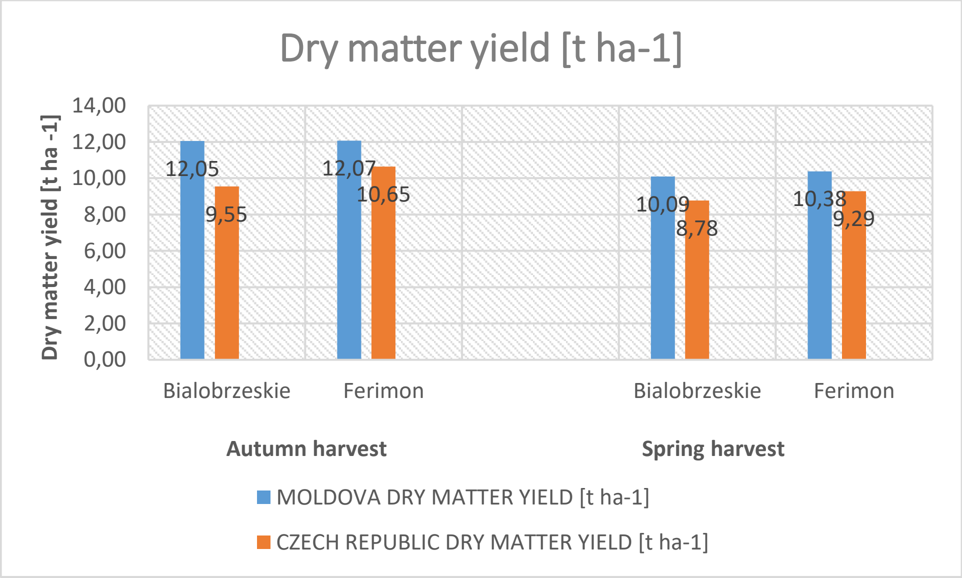

Figure 15: Dry matter (DM) biomass yields
Source: Author (2016)

Figure 15 shows that the Ferimon variety had a 10.3% higher yield in autumn than Bialobrzeskie in the Czech Republic (CR), in the Republic of Moldova (MLD) there was no significant difference between the autumn yields of both varieties. The yield from autumn harvest for Ferimon was 11.8% higher in Moldova, for the Bialobrzeskie variety the yield is higher by 20.8%, both compared with the Czech Republic. Further it was evident that the Ferimon variety had 5.5% higher yield than the Bialobrzeskie during the spring harvest in the Czech Republic. Difference between varieties (in spring) was 2.8% in the Republic of Moldova. The yield from the spring harvest for Ferimon is 10.5% higher in MLD; for the Bialobrzeskie variety the yield in MLD is higher by 13%.

In addition, the following findings arise from the experiment:

- The autumn harvest has higher yields per hectare than spring.

- Moldova has higher yields per hectare than the Czech Republic.
- The biggest DM yield had the Ferimon variety harvested in the autumn in the MLD locality, 12.7 t ha^{-1}.

Biomass yields often vary with the weather conditions during cultivation (Campiglia et al., 2017; Finnan et al., 2013). Major parameters influencing biomass yield are accumulated temperature and precipitation (Prade et al., 2011), which are dependent on e.g. geographic location and sowing date. Higher yield per hectare in MLD locality was caused by more favourable climatic conditions of the country in comparison with the Czech Republic. In the Czech Republic there is a temperate continental climate with the sum of precipitation 500mm on a yearly basis and average temperature 8.7°C (Chuchma et al., 2016). The Republic of Moldova lies in warm humid continental climate (region of Chisinau) with the sum of precipitation per year around 600mm and average temperature 10°C (Cantore, 2017).

According to available literature, DM biomass yield of hemp (*Cannabis sativa*) purposely cultivated for energy varies from 8.5 to 12.5 DMt per hectare (Prade (2011), Kreuger et al. (2011a), Abrham (2009), Campiglia et al., (2017), Sladky (2004)). It can be stated that the trial plots reached the average of the literature standards at both sites.

Moisture content (MC) evaluation

Low MC is necessary for application as a solid fuel in order to decrease losses due to microbial degradation during storage (MC < 30%); achieve sufficient durability of solid biofuel after compression of biomass (10% < MC < 20%); and decrease energy losses in boiler not equipped with flue gasses condensation (MC < 20%) (Prade, 2012).

Hemp harvesting dates for briquettes´ production should be optimised in regard to moisture content.

Figure 16 shows a change in moisture content of *Cannabis sativa L.* (Bialobrzeskie variety) experimentally tested from 21st October 2014 to 25th March 2015 in the trial plot of the Czech University of Life Sciences (Medová, 2015). It is visible from the graph that plant biomass MC decreased from average 60% in October to average 15% in March. In the beginning of the experiment, the water content in plants ranged around 62% and gradually declined until November. In mid-December the water content in plants still ranged around 50%. The significantly drying rates occurred in the period December – January, i.e. decrease by 34%. MC values measured on biomass from the MLD and CR experimental sites are in line with the results that were found in related experiments carried out in the indirect connection with this work on the site of the Czech University of Life Sciences Prague.

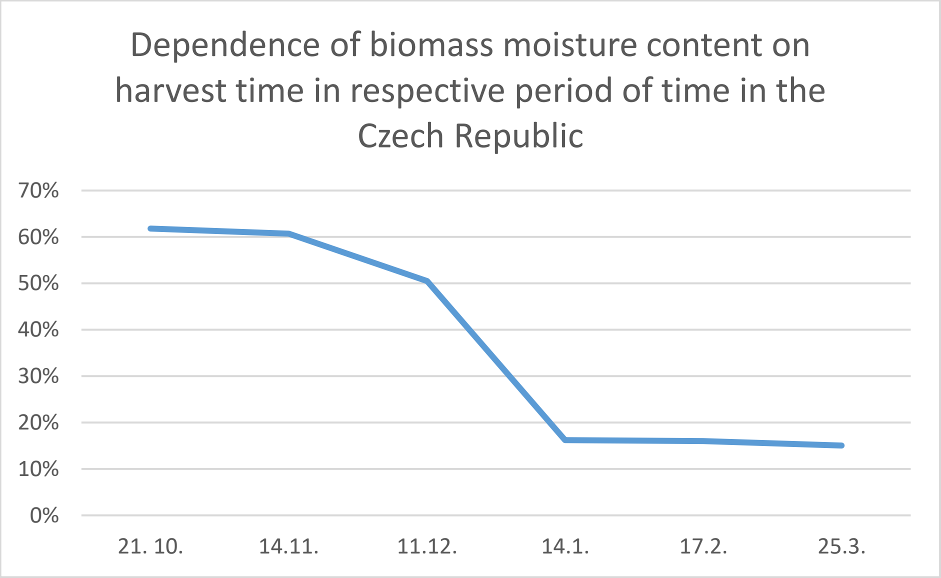

Figure 16: Dependence of biomass moisture content on harvest time
Source: Medová (2015)

Content of water in the bio material is crucial when used for biofuels. Not only in the case of industrial hemp, but all crops harvested in autumn have significantly higher yield than in spring (Ruf et al., 2017; Balezentiene, 2011). One of the advantages of spring harvest is low moisture content. This pros is balanced off by a lower yield. Autumn harvest is always connected with the problem of biomass drying, which is consequently linked with additional inputs in the form of energy or necessity of suitable storage place available.

Prade et al. (2012) in his study states that biomass of industrial hemp grown for the production of solid biofuels and biogas contained 65% of water during the harvest period from September to October, whereas during the harvest period from February to April, the water content in biomass decreased to 15%. Kreuger (2011b) mentioned in the results of his experiments that high biomass dry matter yield and high degradability are advantageous for methane energy yield and high moisture content is seen as not a disadvantage. Foreign literature sources further mention that the optimal moisture content in plant biomass considered for combustion should be in the range of 10-15% (Chen et al., 2009)

Gross calorific value evaluation (GCV)

In Moldova experiment the GCV of the hemp biomass increased from an average 18.1 MJ kg^{-1} in October to an average of 18.4 MJ kg^{-1} in March for Bialobrzeskie variety and from 18.6 to 18.8 MJ kg^{-1} for Ferimon in autumn and spring, respectively.

In the conditions of the Czech Republic, GCV was determined as 17.6 MJ kg^{-1}, 18.1 MJ kg^{-1} in October variety Bialobrzeskie, Ferimon, respectively and 17.9 MJ kg^{-1}, 18.2 MJ kg^{-1} in March variety Bialobrzeskie, Ferimon, respectively.

This change can occur by reducing the ash content due to the changing chemical composition and biomass structure. According to Kreuger et al. (2011a) results from Sweden, the GCV of the hemp biomass increased significantly from 17.5 MJ kg^{-1} in July to an average of 18.4 MJ kg^{-1} during the period August - December. It further increased significantly to an average of 19.1 MJ kg^{-1} during the period January- April. There are not many sources in the published literature dealing with issue of GCV changes in plants in dependence on harvest time; and targeted research in this area would be beneficial.

Gross calorific value of wood – 19.5 MJ kg^{-1} (Hutla, 2004; Strašil 2005) is similar to that of hemp biomass.

Biomass energy yield evaluation (BEY)

Biomass energy yields as maximal energy potential (energy that can be derived by any conversion) as well as Energy in processed biomass used for sold biofuels were calculated. Consequently considering harvest losses - 10% for autumn harvest and 25% for spring harvest, Energy in harvestable biomass was calculated. When taking into consideration losses during combustion (efficiency of a boiler 80%), useful heat could be determined.

Prade et al. (2011) stated that the maximal energy potential based on the DM yield and the corresponding GCV increased significantly from July to September. No further significant changes in energy yield occurred between September and final sampling in April, and it averaged 201 GJ ha^{-1}(BEY). Poisa et al. (2016) determined the highest thermal capacity for hemp 171.71 ± 18.31 GJ ha^{-1}.

From the achieved results of the Thesis it can be state, that in both studied localities, autumn harvest produced higher energy in harvestable biomass and consequently higher useful energy. Therefore, from the point of outputs, autumn harvest should be preferable.

5.1.2 Energy inputs

Technological process specifications are shown in the table 12 and 13, inputs than in Tables 14-17.

Table 12: Technological process specification (Republic of Moldova)

Technological operation	Repetition	Input (material)	Amount	Machinery and equipment used for operation	Consumption l ha^{-1}	Labor h ha^{-1}
Liming	0.1	Limestone - finely ground	2 t	Wheeled tractor 81kW Fertilizer distributor for mineral fertilizer Trailer + semi-trailer	7.6	1.15
Fertilizing 1	0.15	Stable manure	30 t	Wheeled tractor 120 kW Fertilizer distributor for manure Trailer + semi-trailer	25	1.3
Fertilizing 2	1	Superphosphate Potassium salt	0.25 t 0.29 t	Wheeled tractor 81kW Fertilizer distributor for mineral fertilizer Trailer + semi-trailer	3.5	0.5
Deep tillage	1			Wheeled tractor 120 kW 4 furrow plough	27	1.43
Smoothing	1			Wheeled tractor 81kW +Carrier	4.5	0.35
Fertilizing 3	1	Nitrogen fertilizer	0.35 t	Wheeled tractor 81kW Fertilizer distributor for mineral fertilizers Trailer + semi-trailer	2.5	0.35
Seedbed preparation	1			Wheeled tractor 120kW Combined cultivator	10	0.58
Sowing	1	Hemp seed	60 kg	Wheeled tractor 81kW Amazon AD	4.5	0.83
Harvesting	1			Hand tools		250
Transport	1.2			Tractor 81kW + trailer	2.5	0.3
Stubble ploughing	1			Tractor 120kW Disc tiller	10	0.3

Table 13: Technological process specification (Czech Republic)

Technological operation	Repetition	Input (material)	Amount	Machinery and equipment used for operation	Consump. l ha^{-1}	Labor h ha^{-1}
Deep digging/Chisel ploughing	0.1			Wheeled tractor 120 – 199 kW Chisel Plough	25	0.83
Liming	0.1	Limestone - finely ground	2t	Wheeled tractor 4x4 100 – 119 kW Fertilizer distributor for mineral fertilizer; Trailer + semi-trailer	5.1	0.71
Fertilizing 1	0.15	Stable manure	30 t	Wheeled tractor 120 – 199 kW Fertilizer distributor for manure; Trailer + semi-trailer	23.6	1.25
Fertilizing 2	1	Amofos Potassium salt	0.25 t 0.29 t	Wheeled tractor 120 – 199 kW Fertilizer distributor for manure; Trailer + semi-trailer	2.4	0.36
Deep tillage	1			Wheeled tractor 120 – 199 kW Two-way reversible plough with seven mouldboards; Cambridge roller	27	0.83
Smoothing and Harrowing	1			Wheeled tractor 4x4 80 – 99 kW Land leveller; Ridge harrow	5	0.22
Fertilizing 3	1	Ammonium sulphate	0.35 t	Wheeled tractor 4x4 120 – 199 kW Fertilizer distributor for manure; Trailer + semi-trailer	2.4	0.36
Seedbed preparation	1			Wheeled tractor 200 kW and more; combinator	8.2	0.24
Sowing	1	Hemp seed	60 kg	Wheeled tractor 4x4 80 – 99 kW Universal seed drill (working width over 6 m)	4.2	0.29
Fertilizing 4	1	Ammonium salt peter with limestone	0.25 t	Wheeled tractor 4x4 100 – 119 kW Fertilizer distributor for mineral fertilizer; Trailer + semi-trailer	2	0.29
Mowing	1			Wheeled tractor 4x4 70 – 79 kW; Mowing machines	7	0.71
Baling	1	Hemp stalks	12 t	Wheeled tractor 4x4 80 – 99 kW; Baler	4.5	0.67
Transport	1.2			Wheeled tractor 4x4 100 – 119 kW Trailer + semi-trailer (10 – 14 t)	2	0.3
Stubble ploughing by disc tiller	1			Wheeled tractor 120 – 199 kW Disc tiller	8.6	0.25

Table 14: Energy inputs for technological process of hemp cultivation and processing in the Republic of Moldova (all inputs are expressed in MJ ha^{-1})

	Direct inputs		**Indirect inputs**			
Field Operation	**Human labor**	**Fuels**	**Machines**	**Fertilizers**	**Seeds**	**Sum**
Liming	0.067	33.820	2.122	490.000		526.009
Fertilizing 1	0.114	166.875	30.468	678.780		876.237
Fertilizing 2	0.292	155.75	9.226	2,732.650		2,897.918
Deep tillage	0.834	1,201.500	33.697			1,236.031
Smooting and harrowing	0.204	200.250	5.321			205.775
Fertilizing 3	0.204	111.250	6.458	3,528.000		3,645.912
Seedbed preparation	0.338	445.000	26.874			472.212
Sowing	0.484	200.250	22.917		122.63	346.281
Harvesting	145.750					145.750
Transport	0.210	133.500	6.028			139.738
Stouble ploughing	0.175	445.000	6.712			451.887
SUM for field operations	**148.672**	**3,093.195**	**149.823**	**7,429.430**	**122.63**	**10,943.754**

Note:

Liming – Limestone (0.2 t)

Fertilizing 1 – farmyard manure (4.5 t)

Fertilizing 2 – superphosphate (0.25 t), potassium salt (0.29 t)

Fertilizing 3 – ammonium sulphate (0.35 t)

Table15: Briquetting process specification in MLD

Operation	BY 15 [t ha^{-1}]	Human Labor [h ha^{-1}/MJ ha-^{1}]	Electricity [kWhha^{-1}/MJ ha^{-1}]	Energy in equipment [MJ ha^{-1}]	SUM [MJ ha^{-1}]
Briquetting process 1	14.19	35.475/20.681	956.05/5,162.67	500.637	**5,683.988**
Briquetting process 2	12.04	30.1/17.548	811.195/4,380.45	424.823	**4,822.824**

Note:

Briquetting process 1- processing of autumn harvested biomass

Briquetting process 2- processing of spring harvested biomass

Considering BRIKSTAR 400 + crusher (considered average power)

BY15 - average yield value for both varieties

Table 16: Energy inputs for technological process of hemp cultivation and processing in the Czech Republic (all inputs are expressed in MJ ha^{-1})

	Direct inputs		**Indirect inputs**			
Field Operation	**Human labor**	**Fuels**	**Machines**	**Fertilizers**	**Seeds**	**SUM**
Deep Digging/ Chisel Ploughing	0.048	111.25	3.725			115.023
Liming	0.041	22.70	1.213	490.000		513.954
Fertilizing 1	0.109	157.53	23.077	678.780		859.496
Fertilizing 2	0.209	106.8	6.240	2,732.650		2,845.899
Deep tillage	0.484	1,201.5	31.320			1,233.304
Smoothing and Harrowing	0.128	222.5	6.390			229.018
Fertilizing 3	0.210	106.8	6.240	3,528.000		3,641.250
Seedbed preparation by combinator	0.140	364.9	19.826			384.866
Sowing	0.169	186.9	8.717		123.930	319.716
Fertilizing 4	0.169	89.0	5.027	3,380.000		3,474.196
Mowing	0.414	311.5	19.677			331.591
Baling	0.390	200.25	19.633			220.273
Transport	0.210	106.8	6.487			113.497
Stubble ploughing by disc tiller	0.146	382.7	4.295			387.141
SUM for field operations	**2.867**	**3,571.125**	**161.867**	**10,809.430**	**123.930**	**14,669.219**

Note:
Liming – Limestone (0.2 t)
Fertilizing 1 – farmyard manure (4.5 t)
Fertilizing 2 – super phosphate (0.25t), potassium salt (0.29 t)
Fertilizing 3 – ammonium sulphate (0.35 t)
Fertilizing 4 – LAV- Ammonium saltpeter with limestone (0.25 t)

Table 17: Briquetting process specification CR

Operation	BY 15 [t ha^{-1}]	Human Labor [h ha^{-1}/MJ ha-^{1}]	Electricity [kWh ha^{-1}/MJ ha^{-1}]	Energy in equipment [MJ ha^{-1}]	SUM [MJ ha^{-1}]
Briquetting process 1	11.89	29.73/17.333	801.224/4,326.61	310.660	**4,654.603**
Briquetting process 2	10.63	26.58/15.496	716.331/3,868.187	277.777	**4,161.460**

Note:
Briquetting process 1- processing of autumn harvested biomass
Briquetting process 2- processing of spring harvested biomass
Considering BRIKSTAR 400 + crusher (considered average power)
BY15 - average yield value for both varieties

The results of energy inputs for each scenario are summarized below.

Energy inputs autumn Moldova – Scenario 1
Human labor = 169.353 MJ ha^{-1}
Fuels (diesel + electricity) = 8,255.865 MJ ha^{-1}
Machines = 650.46 MJ ha^{-1}
Fertilizers =7,429.43 MJ ha^{-1}
Seeds = 122.63 MJ ha-1
Total = 16,627.738 MJ ha^{-1}

Energy inputs spring Moldova – Scenario 2
Human labor =166.22 MJ ha^{-1}
Fuels (diesel + electricity) =7,473.648 MJ ha^{-1}
Machines = 574.646 MJ ha^{-1}
Fertilizers =7,429.43 MJ ha^{-1}
Seeds = 122.63 MJ ha^{-1}
Total = 15,766.574 MJ ha^{-1}

Energy inputs autumn Czech Republic – Scenario 3
Human labor =20.2 MJ ha^{-1}
Fuels (diesel + electricity) =7,897.735 MJ ha^{-1}
Machines = 472.527 MJ ha^{-1}
Fertilizers =10,809.430 MJ ha^{-1}
Seeds = 123.93 MJ ha^{-1}
Total = 19,323.822 MJ ha^{-1}

Energy inputs spring Czech Republic – Scenario 4
Human labor =18.363 MJ ha^{-1}
Fuels (diesel + electricity) =7,439.312 MJ ha^{-1}
Machines = 439.644 MJ ha^{-1}
Fertilizers =10,809.430 MJ ha^{-1}
Seeds = 123.93 MJ ha^{-1}
Total = 18,830.679 MJ ha^{-1}

Energy inputs evaluation

The input analysis of the Scenario 1 shows Figure 17.

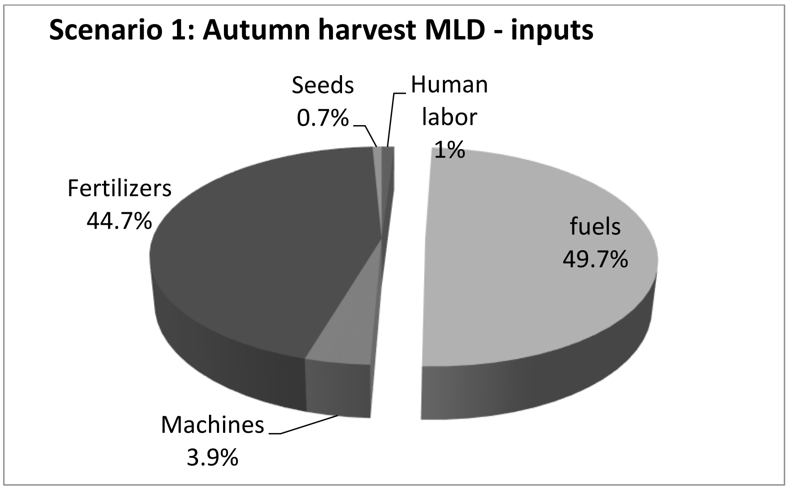

Figure 17: Energy inputs for Scenario 1

- Share of energy inputs is as follows: energy in seeds (122.6 MJ ha^{-1}), energy of human labor (169.4 MJ ha^{-1}), energy embedded in machines (650.5 MJ ha^{-1}), in fertilizers (7,429.4 MJ ha^{-1}), and energy in fuels (8,255.9 MJ ha^{-1}) as it is visible in percentage share from the Figure 17.
- Total inputs of Scenario 1 are 16,627.7 MJ ha^{-1}.
- Direct energy inputs (human labor, fuels – 8,425.3 MJ ha^{-1}) account for 50.7% of total inputs.
- The most energy-intensive material inputs are fertilizers (7,429 MJ ha^{-1}), which make more than 44.7% of total inputs, from which the highest amount creates ammonium sulphate – 3,528 MJ ha^{-1} (21.2% of total inputs).

The input analysis of the scenario 2 shows Figure 18.

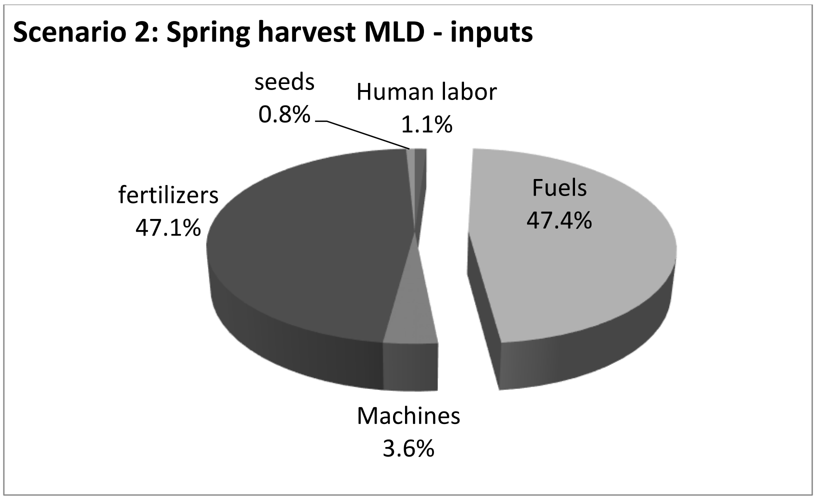

Figure 18: Energy inputs for Scenario 2

- Share of energy inputs is as follows: energy in seeds (122.6 MJ ha^{-1}), energy of human labor (166.2 MJ ha^{-1}), energy embedded in machines (574.6 MJ ha^{-1}), energy in fertilizers (7,429.4 MJ ha^{-1}), and energy in fuels (7,473.7 MJ ha^{-1}), as it is visible in percentage share from the figure 18.
- Total inputs of Scenario 2 are 15,766.6 MJ ha^{-1}.
- Direct energy inputs (human labor, fuels – 7,639.9 MJ ha^{-1} account for 48.5% of total inputs.

The most energy-intensive material inputs are fertilizers (7,429 MJ ha^{-1}), which make more than 47.1% of total inputs, from which the highest amount creates ammonium sulphate – 3,528 MJ ha^{-1}(22.4% of total inputs).

The input analysis of the Scenario 3 shows Figure 19.

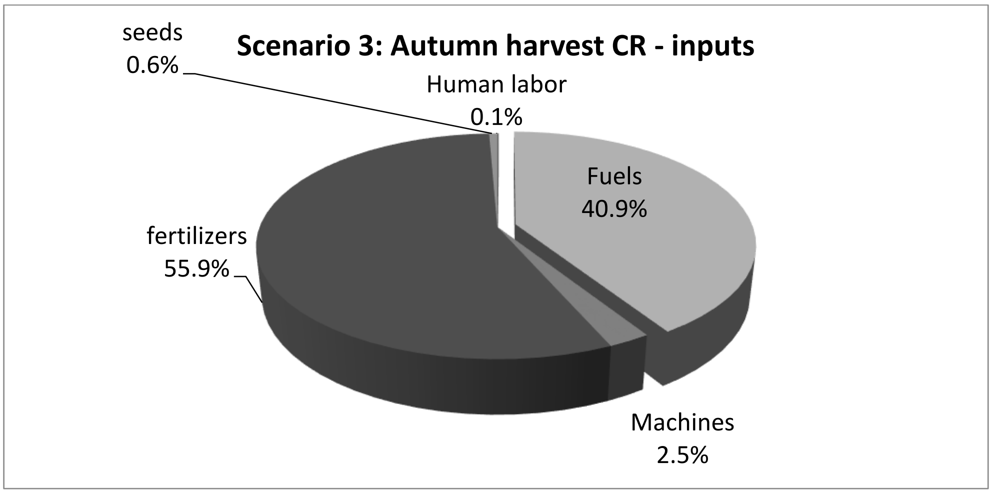

Figure 19: Energy inputs for Scenario 3

- Share of energy inputs of field operations is as follows – energy of human labor (20.2 MJ ha^{-1}), energy in seeds (123.9 MJ ha^{-1}) energy embedded in machines (472.5 MJ ha^{-1}), energy in fuels (7,897.8MJ ha^{-1}), and energy in fertilizers (10,809.4 MJ ha^{-1}) as it is visible in percentage share from the figure 19.
- Total inputs of Scenario 3 are 19,323.8 MJ ha^{-1}.
- Direct energy inputs (human labor, fuels – 7,918 MJ ha^{-1}) account for 41% of total inputs. In connection with direct costs the deep tillage is the most demanding field operation.
- The most energy-intensive material inputs are fertilizers, which make almost 55.9% of total inputs, from which the highest amount creates ammonium sulphate - 3,528 MJ ha^{-1}(18.3%) and ammonium saltpeter with limestone 3,380 MJ ha^{-1}(17.5%).

The input analysis of the Scenario 4 shows Figure 20.

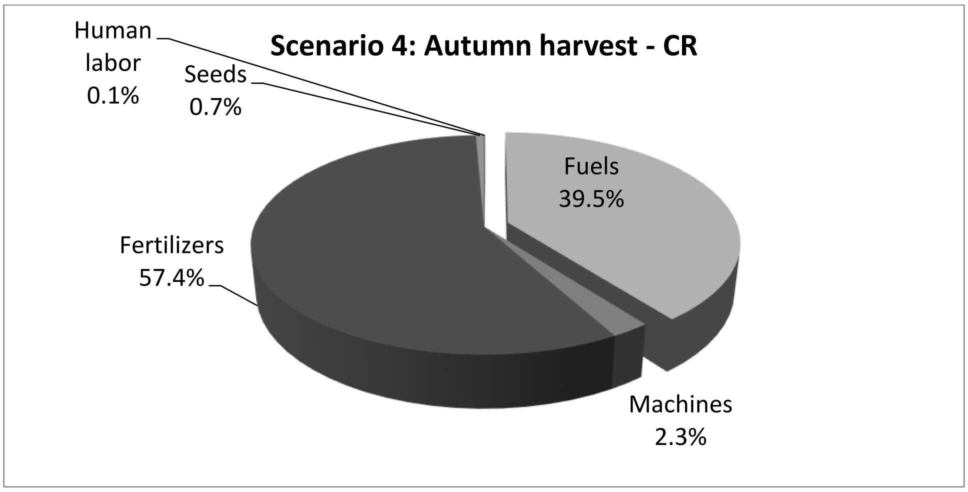

Figure 20: Energy inputs for Scenario 4

- Share of energy inputs is as follows: energy of human labor (18.4 MJ ha^{-1}), energy in seeds (123.9 MJ ha^{-1}), energy embedded in machines (439.6 MJ ha^{-1}), energy in fuels (7,439.3 MJ ha^{-1}), and energy in fertilizers (10,809.4 MJ ha^{-1}) as it is visible in percentage share from the figure 20.
- Total inputs of Scenario 4 are 18,830.7 MJ ha^{-1}.
- Direct energy inputs (human labor, fuels – 7,457.7 MJ ha^{-1}) account for 39.6% of total inputs.
- The most energy-intensive material inputs are fertilizers (10,809 MJ ha^{-1}), which make more than 57.4% of total inputs, from which the highest amount creates ammonium sulphate – 3,528 MJ ha^{-1} (18.7%) and ammonium saltpeter with limestone 3,380 MJ ha^{-1} (18%).

Direct inputs

Human Labor

Calculated as spent hours per operation in equivalent of human labor (0.583 MJ ha^{-1}). In all scenarios varies from 20 to 169 MJ ha^{-1}, which corresponded to share 0.1 – 1.1%. Proportionally (together with energy in seeds) it is the smallest input. The difference in scenarios from the MLD and the CR is due to a large proportion of manual work in Moldovan agriculture (8 times higher inputs).

Energy of human labor, one of the most discussed items. Its amount depends on an appropriate energy equivalent. According to Bechnik (2009) his experiment takes into consideration 2.3 MJ h^{-1}, which is determined on the basis of energy consumption for food production in the Czech Republic. Míša (2006) used value 25.65 MJ h^{-1} for energy balance calculation. According to Prenienger (1987), this value is too high. As the author states himself, the value is higher than in the foreign literature. He justifies this by including direct energy spent in the labor process as well as energy for reproduction of living labor (maintenance). Some of researchers do not include energy of human labor to the energy balance (Špička, 2008), since it is consider as renewable source.

Fuels

One of the leading consuming items for all scenarios is fuel. Share on total energy inputs vary from 40 to 50%. Energy in diesel creates 3 GJ ha^{-1} in MLD and 3.6 GJ ha^{-1} in CR (for field operations). The main share of this category is occupied by electricity, consumption varies from 4.1 to 5.7 GJ ha^{-1}, and differences are due to amount of processed biomass in briquetting press.

For all phytomass with moisture content over 20%, additional energy inputs must be considered in the form of drying, which are characterized by high energy demands. In our previous research we were focused on technological processes including drying of biomass by drum dryer. According to our results, additional equipment for loosening of water content meant average increasing of energy demand by 3.2 GJ ha^{-1} (Kolarikova et al., 2013). That´s why in this system analysis we were focused on technological process without additional inputs in the form of drying - spring harvest, when moisture content decrease to demanded 15%, and autumn harvest when natural drying of small volumes of biomass without controlled ventilation takes place.

Indirect energy inputs

Hanu et al. (2010) mentioned importance of indirect energy inputs. Since direct energy input is easy to identify and analyze, indirect energy input is also relatively easy to identify but more difficult to analyze. Indirect energy items, i.e. energy embedded in machines and energy in seeds, are often small so they are considered insignificant and are neglected (Hanu et al., 2010).

Fertilizers

In all our scenarios, fertilizers created from 44 to 57% with energy inputs 7.4 to 10.8 GJ ha^{-1}, which are in line with results of literature references. According to Gissén et al. (2014), the energy input represented by mineral fertilizer in cultivation of hemp, maize and ley in Swedish conditions accounted for in average 48% of the total energy input in crop production. As Hutla (2004) mentioned in his research, fertilizers for the production of energy crops accounts for 10.9 GJ ha^{-1}.

As it is visible from our research, Moldova, due to its different pattern in crop fertilization eliminated one of processes (ammonium fertilization during vegetation process), which has decreased energy inputs by 3.4 GJ ha^{-1}.

Fertilizer is the only input that can be influenced and input by which technological process and consequent energy balance can be optimize at high level. It is an input, which has great potential to be replaced by less demanding energy inputs. It is possible to use fertilizers with lower energy demand for their production, as well as use of manure fertilizers; very popular among farmers is the use of ashes from biomass combustion and byproducts of the biogas station i.e. digestate, fugate (Finnan, 2013; Gissén, 2014).

5.1.3. Energy balance calculation:

Scenario 1: AUTUMN Moldova

Energy outputs as useful heat: 142.48 GJ t^{-1}

Energy inputs calculated: 16.63 GJ t^{-1}

Energy profit: 125.85 GJ t^{-1}

Energy return on energy invested (EROEI): 8.56

Scenario 2: SPRING Moldova

Energy outputs as useful heat: 102.28 GJ t^{-1}

Energy inputs calculated: 15.77 GJ t^{-1}

Energy profit: 86.51 GJ t^{-1}

Energy return on energy invested (EROEI): 6.49

Scenario 3: AUTUMN Czech Republic

Energy outputs as useful heat: 115.2 GJ t^{-1}

Energy inputs calculated: 19.32 GJ t^{-1}

Energy profit: 95.88 GJ t^{-1}

Energy return on energy invested (EROEI): 5.96

Scenario 4: SPRING Czech Republic

Energy outputs (of higher yielding variety) as useful heat: 88.02 GJ t^{-1}

Energy inputs calculated: 18.83 GJ t^{-1}

Energy profit: 69.19 GJ t^{-1}

Energy return on energy invested (EROEI): 4.67

Figure 21 shows graphical expression of EROEI for all scenarios.

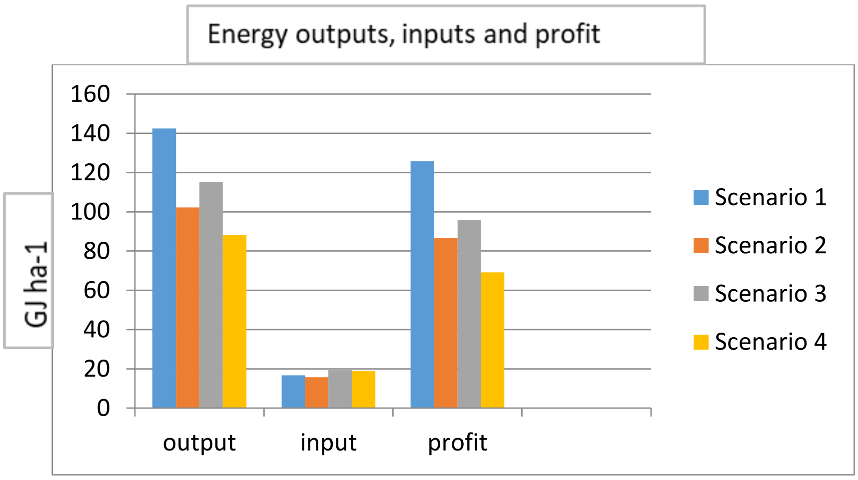

Figure 21: Graphical summarization of energy outputs, inputs, profits

Source: Author (2016)

It is clear from the graphical expression (Figure 21) that the highest output is visible at Scenario 1, followed by Scenarios 3, 2 and 4. The inputs are the smallest for Scenario 2, followed by

Scenarios 1, 4, and 2. Highest profits are at Scenario 1, then Scenario 3, 2 and 4. Real numbers of net usable energy ranging from 69 to 125 GJ ha^{-1}.

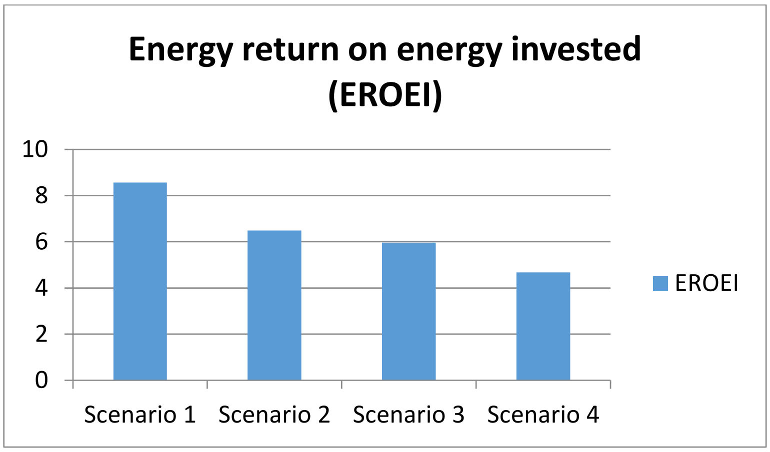

Figure 22: Graphical expresion of EROEI for all scenarios

Source: Author (2016)

EROEI

A can be seen from the Figure 22 both scenarios from Moldova show the highest value in terms of energy output to energy inputs. This is due to the more favourable climatic conditions for *Cannabis sativa* cultivation (higher outputs due to higher yield); another reason is a lower energy input in the form of mineral fertilizers (nitrogen fertilizer, which production is energy demanded). If we would evaluate cultivation of hemp from the economic point of view, another crucial factor will play a very important role - the share of manual labor in Moldovan agriculture, which is negligible in the case of the energy balance.

According to Prade (2011) the net energy yield (energy profit) per hectare for heat from briquettes was 65 GJ ha^{-1}, and the output-to-input ratio 5.1. This scenario considered spring harvest.

Energy return on invested (EROI) for the most important fossil fuels (as is visible from the Figure 23) - world oil and gas has a mean about 20:1 (Lambert et al., 2012; Dale, 2010); coal, with high importance in many countries, has EROEI value with no trend over time (Hall et al., 2014) and a mean EROEI of 46:1 (Lambert et al., 2012).

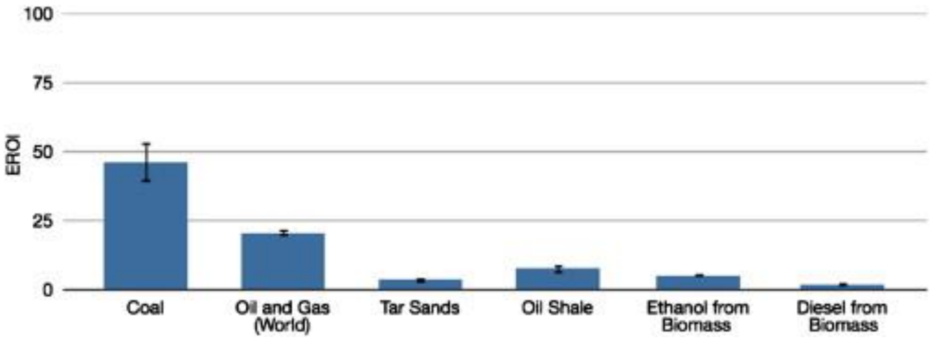

Figure 23: Mean EROI (and standard error bars) values for thermal fuels based on known published values
Source: Hall et al. (2014)

4.4. Environmental impact

Definition of scope

For this study the following scenarios were set scenarios - life cycle assessment of fuel briquettes made of purposely grown biomass (*Cannabis sativa*) for conditions of 1. the Czech Republic and 2. Moldova; chosen source of energy is taken into account for the heating of boiler for household use.

Setting up a production unit and reference flow

The production unit intended for this case is **1 MJ of produced heat energy**;

The reference flow is considered to be: 1 MJ of heat energy produced from the combustion of a certain amount (kg) of hemp briquettes in a household boiler. Product system covers all relevant processes and technologies specified in technological processes for energy balance calculation.

Determination of system boundaries

System boundaries are described on the Figure 24. A chain of production for biofuels with energy and GHG requirements (inputs) and emissions (outputs) is defined at each step in the production process.

Into the border of the production system, there were included processes of basic raw material obtaining, processes of obtaining of raw materials and materials used for energy production, processes of raw material transport and processes of waste management.

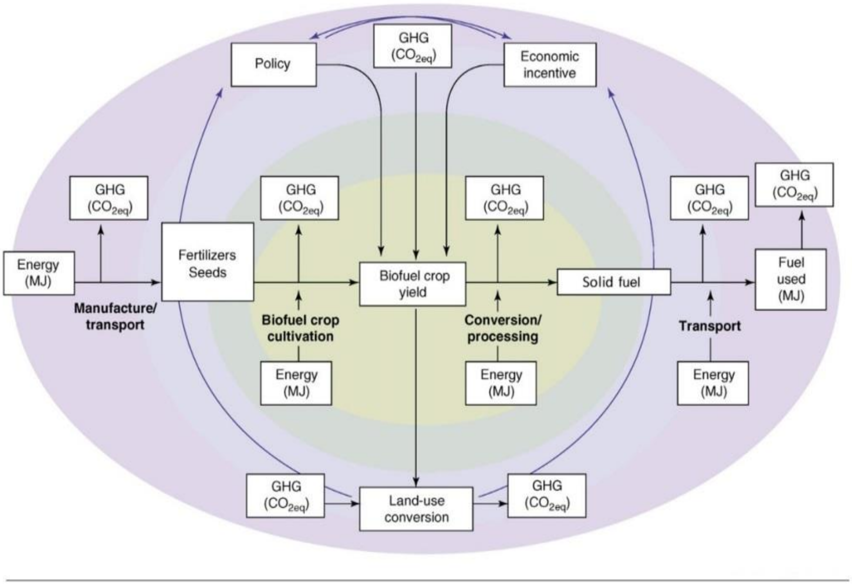

Figure 24: Determination of system boundaries for LCA
Source: Author (2015)

Life cycle inventory analysis

For LCA inventory analysis in the Czech Republic, following items were considered: superphosphate 0.25 t, potassium salt 0.1 t, farmyard manure 4.5 t, ammonium sulphate 0.3 t, limestone 0.2 t, ammonium saltpeter with limestone 0.25 l, diesel 80.2 l, electricity 801 kWh, string for hemp bales (made of polyprophylene) 4.9 kg, seeds 60 kg, average yield 11.5 t ha^{-1} (DM), GCV (DM) 17.5 GJ t^{-1} , small scale boiler for household use – power 18 kW, efficiency 80%, transport to the farm – up to 10 km; relevant machines and equipment for field and processed operations.

Accounted inputs for LCA inventory analysis in the Republic of Moldova: superphosphate 0.25 t, potassium salt 0.1 t, farmyard manure 4.5 t, ammonium sulphate 0.3 t, limestone 0.2 t, , diesel 69 l, electricity 956 kWh, string for hemp bales 4.9 kg, seeds 60 kg, average yield 11.5 t ha^{-1} (DM), GCV (DM) 17.5 GJ t^{-1} , small scale boiler for household use – power 18 kW, efficiency 80%, transport to the farm – up to 10 km; relevant machines and equipment for field and processed operations.

Scheme of Life cycle assessment model

On the basis of the input information from the technological process of growing and use of hemp biomass, LCA models of the evaluated products were used to calculate the environmental indicators (Figure 25 and 26). In the background of each process, there is a dynamically interlinked environmental impact database that was used for the calculations.

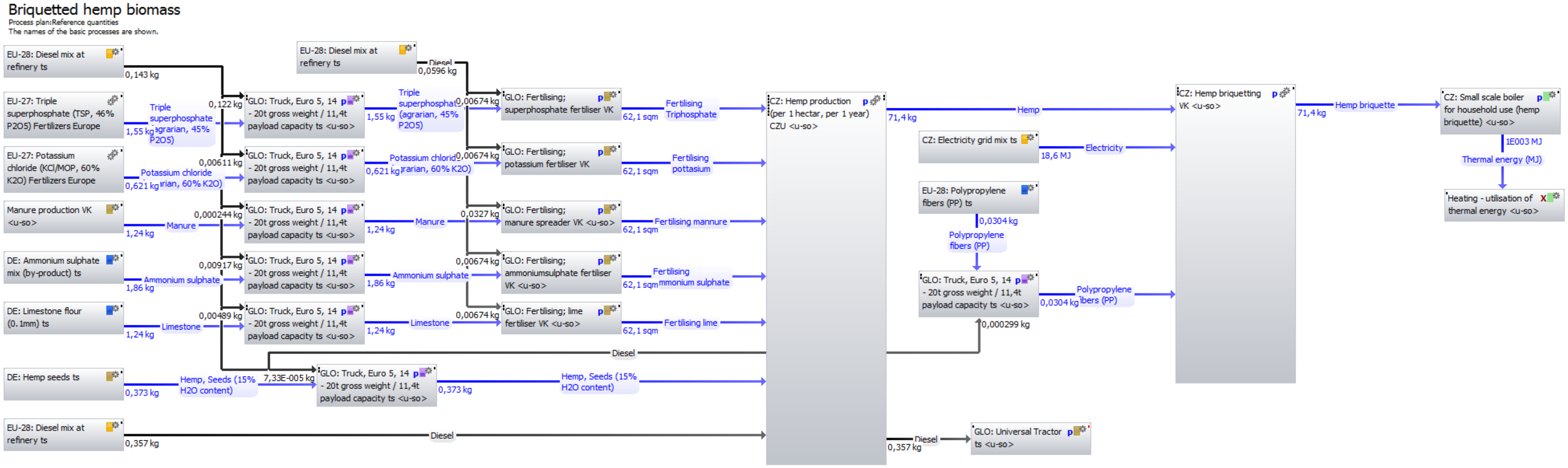

Figure 25: Model scheme of LCA for household heating by hemp briquettes

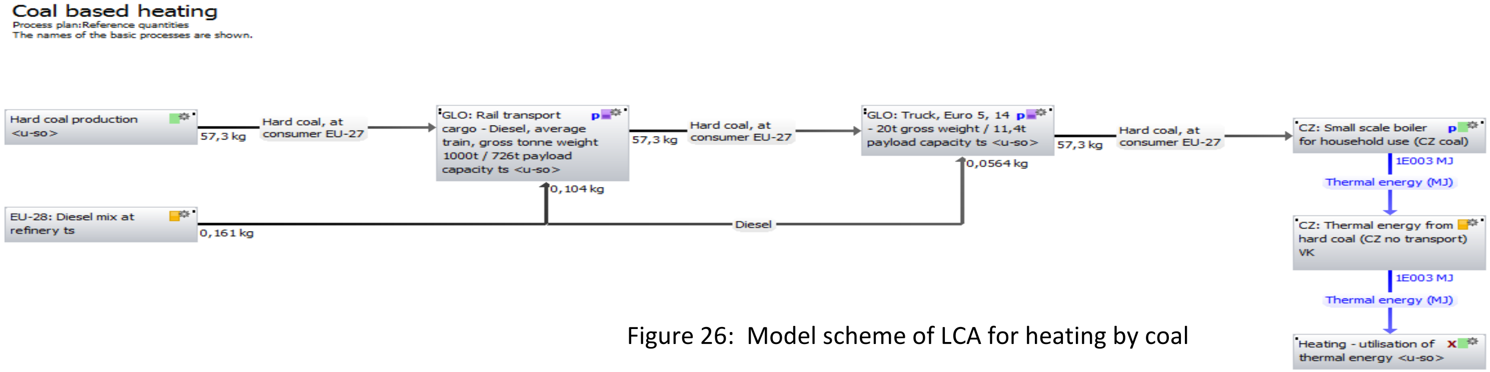

Figure 26: Model scheme of LCA for heating by coal

Life cycle impact assessment (LCIA)

The results of the life cycle impacts of assessed heating methods are summarized below in the Table 18. The following quantity of emissions was released per 1 MJ of thermal energy.

Table 18: Results of life cycle impacts

Impact category	**Unit**	**Briquetted hemp biomass CR**	**Briquetted hemp biomass MLD**	**Coal based heating**
Abiotic Depletion (ADP elements)	[g Sb-Equiv.]	$118 * 10^{-6}$	$101 * 10^{-6}$	$1 * 10^{-6}$
Abiotic Depletion (ADP fossil)	[MJ]	86	82	1420
Acidification Potential (AP)	[g SO_2-Equiv.]	0.037	0.029	0.198
Eutrophication Potential (EP)	[g Phosphate-Equiv.]	0.009	0.007	0.020
Freshwater Aquatic Ecotoxicity Potential (FAETP inf.)	[g DCB-Equiv.]	0.035	0.035	0.039
Global Warming Potential (GWP 100 years)	[g CO_2-Equiv.]	6	5	111
Global Warming Potential (GWP 100 years), excl. biogenic carbon	[g CO_2-Equiv.]	7	6	111
Human Toxicity Potential (HTP inf.)	[g DCB-Equiv.]	0.23	0.12	2.58
Marine Aquatic Ecotoxicity Potential (MAETP inf.)	[g DCB-Equiv.]	326	313	10,100
Ozone Layer Depletion Potential (ODP, steady state)	[g R11-Equiv.]	$23 * 10^{-12}$	$18 * 10^{-12}$	$5 * 10^{-12}$
Photochemical Ozone Creation Potential (POCP)	[g Ethene -Equiv.]	0.002	0.002	0.019
Terrestric Ecotoxicity Potential (TETP)	[g DCB-Equiv.]	0.007	0.006	0.040

From the Table 18 of characterization profiles it is clear that lower values are observed for household heating by hemp briquettes in all evaluated impact categories for both localities, except Ozone Layer Depletion (ODP) and ADP elements. If compared LCA of hemp briquettes from Chisinau locality, we can observe lower values than in the Czech Republic. These differences in all categories are due to lower material and energy inputs – nitrogen fertilizer elimination and lower diesel consumption for field operations.

These results proved the precondition, that heating by tested biofuels made of hemp represents a lower environmental burden, than heating by coal.

The characterization serves to compare the results of the studied products or systems, in this case results of heating, within the different impact categories. If our goal is to determine which categories impose the statistical significant environmental burden, the results obtained should be normalized. The results of the normalization of the characterization profile are presented in the following Tables 19 and 20, where the first one shows the normalization of the raw material impact categories (Table 19) and the second one the normalization of the intervention impact categories (Table 20).

Table 19: Normalised results of raw material impact categories (CML2001 – January 2016)

	Briquetted hemp biomass	Coal based heating
Abiotic Depletion (ADP elements)	7.29E-13	4.85E-15
Abiotic Depletion (ADP fossil)	2.45E-12	4.03E-11

Table 20: Normalised results of intervention impact categories (CML2001 – January 2016)

	Briquetted hemp biomass	Coal based heating
Acidification Potential (AP)	2.19E-12	1.18E-11
Eutrophication Potential (EP)	4.79E-13	1.10E-12
Global Warming Potential (GWP 100 years)	1.19E-12	2.12E-11
Human Toxicity Potential (HTP inf.)	4.65E-13	5.16E-12
Ozone Layer Depletion Potential (ODP, steady state)	2.26E-18	5.18E-19
Photochemical Ozone Creation Potential (POCP)	1.24E-12	1.09E-11

Figure 27 below shows results of raw materials impact category. From the graph it is visible, that a larger share on raw materials impact has coal-based heating; the most affected is the impact category of the depletion of fossil resources.

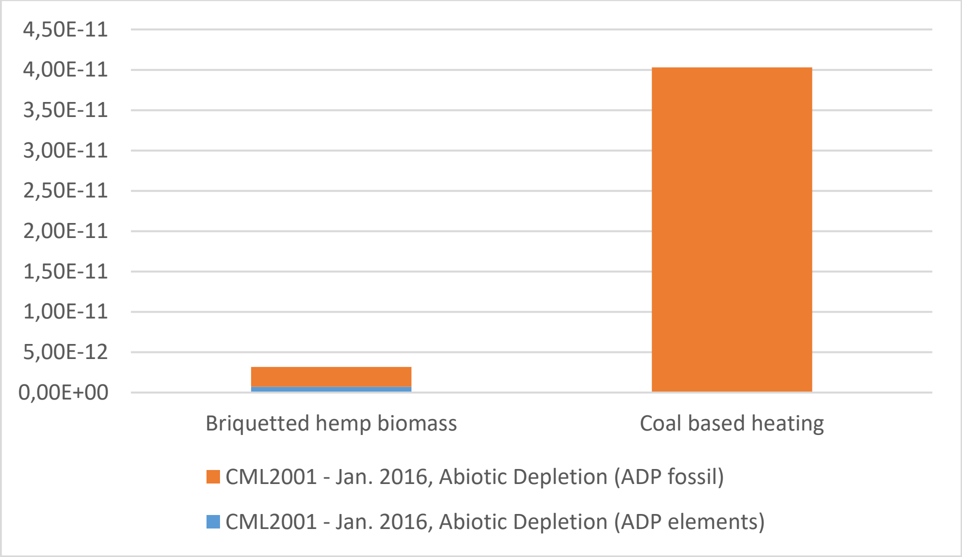

Figure 27: Graphical rendering of raw materials impact category
Source: Author (2017)

In the case of impact intervention categories, after normalization, we can state that coal - based heating represents a greater environmental burden (see Figure 28). Dominant impacted categories are Global Warming (94% higher impact on environment), Human Toxicity Potential (91%), Photochemical Ozone Creation (89%) and Acidification (81%).

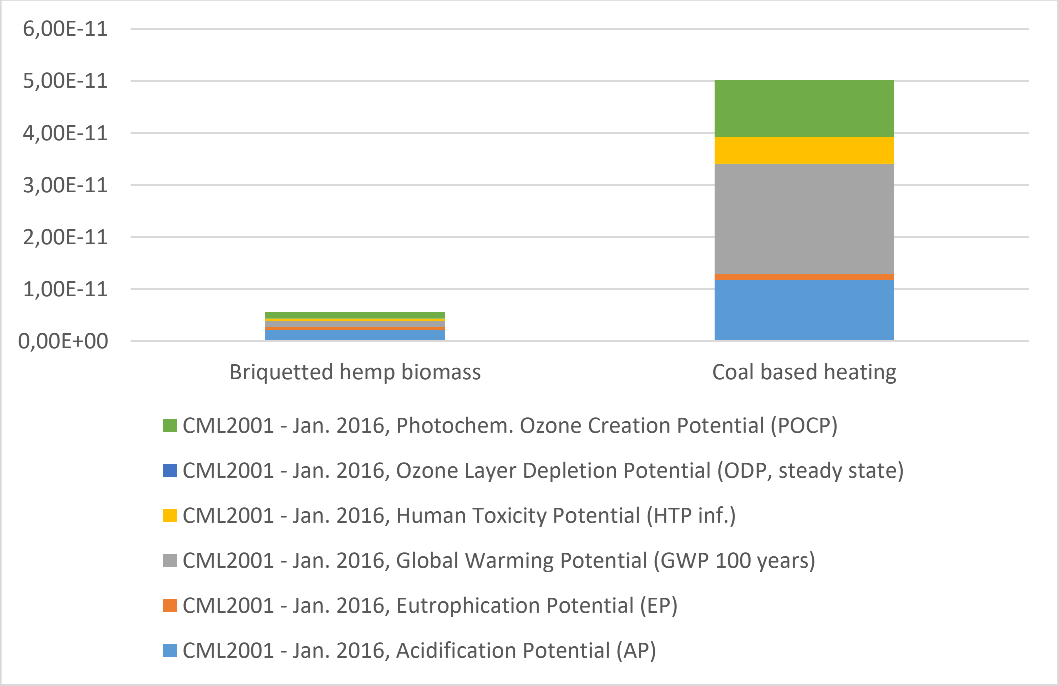

Figure 28: Impact intervention categories
Source: Author (2017)

In the comparable literature resources, Wang et al. (2017) mentioned results of his research – the dominant impact categories are climate change and fossil depletion impacts of cornstalk of biomass briquette fuel in China, which reaches value 11 g CO_2 equiv. MJ^{-1} and 2 g oil equiv. MJ^{-1}, respectively; they are an order of magnitude lower than those of coal 146 g CO_2 equiv. MJ^{-1} and 26 g oil equiv. MJ^{-1}, respectively. In our case – GWP for Hemp briquettes as well as for coal is lower (5-6 and 111 g CO_2 equiv.MJ^{-1}), respectively. On the other hand, fossil depletion of briquettes and coal are higher (82-86 and 1420 g oil equiv.MJ^{-1}). This category includes the impact of the product system on the irreversible use of non-renewable raw materials and on the consumption of renewable resources; results are different for each country.

Since results are expressed in quantity of emissions released per 1 GJ of thermal energy, we can interpret the most important category - Global Warming Potential for 1 kg of fuel for better comparison with literature. Recalculation was based on normalised yield (11.5t ha^{-1}) and average GCV (17.5 GJ ha^{-1}), value for GWP in kg per MJ of heat, which resulted in 87.5 g and 105 g CO_2 per kg of hemp briquettes for locality of Moldova and Czech Republic, respectively. Straka (2010) in his publication presents a detailed overview of the theoretical CO_2 emissions, depending on the calorific value. He mentioned only pellets of plant origin - for comparison - with 90.3 g CO2 kg^{-1} of fuel.

Song et al. (2017) evaluated in his research life cycle assessment of pellet fuel from corn straw in China. His results indicate that the utilization of this biofuels can eliminate 90.46% of the life cycle GHG emissions by replacing coal burning. In our models GHG emissions account for 94%.

5. CONCLUSION

Do briquettes made of hemp biomass grown in Moldova and Czech Republic fulfil criteria of sustainability?

Industrial hemp (*Cannabis sativa L.*) has a high yield in a short period of time and reaches a gross calorific value similar to that of wood. In the considered technological processes at both localities - hemp harvested as a green plant in autumn and left under a roof for losing moisture, without additional inputs in the form of drying - produced higher biomass yield and consequently useful heat in comparison with spring harvest, when biomass was left in the field till the moisture content reached the required value. Energy balance expressed as EROEI was positive in all localities and showed values from 4.67 to 8.56.

Energy balance should reveal existing reserves. In this case, reserves can be seen in the optimization of inputs - reducing the amount of mineral fertilizers and replacing them with alternative (digestate, ash from biomass, etc.).

From an energy point of view, the value of EROEI for coal is incomparable, when world average reaches value 46: 1 (Hall, 2015).

As it was supposed, household heating by briquettes made of hemp (*Cannabis sativa*) create less emissions with consequent impacts on environment during its whole life cycle than coal heating. According to results from the Czech Republic and Moldova, briquetted hemp biomass can be considered as significantly more environmentally friendly than heating coal.

Furthermore, we can state that briquettes made of hemp used for household heating comply with the sustainability criteria according to the European Commission's Directive on sustainability requirements of biofules, as they have saved more than 60% of greenhouse gas emissions throughout their life cycle.

The best-rated scenario 1 – Hemp cultivated in the area of Chisinau (Moldova) for the production of solid biofuels as briquettes and their use for local heating in small scale boilers, appears to be promising for solving the environmental and energy situation of small farmers in Moldova.

REFERENCES

Abrham Z, Kovářová M, Mužík O, Richter J, Herout M, Scheufler V. 2009. Technologie a ekonomika plodin – konopí. Výzkum,ný ústav zemědělské techniky, v.v.i. Available on lineat: http://www.vuzt.cz/cgi-bin/start99.cgi Accessed 2014-5-1.

Achten, W M J, E. Mathijs J.E. 2007. Jatropha biodiesel fueling sustainability? Biofuels Bioproducts & Biorefining-Biofpr 1(4): 283-291.

Achten WMJ and Verchot LV. 2008. Jatropha bio-diesel production and use. Biomass & Bioenergy 32(12): 1063-1084.

Achten WMJ and Verchot LV. 2011. Implications of Biodiesel-Induced Land-Use Changes for CO2 Emissions: Case Studies in Tropical America, Africa, and Southeast Asia. Ecology and Society 16(4).

AEBIOM. 2013. Annual report. Brusells: European biomass association. 36p.

Ahmad M. 2011. Physiochemical Analysis of Hemp Oil Biodiesel: A Promising Non Edible New Source for Bioenergy. Energy Sources 33(14): 1365-1374.

Alluvione F, Bertora C. 2010. Nitrous Oxide and Carbon Dioxide Emissions Following Green Manure and Compost Fertilization in Corn. Soil Science Society of America Journal 74(2): 384-395.

Amaducci S, Scordia D, Liu FH, Zhang Q, Guo H, Testa G, Cosentino SL. 2015. Key cultivation techniques for hemp in Europe and China. Industrial Crops and Products 68: 2-16.

Balezentiene L., 2011. Fluctuation of Sustainable and Renewable Energy Value of Galega Biomass during Vegetation Period. Rural Development in Global Change 5(1): 303-307.

Balezentiene L., 2011. Fluctuation of Sustainable and Renewable Energy Value of Galega Biomass during Vegetation Period. Rural Development in Global Change 5(1): 303-307.

Barta Z, Oliva M, Ballesteros D, Dienes D, Ballesteros M, Réczey K. 2010. Refining Hemp Hurds into Fermentable Sugars or Ethanol. Chemical & Biochemical Engineering Quarterly 24(3): 331-339.

Baumann H, Tillman A. 2004. The Hitchhiker’s Guide to LCA: An orientation in Life Cycle Assessment Methodology and Application. Sweden: Lund Student litteratur. 218p.

Bechník B. 2009. Energy yields of grown biomass. TZBinfo. History and perspectives of RES - biomass II. Available at: http://oze.tzb-info.cz/biomasa/5933-historie-a perspektivy-oze-biomasa-ii. Accessed 2014-1-5.

Bjelkova M. 2005. The effect of increased cadmium and lead soil concentrations on the growth and heavy metal accumulations by hemp (Cannabis sativa L.) plants. Phytotechnologies to promotore sustainable land use and improve food safety: Pisa, Italy: CNR Research Campus, pp. 12-15.

BP. 2015. BP Statistical Review of World Energy. London: British Petroleum Stats. 48p.

Brega V, Taranu M, Scorpan V, Brasoveanu V. 2011. Republic of Moldova´s greenhouse gas inventory. Quality assurance/ quality control and inventory uncertainty. Ecoterra 26: 11-18.

Campiglia E., Radicetti E., Mancinelli R. 2017. Plant density and nitrogen fertilization affectagronomic performance of industrial hemp (Cannabis sativa L.) in Mediterraneanenvironment. Industrial crops and Products 100: 246-254.

Cleveland J. et al. 2004. Encyclopedia of Energy. Washington, D.C.: Elsevier. 815p.

Dale M, Krumdieck S, Bodger P. 2012. Global Energy Modeling: A Biophysical Approach (GEMBA). Ecological Economics 73: 158-167.

Doloscanu T. 2010. Renewable Energy in the Republic of Moldova. Potsdam Economic Forum. Available at: http://www.ostausschuss.de/sites/default/files/pm_pdf/ConsultGroup.pdf. Accessed 2014-10-22.

ENCROP. 2009. Energy from field energy crops- a handbook for energy producers [online]. Jyväskylä, Finland: http://www.encrop.net/default.asp?SivuID=23515. Accessed 2014-10-22.Jyväskylä Innovation Oy. Available at:

ENER21. 2014. Country report Moldova Energy sector in the Republic of Moldova. Brussel: European Commission. 38p.

EU. 2003. Council regulation EC 1782/2003. Brussel. p. 69.

EUROSTAT. 2014a. Demography Report Older, more numerous and diverse Europeans. Brussels: European Union. 82p.

EUROSTAT. 2014b. Renewable energy in the EU28. Brussels: European Commission. 3p.

FAO. 2004. Food and nutrition technical report series 1: Human energy requirements Report of a Joint FAO/WHO/UNU Expert Consultation. Rome: United Nations University, World Healh Organization, Food and Agriculture Organization of United Nations. p. 103. ISBN 92-5-105212-3.

FAO. 2009. Hemp's future in Chinese fabrics. Available at: http://www.naturalfibres2009.org/en/stories/hemp.html. Accessed 2012–04 -15.

FAO. 2014. FAOSTAT: Production – Crops. Available at http://faostat.fao.org/. Accessed 2014 – 5 – 1.

Fernando AL, Duarte MP, Vatsanidou A, Alexopoulou E. 2015.Environmental aspects of fiber crops cultivation and use. Industrial Crops and Products 68: 105-115.

Finnan D. 2013. Hemp: a more sustainable annual energy crop for climate and energy policy. Energy Policy, 58: 152-162.

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. 2009. Recent developments in Life Cycle Assessment. Environmental management 91(1): 1-21.

Gill P, Soni SK, Kundu K. 2011. Comparative study of Hemp and Jatropha oil blends used as an alternative fuel in diesel engine. CIGR Journal 13(3): 71-77.

Gissén Ch, Prade T, Kreuger E, Nges IA, Rosenqvist H, Svensson SE, Lantz M, Mattsson JE, Borjesson P, Bjornsson L. 2014. Comparing energy crops for biogas production – Yields, energy input and costs in cultivation using digestate and mineral fertilization. Biomass and Bioenergy 64: 199 -210.

Gonzáles- García S, Luo L, Moreira T, Feijoo G, Huppes G. L. 2012. Life cycle assessment of hemp hurds use in second generation ethanol production. Biomass and Bioenergy 36: 268-279.

Gumuskaya E. 2007. Carbohydrate components and crystalline structure of organosolv hemp (Cannabis sativa L.) bast fibers pulp. Bioresource Technology 98(3):491-7.

Hall Ch, Lambert J, Balogh S. 2014. EROI of different fuels and the implications for society. Energy Policy 64: 141-152.

Hanu M, Jukka A. 2010. Indirect energy input of agricultural machinery in bioenergy production, Renewable Energy 35(1): 23:28.

Hill J, Nelson E, Tilman D, Polansky S. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences of the United States of America 103(30): 11206-11210.

Hollebane JE. 1999. Industrial Hemp Factsheet. Kamloops: Ministry of Agriculture and Food. Available at:http://www.agf.gov.bc.ca/speccrop/publications/documents/hempinfo.pdf. Accessed 2015 - 5 – 1. Accessed 2014-10-22.

Hutla P. 2004. Systémové využití energetické biomasy v podmínkách ČR . Periodická zpráva projektu Z-2423. Praha: VÚZT. 6p.

IEA. 2013. Key World Energy Statistics. Paris: International energy agency. 82p.

Jakubes J., Spitz J. 2002. Environmentální vyhodnocení v rámci energetických auditů. Česká energetická agentura. 28 pp.

Jelínek L. 2010. Ekonomický systém hodnocení výkonnosti zemědělských podniků respektující principy trvalé udržitelnosti hospodaření s přírodními zdroji. Praha: ÚZEI. p. 95.

Karakosta Ch, Dimopoulou S. 2011. The potential role of renewable energy in Moldova. Renewable Energy 36 (12): 3550–3557.

Kavka M. et al. 2008. Normativy pro zemědělskou a potravinářskou výrobu. Praha: ÚZPI, 2008. p. 301.

Kočí V. 2012. Na LCA založené srovnání environmentálních dopadů obnovitelných zdrojů energie. LCA studio, Ústav chemie ochrany prostředí, VŠCHT Praha. 111p.

Kolaříková M, Havrland B, Ivanova T. 2013. Energy Balance of Hemp (Cannabis sativa L.) Grown for Energy Purposes. Agricultura Tropica and Subtropica 46(1): 10-15.

Kreuger E, Prade T, Escobar F, Svenson J, Englund E, Bjornsson L. 2011a. Anaerobic digestion of industrial hemp – Effect of harvest time on methane energy yield per hectare. Biomass & Bioenergy 35(2): 893-900.

Kreuger E, Sipos B., Zacchi G, Svensson SE, Bjornsson L. 2011b. Bioconversion of industrial hemp to ethanol and methane: the benefits of steam pretreatment and coproduction. Bioresource Technology 102(3): 3457-3465.

Lambert J, Hall C, Balogh S, Poisson A, Gupta A, 2012. EROI of Global Energy Resources: Preliminary Status and Trends. Report 1 of 2. UK-DFID 59717.

Li X, Wang S, Du G, Wu Z, Meng Y, Wang L. 2012. Variation in physical and mechanical properties of hemp stalk fibers along height of stem. Industrial Crops and Products 42(1): 344-348.

Medová B. 2015. Vliv průběhu vegetačního období na základní parametry vybraných energetických plodin [BSc.]. Prague: Czech University of Life Sciences Prague, 65p.

ME. 2009. Fifth national communication of the Czech Republic on the United Nations framework convention on climate change including information pursuant to Article 7.2 of the Kyoto Protocol. Praha: Ministry of Environment. 195p.

ME. 2013. Sixth national communication of the Czech Republic under the United Nations framework convention on climate change including supplementary information pursuant to Article 7.2 of the Kyoto Protocol. Praha: Ministry of Environment. 251p.

Míša P. 2006. Hodnocení setrvalosti modelových systémů rostlinné produkce [DDP]. Brno: MZLU. 136p.

MPO. 2014. Primary energy sources. Available at: https://www.mpo.cz/en/energy/statistics/primary-energy-sources--148856/. Accessed 2014-10-22.

MZE. 2013. Zpráva o stavu zemědělství ČR za rok 2013 "Zelená zpráva". Praha: Ústav zemědělské ekonomiky a informací. 90p.

MZP. 2012. Státní politika životního prostředí České republiky 2012 – 2020. Praha: Ministerstvo životního prostředí. 90p.

MZP. 2014. Metodický pokyn odboru ochrany ovzduší pro osoby autorizované k certifikaci procesu výrobního řetězce udržitelných biopaliv a ověřování zprávy o emisích u dodavatelů pohonných hmot podle § 32 odst. 1 písm. g) zákona č. 201/2012 Sb., o ochraně ovzduší. Available at: line: https://www.mzp.cz/C1257458002F0DC7/cz/kriteria_udrzitelnosti_ovzdusi/$FILE/OOO metodicky_pokyn-20141105.pdf. Accessed 2014-10-22.

NREAP. 2013. National renewable energy action plan for the Republic of Moldova for 2013 – 2020. Chisinau: Ministry of Industry. 80p.

O'Mahony SJ. 2011. Life cycle assessment of biodiesel from Cannabis sativa L. for transport fuel in the UK [DDP]. London: University of East Anglia. 285p.

Pakarinen A, Maijalal P, Jaakkola S, Stoddard l, Kymalainen M, Viikari L. 2010. Enhance methane production and enzymatic disassembly of annual crops by ensiling. Journal of Biotechnology 150: 312-321.

Papadopoulou E, Bikiaris D, Chrysafis K, Wladyka-Przybylak M, Wesolek D, Mankowski J, Kolodziej J, Baraniecki P, Bujnowicz K, Gronberg V. 2015. Value-added industrial products from bast fiber crops. Industrial Crops and Products 68: 116-125.

Pari L, Baraniecki P, Kaniewski R, Scarfone A. 2015. Harvesting strategies of bast fiber crops in Europe and in China. Industrial Crops and Products 68: 90-96.

Petr J, Húska J. 1997. Speciální produkce rostlinná – I. Praha: Česká zemědělská univerzita v Praze, Agronomická fakulta, p. 197.

Petříková V. et al. 2006. Energetické plodiny. Praha: Profi Press. p. 127.

Pflieger G. 2014. Kyoto Protocol and Beyond Handbook of Global Environmental Pollution 1: 517-525.

Picková A, Vilhelm V. 2007. Aspekty energetické efektivnosti v zemědělství. Výzkumná zpráva NAZV QH 71016. Praha: VÚZI. p. 10.

Pimentel D. 1973. Food Production and Energy Crisis. Science 182 (4111): 443-449.

Pimentel D. 1992. Handbook of energy utilization in agriculture. Boca Raton, USA: CRC Press.

Poisa L. Bumane S, Cubars E, Antipova L. 2016. Hemp Quality Parameters for Bioenergy Impact of Nitrogen Fertilization. Engineering for Rural Development. Available at: http://tf.llu.lv/conference/proceedings2016/Papers/N180.pdf. Accessed 2014-10-22.

Prade T, Finell M, Svensson SE, Mattsson JE. 2012. Effect of harvest date on combustion related fuel properties of industrial hemp. Fuel 102: 592-604.

Prade T, Svensson SE, Andersson A, Mattsson JE. 2011. Biomass and energy yield of hemp for biogas and solid fuel. Biomass & Bioenergy 35(7): 3040-3049.

Prade T. 2011. Industrial Hemp (Cannabis sativa L.) - a High Yelding Energy Crop [DDP]. Alnarp: Swedish University of Agricultural Science, 2011.

Preininger M. 1987. Energetické hodnocení výrobních procesu v rostlinné výrobe. Metodika č. 7. Praha: ÚVTIZ. 29p.

REN21. 2014. Renewables 2014 Global Status Report. Paris: REN21 Secretariat. 216p.

Ribeiro A, Pochart P, Day A, Mennuni S, Bono P, Baret JL, Spadoni JL, Mangin I. 2015. Microbial diversity observed during hemp retting. Applied Microbiology and Biotechnology 10: 4471 - 4484.

Robinson R. 1995. The Great Book of Hemp: The Complete Guide to the Environmental, Commercial, and Medicinal Uses of the World's Most Extraordinary Plant. Rochester Vermont: Park street press. 364p.

Ruf, T, Schmidt, A, Delfosse, P, Emmerling, Ch. 2017. Harvest date of Miscanthus x giganteus affects nutrient cycling, biomass development and soil quality. Biomass and Bioenergy 100: 62-73.

SEK. 2014. Aktualizace Státní Energetické Koncepce České republiky. Praha: Ministerstvo průmyslu a obchodu. 145p.

Sladký V. 2004. Konopí, šance pro zemědělství a průmysl. Praha: Ústav zemědělských a potravinářských informací. 64p.

Šnobl J. 2004. Rostlinná výroba IV. (Chmel, len, konopí, využití biomasy k energetickým účelům). Prague: Power Print. 119p.

Soddy, F. 1933. Wealth, Virtual Wealth and Debt. London: Allen and Unwin, 1933.

Soimu O. 2014. A SWOT Analysis of Bio-energy Production in Republic of Moldova. Procedia - Social and Behavioral Sciences 149: 896 – 900.

Song S, Liu P, Xu J. 2017. Life cycle assessment and economic evaluation of pellet fuel from corn straw in China: A case study in Jilin Province, Energy 130: 373-381.

Špička J, Jelínek L. 2008. Energy analysis of agricultural enterprises – methodological approach. Economy and Management 2(3): 1-10.

Stevulova N, Kidalova L, Cigasova J, Junak J, Sicakova A, Terpakova E. 2013. Lightweight Composites Containing Hemp Hurds. Procedia Engineering 65: 69-74.

Straka F. 2010. Alternativní energetické zdroje a měrné emise CO2. Available at www: <http://biom.cz/cz/odborne-clanky/alternativni-energeticke-zdroje-a-merne-emise-co2>. Accessed 2014-10-22.

Strašil Z. 2008. Porovnání energetických bilancí a využití globálního záření u vybraných zemědělských plodin a netradičních olejnin. Mezinárodní český a slovenský kalorimetrický seminář. Rožnově pod Radhoštěm: VÚRV. p129–132.

Strašil Z. 2005. Plodiny pro energetické využití vhodné do marginálních oblastí. Sborník příspěvků z odborné konference: Hospodaření v méně příznivých oblastech. Lukavec u Pacova: VÚRV, p 45-49.

Syrový O. 1997. Orientační hodnoty měrné spotřeby paliv a energie v zemědělství. Metodiky pro zemědělskou praxi. Praha: Ústav Zemědělských a potravinářských informací. p47.

Tanase C, Volf I, Popa VI. 2014. Enhancing copper and lead bioaccumulation in rapeseed by adding hemp shives as soil natural amendments. Journal of Environmental Engineering and Landscape Management 22(4): 245 -253.

Transeau EN. 1926. The Accumulation of Energy by Plants. The Ohio Journal of Science. 26(1): 1 – 10.

Tutt M, Olt J. 2011. Suitability of various plant species for bioethanol production. Agronomy Research 9: 261-267.

Twidel J, Weir T. 2015. Renewable energy resources (third edition). Routledge: Taylor and Francis. 784p.

UN. 2010. United Nation Statistic Division: Greenhouse Gas Emissions - Environmental indicators. Available at: http://unstats.un.org/unsd/ENVIRONMENT/qindicators.html: Accessed 2014-10-22.

UNDP. 2015. TIME FOR GLOBAL ACTION. New York: United Nations Development Programme Publication. 48p.

UNDP. 2012. Feasibility study on introducing the emission trading system in Moldova. Available at: http://www.undp.org/content/dam/moldova/docs/Publications/ETS_Feasibility_Study_ NDP.pdf: Accessed 2014-10-22.

Wang ZW, Lei TZ, Yang M, Li ZF, Qi T, Xin XF, He XF, Ajayebi A, Yan, XY. 2017. Life cycle environmental impacts of cornstalk briquette fuel in China. Energy 134: 50-60.

BIBLIOGRAPHY

Kolaříková M, Ivanova T, Hutla P, Havrland B. 2015.Economic evaluation of hemp (Cannabis sativa) grown for energy purposes (briquettes) in the Czech Republic. Agronomy Research 13(2): 328-336.

Kolaříková M, Ivanova T, Havrland B, Amonov M. 2014. Evaluation of sustainability aspect – energy balance of briquettes made of hemp biomass cultivated in Moldova. Agronomy Research 12(2): 519-526.

Kolaříková M, Ivanova T, Havrland B. Energy balance of briquettes made of hemp (Cannabis sativa L.) cultivars (Ferimon, Bialobrzeskie) from autumn harvest to produce heat for household use. Engineering for Rural Development. 2013: 504-508.

Kolaříková M, Havrland B, Ivanova T. 2013. Energy Balance of Hemp (Cannabis sativa L.) Grown for Energy Purposes. Agricultura Tropica et Subtropica 46(1): 10-15.

Ivanova T, Kaválek M, Havrland B, Kolaříková M, Skolpec I. 2015. Comparison of technologic parameters of pellets and other solid fuels produced from various raw materials. Agronomy Research 13(2): 303-310.

Ivanova T, Muntean A, Titei V, Havrland B, Kolaříková M. 2015. Energy crops utilization as an alternative agricultural production. Agronomy Research 13(2): 311-317.

Ivanova T, Kolaříková M, Havrland B, Passian L. 2014. Mechanical durability of briquettes made of energy crops and wood residues. Engineering for Rural Development 2014: 131-136.

Ivanova T, Kolaříková M, Havrland B, Hutla P. 2014. Mechanické a chemické vlastnosti briket z odpadní biomasy konopí (*Cannabis sativa* var. Finola). Agritech Science 8(2): 1-4.

Havrland B – Ivanova T – Lapczynska-Kordon D – Kolaříková M. 2013. Comparative analysis of bio-raw materials and biofuels. Engineering for Rural Development 2013: 541-544.

Kolaříková M, Ivanova T, Andert D. 2014. Pressing of stalks with possibility of large-size briquettes production. Conference: World Sustainable Energy Days 2014.

Kolaříková M, Ivanova T, Havrland B, Špur O. 2013. Physical, mechanical and combustion properties of briquettes made of waste hemp biomass. Sustainability Challenge - Technological advancements and other solutions 2013: 150.

ANNEX

Protocol - laboratory measurement of Hydrogen content.