
Sustainable Agriculture – Energy and Emergy Aspects of Agricultural Production

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Anna Kuczuk ¹, Janusz Pospolita ²

Abstract:

Purpose: The objective of the study was to perform the analysis of agricultural production in terms of its energy consumption and environmental impact. To determine this impact, the emergy calculus was utilized.

Design/Methodology/Approach: The notion of cumulative energy intensity was applied in the analysis. The calculations were performed with regard to conventional and organic production systems. It was assessed which production inputs generate the highest energy consumption. In order to assess the degree of environmental impact of production, the emergy calculus was used. The ELR and EYR indicators were taken into account to measure the degree of environmental loading.

Findings: The conducted analysis of cumulative energy consumption demonstrates that in the case of conventional systems, the ratio of machinery and equipment use as well as fertilizers and plant protection products use could account for over 70% of cumulative energy consumption. Energy intensity in similar ecological farming systems can be reduced two times.

Practical Implications: The work indicates the course of the activity that can contribute to the decrease of the energy consumption in agricultural production and reduce the negative impact on the environment.

Originality/value: The work contains the results of research on agricultural systems: conventional and ecological, in specific environmental and territorial conditions of Poland, conducted on the basis of the emergy account and cumulated energy consumption.

Keywords: Agriculture, cumulative energy intensity, emergy, environment.

JEL classification: Q10, Q20, Q40, Q51, Q56.

Paper Type: Research study.

¹Opole University of Technology, Mechanical Faculty, Department of Thermal Engineering and Industrial Facilities, a.kuczuk@po.edu.pl;

²Opole University of Technology, Mechanical Faculty, Department of Thermal Engineering and Industrial Facilities, j.pospolita@po.edu.pl;

1. Introduction

The development of the economy and the constant increase in the demand for various goods and services are associated with considerable level of energy consumption. Various sources are applied for these purposes, mainly non-renewable ones. Due to the limited resources of energy, the activities involving the use of energy should be rational and sustainable in the long-term perspective. These actions should also take into account the environmental aspects of extracting energy resources, their conversion from one form to another, distribution and local consumption. Rationality at each of these stages offers a final positive impulse for the economy and protection of the environment.

The mean annual consumption of final energy³ in the EU and in Poland in the period from 2006 to 2017 was equal to 1128.92 million tons of oil equivalent (toe⁴) in the EU and 64.06 tons in Poland, respectively (EUROSTAT, Final energy consumption). Yet, in the analyzed decade, a certain downward trend in final energy consumption in the EU has been observed (Figure 1). It is related with changes in the economies of new member states. The measures taken were aimed at improving the quality of manufacturing processes and the use of energy-saving technologies. However, starting from 2014 (consumption: 1065.57 million toe), we faced a mean constant increase in final energy consumption (EUROSTAT, Final energy consumption). For the case of Poland (Figure 2) we can see a similar condition. Following the year 2009, there has been an increase in the energy consumption lasting until 2011 (66.67 million toe). In the following years, we had to do a decline in this consumption, with a recorded increase in consumption after 2014. The year 2017 saw the highest final energy consumption (70.92 million toe) recorded since 1990 (EUROSTAT, Final energy consumption; Wysokiński *et al.*, 2017).

However, in accordance with the statistical data, in the period from 2006 to 2016, there was a decrease in the consumption of primary energy carriers by over 3% annually, and the final energy use by over 2% (Statistics Poland, 2018). Moreover, the increase in final energy consumption in Poland in 2016–2017 expressed in per cent was higher than the EU average and amounted to approximately 6 per cent. We can emphasize again that Poland is one of the three countries (with the exception of Malta and Slovakia) in which the highest increase in final energy consumption was recorded in this period. Countries that have recorded a decrease in its consumption include, for example: Belgium, Great Britain and Italy. Similar relations can be noted in the consumption of primary carriers⁵.

³Final energy – energy consumed by industry, transport, households, services and agriculture. It does not include consumption by the energy sector and losses during transformation and distribution of energy and non-energy use of energy carriers.

⁴Ton of oil equivalent is the energy equivalent of 41868 MJ.

⁵Primary energy – energy contained in primary energy sources obtained directly from renewable and non-renewable natural resources. Its consumption demonstrates the total energy demand in a given country.

Figure 1. Use of final energy in EU in the period from 2006 to 2017 [million toe]

Source: Own study results based on (EUROSTAT, Final energy consumption).

Figure 2. Use of final energy in Poland in the period from 2006 to 2017, million

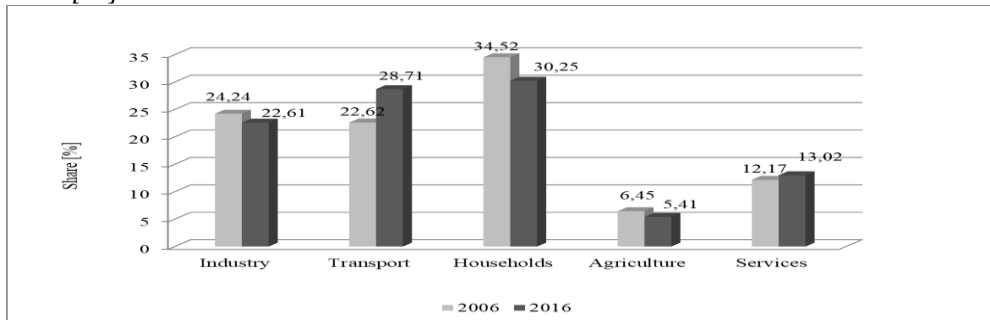
Source: Own study results based on (EUROSTAT, Final energy consumption).

Agriculture forms one of the production and service sectors in the country's economy that is responsible for a proportion of energy consumption. This sector consumed 2.7% of final energy in the EU in 2016. In the case of Poland, the ratio of agriculture in total final energy consumption in 2016 was equal to 5.3%. This ratio decreased by 0.9% since 2006 and by 2.1% compared to 1996. Overall, energy consumption in EU agriculture in 1996-2016 clearly decreased, by as much as 24% (EUROSTAT, Energy consumption by agriculture ...). This is due to the use of increasingly energy-efficient manufacturing technologies. The data regarding final energy consumption in Poland (Statistics Poland, 2018) by sectors for 2006-2016 also demonstrates that agriculture has always been the smallest consumer of energy in the final economy of the country (Figure 3). Quite apparently, this does not necessarily mean that energy is utilized in a sustainable manner in this sector.

It is noteworthy to mention that this database applies to energy consumption understood only in terms of the use of coal, petroleum derivatives, gas, electricity, as well as biofuel. However, a more detailed look at energy consumption in agriculture is given by the data per specific units of agricultural land (AL). In this approach, the mean energy consumption in EU agriculture in 2016 amounted to 0.13 toe per 1 ha of AL. The country with the highest consumption was the Netherlands (2.7 toe), and the lowest – Romania (0.03 toe). Polish agriculture used energy equivalent to 0.25 toe per 1 ha of AL. (EUROSTAT, Agri-environmental indicator...). Its amount was

used to generate an average agricultural production worth EUR 1074.32 per 1 ha (Statistical Yearbook of Agriculture, 2017).

Figure 3. Final use of energy according to sectors in Poland in the years 2006 and 2016 [%]



Source: Own study results based on (Statistics Poland, 2018).

2. Cumulative Energy Efficiency of Agricultural Production

The data and information referred to above generally deal with the issues related to quantitative use of energy in agriculture, and this data refers to the above-mentioned energy used in the so-called direct form. However, energy consumption in every production process and at every stage of it forms a rather complex issue.

This issue can also be considered a bit differently, by taking an assumption that each production factor involved in the production requires energy input needed for this production. Energy understood in this way is gradually consumed throughout one or more production processes stages. Therefore, although the information contained in the introduction is important, it does not offer comprehensive energy assessment of the production process itself. The comparison of the energy consumption of a given crop also requires an assessment of the amount of energy used to produce means of production, e.g. agricultural machinery or fertilizers. It is then possible to faithfully assess the energy consumption of production processes in various systems, e.g. conventional or organic ones.

The modern agriculture should strive to achieve sustainable production, with due respect paid both energy to energy and the environment (Wójcicki, 2007). When an evaluation is made of the efficiency of the production process, one cannot focus solely on the yields obtained per unit of the cultivated area. It is also important to take the effort to assess it by applying the perspective related to the tools and practices utilized to protect the agricultural ecosystem (including, for example, soil or biological diversity). Many of them can be utilized to save energy consumed in agricultural practice, e.g. by application of simplified crop structure or use of biodiversity in sowing (Jordan, 2013).

One of the tools that enable the evaluation of the impact of agricultural production

on the environment, taking into account the incurred energy inputs, is related to the cumulative energy consumption of this production. As a result of using this approach, it is possible to perform a more adequate evaluation of the energy consumption in the agricultural production process. It depends on the type of production technology and the level of deficiencies in the thermodynamic processes that accompany this production (Kuczuk (b), 2016). The analysis of cumulative energy consumption provides the assessment of energy consumption applies during a given production process. It includes not only the traditional consumption of fuels or electricity, but also energy inputs related to the use of human labor, the consumption of agricultural machinery and other materials used in production (e.g. fertilizers, seeds).

The concept of cumulative energy consumption in agricultural production is quite widely described in many papers in the field (such as: Coppola *et al.*, 2008, Gelfand *et al.*, 2010; Kuczuk (b), 2016; Pimentel, 1984; Pimentel, 2009; Sławiński, 2011; Taheri and Shamabadi, 2013). However, it continuously attracts the interest in research due to the shifting approach to the production methods and the use of resources in the agricultural production.

According to (Wójcicki, 2015), research into the cumulative energy consumption of various agricultural production can be carried out using the so-called energy and material inputs, estimated in energy units (GJ or kWh) as well as grain units⁶ (GU). Therefore, the cumulative energy consumption of agricultural production can be expressed by the following components:

a) for crop production:

$$E_C = \Sigma_M + \Sigma_F + \Sigma_{MAT} + \Sigma_L [MJ] \quad (1)$$

where: E_C -cumulative energy intensity of crop production, ΣE_M – cumulative energy intensity in tractors, combines, agricultural machinery and maintenance parts, ΣE_F -cumulative energy intensity of fuel consumed for production, ΣE_{MAT} - cumulative energy intensity related to the generation of materials applied in the production (fertilizers, plant protection means, seeds), ΣE_L -cumulative energy intensity of human labor,

b) for animal production:

$$E_A = \Sigma_M + \Sigma_F + \Sigma_{MAT} + \Sigma_L [MJ] \quad (2)$$

where: E_A - cumulative energy intensity of animal production, ΣE_M -cumulative energy intensity in tractors, combines, agricultural machinery and means of transport, ΣE_F -cumulative energy intensity of fuel applied for production, ΣE_{MAT} -

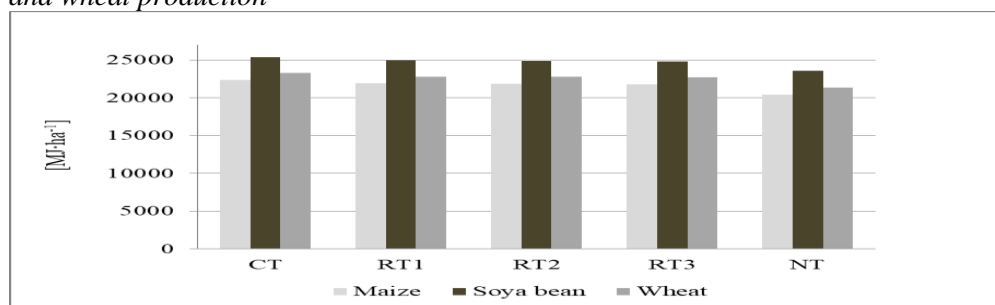
⁶Grain unit (GU) - conventional measure that allows to determine the value of plant and animal products with one number. One J corresponds to the value of 100 kg of grain. The value for individual agricultural products is obtained by multiplying their weight by appropriate coefficients.

cumulative energy intensity of material use (fodder), ΣE_L -cumulative energy intensity of human labor.

Cumulative energy consumption of agricultural production is relative to many factors, both external (e.g. weather conditions) and internal nature occurring on the farm, e.g. the type of soil, layout of a farm and shape of fields, plant structure, type of applied machinery, and finally the type of the production system: intensive or one that is focused on limiting the effect on the natural environment. The inputs incurred on production in a given farm may also differ in subsequent years due to varying weather conditions, changes in the irrigation system (Ansari *et al.*, 2018), as well as the use of the technologies (e.g. advancements in the machinery park, reduction of chemical use). For example, the introduction of the so-called no-tillage production may not only improve the biological life of the soil, but also possible savings in labor and fuel consumption. This, in turn, has a positive effect on the economic balance of the farm. Lower energy inputs are also higher energy efficiency expressed in these inputs per unit area or yield unit. Research carried out in this area (Rusu, 2014) confirms the highest energy performance in the case of cultivating corn, soybean and wheat without plowing, compared to other methods of cultivating these plants (Figure 4.).

Another study (Kuczuk (a), 2016) was concerned with the comparison of the cumulative energy intensity related to the production of winter wheat in the organic and conventional systems and it demonstrated that the use of eco-production may be accompanied by a lower input of resources for the purposes of production that is mainly attributable to the reduced consumption of chemicals. Research results (Pimentel *et al.*, 2005) also indicate that the energy inputs in the organic livestock production system and legume production were 28% and respectively 32% lower than in the case of conventional maize cultivation, which is largely due to the intensive use of machines and chemical means of production.

Figure 4. Effect of tillage system on energy efficiency [$MJ\cdot ha^{-1}$] of corn, soya bean and wheat production



Note: CT-conventional tillage: classic plow (20–25 cm) + disc harrow - 2 times (8 cm); RT1-reduced tillage: deep soil loosening (18–22 cm) + rotational harrow (8 cm); RT2-reduced tillage: chisel harrow (18–22 cm) + rotational harrow (8 cm); RT3-reduced tillage: rotational harrow (10–12 cm); NT-no tillage: direct sowing.

Source: Study results based on (Rusu, 2014).

Another example (Pimentel, 2006) performed with the purpose of comparison involving maize cultivation in the organic and conventional systems demonstrated that although the human labor input in the organic system was 32% higher than in the conventional system, this additional cost of energy input was compensated by reduced soil erosion and decrease loss of nutrients in the organic system. The comparison of the two systems in this example provides information on an overall energy saving of 31% in the green system. Other examples of analysis (Sławiński, 2011) report the results of a study into a relationship between an increase in the ecological area of winter rye cultivation and a decrease in the unit energy consumption index and an increase in cumulative energy savings.

The comparative analyses of various production systems also offer insight into the significant differences in the magnitude of individual components of cumulative energy intensity. This information may affect decisions regarding the shift in the production management system. This issue is illustrated by the examples of data contained in Table 1. Conventional farming, in particular for the case of an intensive system, which is characterized by considerable use of agricultural chemicals, is clearly accompanied by a higher stream of fertilizers or plant protection products.

In the case of buckwheat cultivation (Kuczuk (b), 2016), the use of natural fertilizers resulted in a higher ratio of materials in the organic production system. However, the higher energy intensity in this case is compensated by the improvement of the soil organic matter. Certainly, in ecological production, a higher human labor input is noteworthy. It is often characteristic of this type of production, which limits the excessive interference of machines and agricultural chemicals into the soil.

Table 1. Percentage ratios of particular components of cumulative energy intensity in particular types of production for buckwheat, winter wheat and corn.

Crop	Components of energy intensity			
	Machines	Fuel	Materials	Human labour
Buckwheat C ¹	13	36	41	10
Buckwheat O ¹	9	22	62	6
Buckwheat C ²	10	23	63	4
Buckwheat O ²	17	27	51	5
Rye O ³	15	49	32	4
Wheat C ⁴	9	11	73	6
Wheat O ⁴	18	21	51	10
Wheat C ⁵	4	17	78	1
Maize O ⁶	19	26	44	11
Maize C ⁶	13	18	63	6

Note: O-organic system C-conventional system

Source: Study based on: ¹Kuczuk (b), 2016; ²Sławiński et al., 2009; ³Sławiński, 2011; ⁴Kuczuk (a), 2016; ⁵Ansari et al., 2018; ⁶Pimentel, 2006)

Similar relations of cumulative energy consumption results apply to animal production. Ecological livestock production usually requires lower energy inputs than its conventional equivalent (Table 2). However, we should remember that large

differences in inputs, in individual countries, may result primarily from different climatic and fodder conditions or the intensity of animal rearing. Additional parameters are used to assess the cumulative energy consumption of a given agricultural production. They make it possible to relate the inputs of individual energy streams or the value of the total cumulated energy consumption to the achieved production results. Examples of common indicators include:

- energy efficiency that defines the cumulative Energy intensity [MJ] associated with generating GU of a given production,
- energy outlays [$\text{MJ}\cdot\text{ha}^{-1}$],
- indicator expressing energy intensity (WEE) that defines the relations between the energy value of a product (crop) (WEP) [$\text{MJ}\cdot\text{ha}^{-1}$], and the investment (NE) associated with this production [$\text{MJ}\cdot\text{ha}^{-1}$] (Sławiński et al., 2009):

$$W_{EE} = \frac{W_{EP}}{N_E} \quad (3)$$

Table 2. Investment outlays for production of 1 kg milk [$\text{MJ}\cdot\text{kg}^{-1}$]

Outlays [$\text{MJ}\cdot\text{kg}^{-1}$]	Production system	Source
3.3	conventional - Denmark	(Refsgaard <i>et al.</i> , 1998)
2.1	organic - Denmark	
3.5	conventional Sweden	(Cederberg <i>et al.</i> , 2000)
2.5	organic - Sweden	
5.0	conventional – Netheralnds	(Thomassen <i>et al.</i> , 2008)
3.1	organic - Netherlands	
6.4	conventional – Finland	(Grönroos, <i>et al.</i> , 2008)
4.4	organic - Finland	
5.35	conventional - Estonia	(Frorip, <i>et al.</i> , 2012)
1.51	conventional – New Zeland	(Basset-Mens, <i>et al.</i> , 2009)
2.45	conventional - Ireland	(Upton <i>et al.</i> , 2013)

Source: Study based on: ¹Kuczuk (a), 2016; ²Kuczuk (b), 2016)

The examples coupled with data derived for various production system (Kuczuk (a), 2016, Kuczuk (b), 2016) are summarized in Table 3.

Table 3. Examples with results of energy based indicators related to selected types of agricultural production

Indicator	Unit	Production	
		Organic	Conventional
Buckwheat ¹			
yield	$\text{dt}\cdot\text{ha}^{-1}$ or $\text{JZ}\cdot\text{ha}^{-1}$	10.91	11.74
energy outlays per 1 ha	$\text{MJ}\cdot\text{ha}^{-1}$	10665.22	7971.23

energy outlays per GU	MJ·JZ ⁻¹	978	697
$W_{EE} = \frac{W_{EP}}{N_E}$	MJ·ha ⁻¹ ·MJ·ha ⁻¹	1.47	2.11
Winter wheat ²			
yield	dt·ha ⁻¹ ; JZ·ha ⁻¹	39.06	66.98
energy outlays per 1 ha	MJ·ha ⁻¹	11247.46	23934.54
nakłady energy outlays per GU	MJ·JZ ⁻¹	287.95	357.34
$W_{EE} = \frac{W_{EP}}{N_E}$	MJ·ha ⁻¹ ·MJ·ha ⁻¹	4.20	3.03

Source: Study based on: (¹Kuczuk (a), 2016; ²Kuczuk (b), 2016)

The obtained indicator values provide valuable information regarding the projected production costs and the calculated price. Often, similar inputs in both production systems, with a simultaneous reduced yield in organic farming, are converted into higher market prices of food from organic production.

3. Emergy – Measure of Energy Use from Environment

3.1 Notion of Emergy

In emergy calculus, the starting point is based on the assumption that every product generated in the economy, every service, and every activity that is undertaken begins with the inflow of solar energy. As a consequence, it is possible to create any environmental resources, which are then used in the production processes and the for the purpose of thriving of ecosystems. The emergy calculus is based on the determination of the consumption of solar energy accumulated in renewable and non-renewable sources (Jankowiak and Miedziejko, 2009; Miedziejko, 2006). It offers the means to determine the degree of use of these resources in the production process and to assess the environmental loading (Kuczuk (b), 2016). It can be assumed that emergy (Em) is a universal measure of the actual wealth of both nature and society (Tilley and Martin, 2006).

Examples of the true wealth of a given economy are all products of labor, mainly of the environment, but also generated by humans (Odum, 1996). Figure 5. contains a graphic presentation of this relation, showing at the same time that the accumulated resources/goods also support the development process again (the return path) by using the energy contained in them. However, since some of the available energy is lost in different processes, the resulting resources/goods consume a much smaller ratio of converted energy.

The emergy value of a given, manufactured product is not the same as the energy related to the production process (as in the case of cumulative energy intensity). It is more to be understood as the amount of (solar) energy that has been used in the

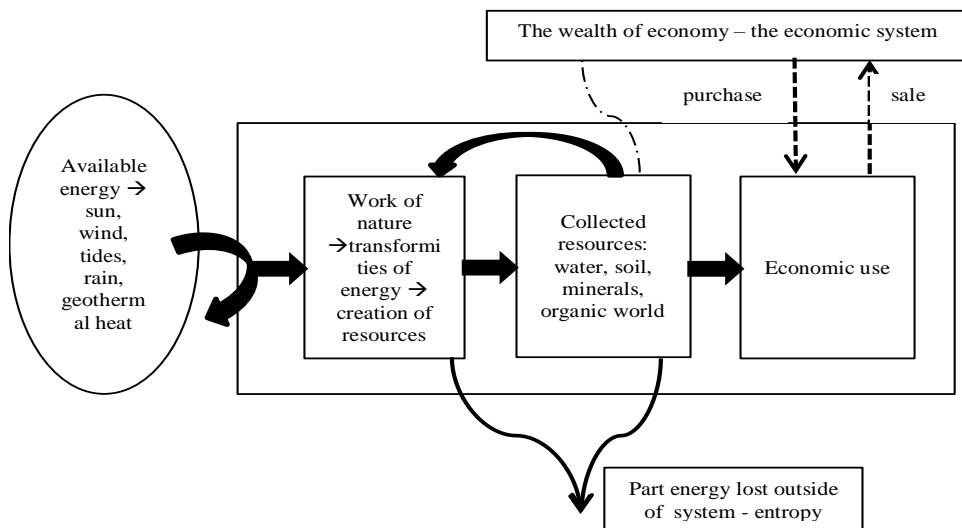
process of many transformations to produce a product/service. Therefore, energy forms a measure of the available energy that has already been utilized to generate a given product/service. (Haden, 2003, Odum, 1996). In mathematical terms, energy is determined by the product of the exergy (Ex) of a given substance (resource/good) and its solar transformity (τ), and is expressed by the unit named seJ (or emjoule):

$$Em = Ex \cdot \tau , \tag{4}$$

Exergy is the minimum amount of work necessary to obtain a given substance (resource/good) in the required state from common components in the surrounding nature (Szargut, 2009). In turn, solar transformity forms an indicator that expresses the amount of solar energy that has been used at each stage of creating environmental resources needed to obtain 1 J of exergy of a product or in the service. In the case of complex products, e.g. machinery and equipment, the cumulative consumption of solar energy in the subsequent production stages, based on various processes and materials, is captured by solar convertibility.

Examples of data on the transformation of solar resources and goods are presented in Table 4. For example, solar energy consumption equal to $7.4E+4$ joules is needed to produce 1 joule of soil organic matter. The data presented in the Table 4 also demonstrates that the resources/goods that required the most labor to produce them and often have relatively low specific exergy, at the same time have the greatest transformity (e.g. pesticides, nitrogen fertilizers) (Odum, 1996).

Figure 5. Production taking place in the environment, storage of wealth, and its economic use



Source: Modified graph based on (Odum, 1996)

Table 4. Examples of solar transformity values for selected goods and services

Source/good	Solar transformity [$\text{seJ}\cdot\text{J}^{-1}$]	Source
Sun	1	(Odum, 1996)
Wind	1.50E+03	
Rain	1.82E+04	
Coal	4.00E+04	
Petroleum	5.40E+04	
Soil organic matter	7.40E+04	
Pesticides	1.48E+10	(Brown and Arding, 1991)
N (fertilizer)	1.90E+06	(Odum, 1996)
Electricity	1.74E+05	
Rice	7.74E+04	(Ulgiati <i>et al.</i> , 1994)
Maize	8.52E+04	
Sugar beet	8.49E+04	
Wheat	15.90E+04	
Agricultural production	4.07E+04 (data for year 1999)	(Haden, 2003)
Animal production	2.13E+05 (data for year 1999)	

Source: Own study.

3.2 Emergy of Agricultural Production

The production of any type of agricultural product or service interferes with the environment and is responsible for consumption of energy stored in renewable and non-renewable resources in nature. Each agricultural system also depends on the influx of human-made resources and goods. The state of the balance in a given agricultural production and its effect on the environment as well as the use of energy is also dependent on the scale of human involvement and the manner of dealing with means of production applied in the production process. Intensive agricultural production methods extract a significant volume of energy that was converted into fuels (e.g. in the production process of artificial fertilizers). Environmentally sustainable methods try to use primarily energy from the environment (Tilley and Martin, 2006)

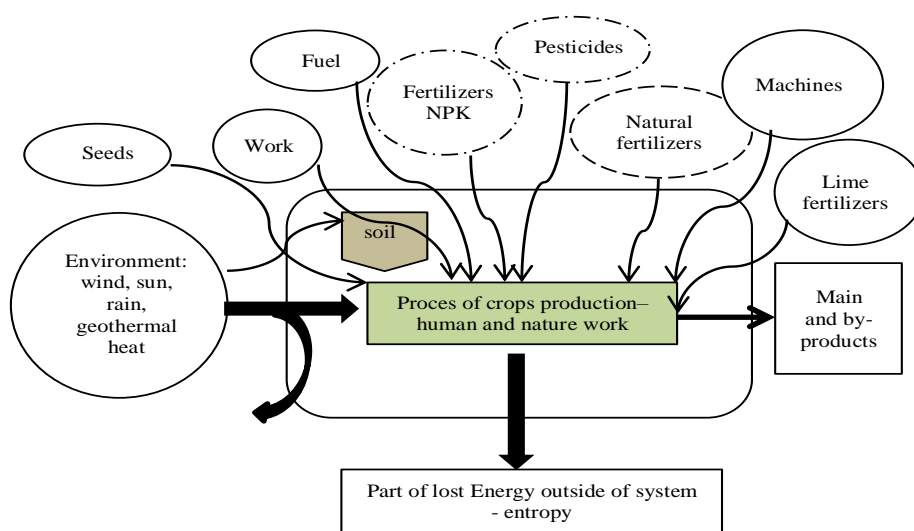
Environmental resources and the energy stored in them can be divided in the production process into those coming from the outside (energy of the sun, wind, rain, geothermal heat) and soil, which is a permanent agricultural resource. Besides, large amounts of matter and energy accumulated in non-renewable resources (e.g. agricultural chemicals, seeds, fodder, machine work) and renewable resources (e.g. human labor, seeds) often flow into the soil ecosystem from the outside, and the result takes the form of agricultural products (Figure 6). All ingredients delivered to the soil contain emergy utilized in the production process.

The use of emergy aspect in the assessment of the impact of production on the environment provides an alternative possibility of finding out about environmental sustainability of a given system and regarding the extent in which the environment has been deprived of non-renewable resources and learning about their emergy (solar) value (Dong *et al.*, 2009).

The analysis of energy requires input with weather data, as well as data on the exergy of seeds, fertilizers, fuel or degraded organic matter. It must also take into account the work of machines and people. Additionally, to better illustrate the efficiency of production, various indicators can be used (Table 5), e.g. EYR (field ratio) expressing the ratio of the total energy applied to the total of energy from non-renewable resources such as fertilizers, plant protection chemicals, fuel and machines.

Other examples of indicators include ELR (Environmental Loading Ratio), which expresses the relation between energy originating from non-renewable resources and renewable resources and PR – the ratio of energy from renewable sources to the total energy applied in a process, or the total consumption of energy per unit (or dt) of the final production ($Y \cdot GU^{-1}$). We can emphasize that the literature contains various approaches applicable to determining the components of the above indicators and different methods of calculating them. (Coppola *et al.*, 2008; Dong *et al.*, 2009; Jankowiak and Miedziejko, 2009; Kuczuk (b), 2016).

Figure 6. Sources of energy applied in organic and conventional plant production



Note: Sources of energy applied in conventional production: - - - - -

Sources of energy applied in organic production: - - - - -

Sources of energy applied in both production systems: —————

Source: Study results based on (Coppola *et al.*, 2008, Jankowiak and Miedziejko, 2009)

Table 5. Examples of energy indicators describing environmental loading

Indicator	Equation
P_R	$P_R = \frac{Em_R}{Em_R + Em_{MAT} + Em_M + Em_S + Em_F}$
ELR	$ELR = \frac{Em_{MAT} + Em_M + Em_S + Em_F}{Em_R}$

EYR	$EYR = \frac{Y}{Em_{MAT} + Em_F + Em_M}$
Emergy use per GU (or dt)	$Y \cdot JZ^{-1}$

Note: Y -total use of emergy; Em_R -emergy derived from renewable sources such as: sun, wind, waster, seeding material and labor; Em_{MAT} -emergy of plant protection agents and fertilizers; Em_M -emergy of machinery and equipment; Em_S -emergy of degraded organic soil matter; Em_F - emergy of fuel.

Source: Study based on: (Coppola et al., 2008; Jankowiak and Miedziejko, 2009; Kuczuk (b), 2016)

The analysis of emergy related to agricultural production provides insights into the relations between energy consumption derived from the environment and the method of production and soil conditions. Usually, non-renewable flows have a greater ratio in the consumption of emergy. In organic as well as environmentally sustainable crops, a relatively higher ratio of renewable resources emergence is observed. This statement is graphically illustrated in Table 6, which presents examples with mean values of the emergy use from renewable and non-renewable sources using an example of selected agricultural production. The ratio of the emergy derived from renewable sources in relation to the emergy from non-renewable sources is very different depending on the type and system of production. Generally, emergy from non-renewable sources occupies a dominant proportion of total energy use in conventional, intensive agricultural production with a large volume of agricultural chemicals. Additionally, Table 7 presents exemplary values of emergy indicators related to examples of organic and conventional crops on the basis of data derived from selected farms in the Opolskie province. In conventional wheat cultivation, the ELR is much greater than in the comparable organic system. For example, buckwheat, comparable values of indicators originate from the use of manure or calcium fertilizers in organic farms. We can noteworthy mention, however, that the benefits of manure application are significant from the point of view of developing soil organic matter. For example, the input of 30 tons of manure per hectare of cultivation in a given year may result in the reproduction of soil organic matter in the amount of about 2.6 tons on this hectare this year.

Table 6. Values of emergy related to examples of production and final products

Production	Unit	Emergy	
		renewable sources	nonrenewable sources
Chicken eggs ¹	seJ·100 chickens ⁻¹ ·y ⁻¹	7.09E+16	2.03E+16
Corn (grain) dry weight ¹	seJ·ha ⁻¹ ·y ¹	1.69E+15	1.17E+16
Milk (dry weight) ¹	seJ·cow ⁻¹ ·y ⁻¹	4.63E+15	2.12E+16
Buckwheat O ²	seJ·ha ⁻¹ ·y ¹	6.66E+14	6.32E+15
Buckwheat C ²	seJ·ha ⁻¹ ·y ⁻¹	6.82E+14	7.08E+15
Wheat O ³	seJ·ha ⁻¹ ·y ⁻¹	5.6E+15 – sandy soil 5.4E+15 – sandy loamy soil	
Wheat C ³	seJ·ha ⁻¹ ·y ⁻¹	6.6E+15 – sandy soil	

		6.9E+15 – sandy loamy soil	
Spring barley ⁴ – without PK	seJ·ha ⁻¹ ·y ⁻¹	2.43E+15	6.86E+15*
Winter rape ⁴	seJ·ha ⁻¹ ·y ⁻¹	2.43E+15	8.18E+15*
Winter wheat ⁴	seJ·ha ⁻¹ ·y ⁻¹	2.43E+15	9.84E+15*
Oat ⁴ – without NPK	seJ·ha ⁻¹ ·y ⁻¹	2.43E+15	7.03E+15*

Note: O-organic system; C-conventional system; *as the sum of nonrenewable and purchased resources

Source: Study based on: (¹Brandt-Williams, 2011; ²Kuczuk (b), 2016; ³Coppola et al., 2008; ⁴Burges, 2010)

Table 7. Emergy parameters related to examples of agricultural production

Parameter	C	O	Notes
Buckwheat ¹			
P _R	0.13	0.13	Equal ratio of renewable resources in both production systems.
ELR	6.58	6.85	Slightly greater use in organic production.
EYR	1.36	1.39	Similar values of this performance indicator.
Wheat ²			
P _R	0.11	0.21	Higher ratio of use of renewable resources in organic production
ELR	8.27	3.01	Considerably greater ratio of non-renewable resources in conventional production
EYR	1.11	1.27	Higher ratio of renewable resources in organic production

Note: O-organic system; C-conventional system

Source: Study based on: (¹Kuczuk (b), 2016; ²Kuczuk (a), 2016)

4. Cumulative Energy Intensity Vs Emergy of Agricultural Production

As we already mentioned before, emergy consumed in the production process of a given product is not the same as the energy related to the production process (as in the case of cumulative energy consumption). The differences in the results gained by application of the cumulative energy intensity calculus and the account applying the emergy approach are summarized in Figure 7. It contains examples of cumulative energy outlays related to determined values of emergy with regard to individual winter wheat production components, in the conventional and organic systems. The figures contain exemplary results for two farms located in south-western Poland, in the Opolskie province. The farms are characterized by similar soil and climate conditions and have a comparable machine park. The data necessary to calculate the energy consumption of production and their emergence was derived directly from farms and it applies to the year 2014.

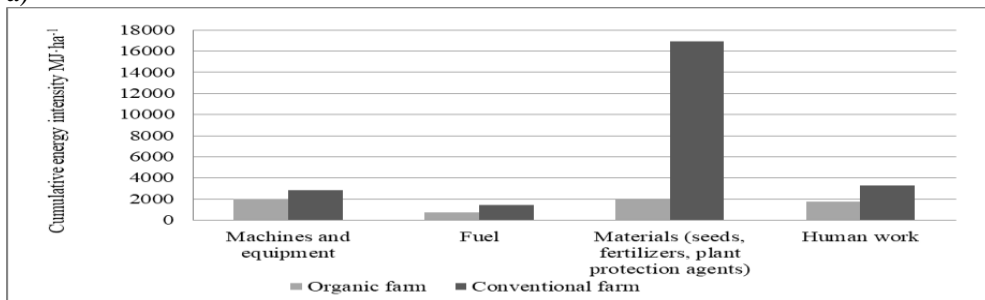
The data presented in Figure 7 indicates that the components understood in terms of the use of agricultural materials, including mineral fertilizers, have the largest ratio in cumulative energy intensity. In conventional production, their ratio in cumulative

energy consumption in the analyzed example was equal to nearly 60%. The ratio of machines and equipment is 11.5%, and for human labor – 13.5%. Therefore, energy savings and rational use of the environment should be sought in particular in the areas related to the use of chemicals machines and equipment in agriculture.

Similar relationships, although slightly different, are observed in the emery calculus. In this case, the use of machinery and equipment (ratio: 40.4% in the total emery) on a conventional farm and 65.5% on an organic farm and mineral fertilizers (nearly 42% ratio in the total emery needed for the production of the conventional farm) are responsible to the greatest extent for the total emery use; this also includes the ratio of nitrogen fertilizers in the environmental loading equal to over 26%. In conventional production, the ratio of mineral fertilizers, in particular nitrogen fertilizers, is often very high. As it was demonstrated by research and agricultural practice, a large proportion of nitrogen from mineral fertilizers leaches into the soil and is volatilized in the case of ammonium compounds. The scale of this phenomenon may be as high as over 40% of the amount of the total use of mineral fertilizers (Levy *et al.*, 2017; Jensen and Hauggaard-Nielsen, 2003). These processes are also related to energy losses and harmful environmental impact.

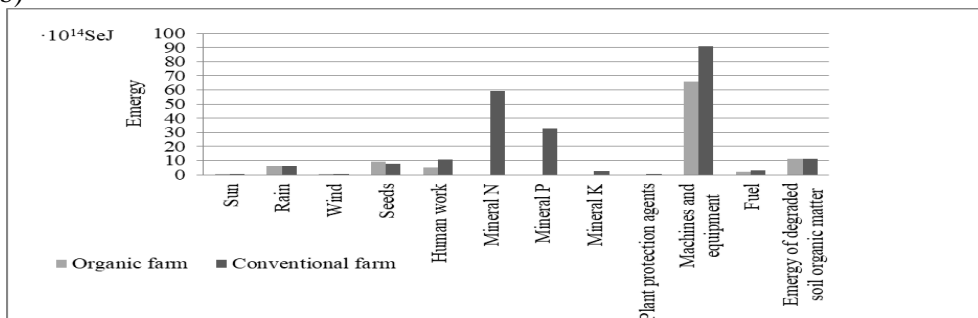
Figure 7. Values of cumulative energy intensity (a) and emery (b) applied in the conventional and organic cultivation of winter wheat

a)



Source: Study results.

b)



Source: Study results.

Moreover, the results of the emery calculus demonstrates the actual scale of the use

of renewable and non-renewable resources. For the example presented above, selected emergence indices were additionally calculated: PR, ELR and EYR. Each result indicates a lower environmental loading in the presented organic production (Table 8).

Table 8. *Emergy indicators related to winter wheat production.*

Indicator	Organic farm	Conventional farm
P _R	0.21	0.11
ELR	3.70	7.94
EYR	1.48	1.19

Source: Study results

Obviously, the above example does not indicate that the presented ratios of individual components responsible for production, both in terms of the cumulative energy consumption account and in the emergy calculus, will always be lower in the case of organic production. It all depends, among others on the type of production, farm equipment including appropriate machinery use as well as soil and climate conditions. However, it is beyond doubt that conventional farms significantly form a considerable threat to the environment by using agricultural chemicals.

5. Summary and Concluding Comments

Agriculture forms a branch of the economy in which the impact of production on the natural environment is particularly visible. The measure of this impact may be represented by the cumulative energy intensity of agricultural production and the amount of expenditure incurred for the purposes of generating the resulting products. Thus, the actual indicator can be related to the cumulative energy consumption, which takes into account “non-energy” outlays, which include energy-intensive inputs used on the farm and in the environment at earlier stages of their generation, such as machinery and mineral fertilizers. The analysis of cumulative energy consumption offers the means to compare various agricultural production systems, related inputs and energy loads related to the cultivated crops.

The cumulative energy calculus indicates that machinery and equipment as well as mineral fertilizers may account for over 70% of the energy consumption of production. Mineral fertilizers can be leached from the soil with precipitation due to intensive fertilization and adverse soil conditions. Such conditions are also adverse from the point of view of cumulative energy outlays.

The presented example of the emergence account offers a look at agricultural production in a broader sense, i.e. in terms of human interference in the environment and using natural resources. Hence, it provides useful insights for the purposes of evaluating the degree of environmental sustainability of various processes, including agricultural production.

In the conditions of Poland, ELR in conventional crops ranges from 6 to 12 and clearly indicates adverse impact of production on the environment. In organic systems, the value of this indicator can be reduced by more than 50%.

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