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ASSESSMENT OF NON-MARKET ENVIRONMENTAL SERVICES IN AGRICULTURAL PRODUCTION

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OCENA POZARYNKOWYCH USŁUG ŚRODOWISKA W PRODUKCJI ROLNICZEJ

STRESZCZENIE: Z punktu widzenia termodynamiki wartość dobra i usługi w ekonomii zależy od jakości energii bezpośrednio i pośrednio wykorzystanej do ich wytworzenia. Ponieważ rynek nie jest doskonały, obliczenia energii zawartej w materii powinny precyzować wartości rynkowych i nierynkowych dóbr i usług.
Metoda oparta na emergii została zastosowana do oceny zarówno wykorzystania strumieni energii, masy oraz nakładów finansowych (azotu, dwutlenku węgla, wody, materii organicznej gleby, nasion, nawozów, środków ochrony roślin, paliw, towarów i usług), jak również produktywności oraz zrównoważenia w typowych uprawach prowadzonych w Wielkopolsce w latach 2006-2008. Obliczono i porównano takie wskaźniki emergetyczne, jak: współczynnik wydajności (EYR), współczynnik obciążenia środowiska (ELR), indeks zrównoważenia (EIS) stopień wymiany (EER) oraz udział inwestycji (EIR) dla upraw pszenicy, rzepaku i buraków cukrowych. Największa wartość EIS występuje w uprawie pszenicy, a uprawa rzepaku charakteryzuje się największa wartością EYR. Wartości nierynkowych usług środowiska w tworzeniu zysku z upraw pszenicy, rzepaku i buraków wynoszą odpowiednio 53%, 60% i 48%. Chociaż uprawa buraków charakteryzuje się największą wartością ELR głównie z powodu degradacji materii organicznej gleby, to równocześnie dostarcza znacznej usługi w procesie stabilizacji klimatu dzięki absorpcji dwutlenku węgla. W ogólności jednostka powierzchni uprawy pszenicy absorbuje taką ilość dwutlenku węgla, jaką dwóch statystycznych obywateli Polski emituje w ciągu roku. Jednostka powierzchni uprawy buraków kompensuje emisje dwutlenku węgla 2,4, a rzepaku 1,5 rocznej emisji *per capita*. Dokonano porównania cen rynkowych (PLN) użytych zasobów z cenami skalowanymi na podstawie obliczeń metodą emergetyczną (EmPLN). Okazało się, ze ceny rynkowe nasion, pracy i paliw są zawyżone PLN>EmPLN, a nawozów są porównywalne PLN » EmPLN.

SŁOWA KLUCZOWE: emergia, seJ, emergetyczny indeks zrównoważenia, emisja dwutlenku węgla *per capita*

Introduction

In order to sustain life and maintain existing social, economic and cultural arrangements the fundamental human activity is focused on the competition in the free energy distribution. There is a close relationship between the value of money and the value of energy. That is because money is used to buy goods and services, of necessity derived from energy. Because energy is the source of economic value wherever a money flow existed in economy there was a requirement for an energy flow in the opposite direction. The driving force of economical growth is the cooperation of energy flow from non-renewable resources controlled by people with the flow of energy from renewable resources of biosphere.

However the large natural energy flows of solar radiation, wind and water have no associated monetary flows. The costs of using these energy flows do not enter into economic transactions directly, often leading to their misuse or the mismanagement of life-sustaining environmental services. Generally money circulates in closed loop, whereas low-entropy energy moves in from the outside, is used for economic tasks, and then leaves the economic system as degraded heat[1].

There is an obvious contradiction with monetary system of values currently existing in the economy, based on the assumption that the measure of the goods and services value is equal to the money that people are willing to pay for them. As a result, the activity of large social groups focuses on the circulation of money that does not have any physical equivalent in the form of streams of matter or energy. It leads to such phenomena as crisis and social inequality which, from the point of view of second law of thermodynamic, are a manifestation of entropy accumulation in the global system.

Moreover, due to existing monetary system of values, goods and environmental services are not taken into consideration because that people are paid for their services but money do not constitute the payment for environmental services. As a result, there is a commonly observed decline of low entropy ecosystem resources, environment pollution with high entropy substances and overall processes of the biodiversity damaging[2].

Threats to economic and civilizational development resulting from the intensive biosphere exploitation can be limited if the principle of sustainable use of resources on the global, national and regional scale is obeyed[3].

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[1] C.J. Cleveland, *Biophysical Economics: From Physiocracy to Ecological Economics and Industrial Ecology*, in: *Bioeconomics and Sustainability*, eds. J. Gowy and K. Mayum, E.E. Publishing, England 1999, p. 125-154; M. Ruth, *Insights from thermodynamics for the analysis of economic processes*, in: *Non-equilibrium thermodynamics and the production of entropy*, eds. A. Kleidon, R.D. Lorenz, Springer-Verlag Germany, Berlin 2005, p. 243-251.

[2] M. Carley, P. Spapens, *Dzielenie się światem,* Instytut na rzecz Ekorozwoju, Wydawnictwo Ekonomia i Środowisko, Białystok-Warszawa 2000.

[3] M.T. Brown, S. Ulgiati, *Emergy-based indices and rations to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation*, 1997 Vol. 9, p. 31-69; M.A. Brown, B.K. Sovacool, *Developing an Energy Sustainability Index to evaluate energy policy*, "Interdisciplinary Science Review" 2007 No. 32, p. 335-349; J.R. Siche, E. Ortega, A. Romeiro,

From the point of view of thermodynamics, the value of a good or a service depends on the quality of energy directly or indirectly used for their production. Since the market is not perfect, the calculations of the energy contained in the matter should specify the value of market and non-market goods and services. It requires the development of holistic measures based on thermodynamics and their application to the control of technological and agrotechnical processes efficiency, together with usually taken into account economical measures.

Especially useful for this purpose is the method introduced by H. Odum in 1980s [4] which has been improved and developed since then. The emergy analysis is an environmental accounting methodology based on the general assumption that, in every ecosystem as in the biosphere, all the energy fluxes belong from solar radiation. The solar emergy (emergy) of flow or storage is defined as the solar energy directly or indirectly required to generate that flow or storage. It is an extensive quantity and its units are solar emergy joules, seJ. In order to convert all the flows involved in the process into this common base, a conversion factors are used: the solar transformities, defined as the emergy per unit flow or unit product.

Emergy can consider as an energy memory because it takes into account all the energy, past and present, needed to check produce that product or flow. The emergy method can be used for resolving many research tasks such as: the efficiency and crops sustainability assessment[5], efficiency of biofuels production[6], and irrigation processes[7], the comparison of the efficiency of generators of elec-

F.D.R. Agostinho, *Sustainability of nations by indices comparative study between the environmental sustainability index, ecological footprint and the emergy performance indices.* "Ecological Economics", 2008, 67, p. 519-525; M.T. Brown, S. Ulgiati, *Updated evaluation of exergy and emergy driving the geobiosphere: A review and refinement of the emergy baseline*, "Ecological Modeling" 2010 No. 221, p. 2501-2508;

[4] H.T. Odum, *Environmental Accounting, Emergy and Environmental Decision Making*, J. Wiley & Sons, inc, New York, 1996.

[5] M.C. Ferreyra, *Emergy perspectives on the Argentine economy and food production systems of the Rolling Papas during the twentieth century*, University of Florida, Thesis 2001; J. Jankowiak, E. Miedziejko, *Energetyczna metoda oceny efektywności i zrównoważenia środowiskowego uprawy pszenicy*, „Journal of Agribusiness and Rural Development" 2009, p. 75-84; J. F. Martin, S.A.W. Diemont, E. Powell, M. Stanton, S. Levy-Tacher, *Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management*, "AGEE" 2006 No. 115, p. 128-140; E. Miedziejko, J. Jankowiak, *Energetyczna wycena usług środowiska w uprawie buraków*. „Ekonomia i Środowisko" 2010 No. 1, p. 190-200; E. Miedziejko, J. Jankowiak, *Energetyczna analiza usług i obciążenia środowiska w uprawie rzepaku*, „ZPPNR" 2010 No. 547, p. 237-248; E. Ortega, M. Miller, *Comparison of ecological and agro-chemical soybean cultivars using emergy analysis. Hypothesis and first results*, Book of Workshop Proceedings 2nd International Workshop Advances in energy studies Porto Venere Italy, 2007.

[6] D. Pimentel, T.W. Patzek, *Ethanol production using corn, switch grass and wood; biodiesel production using soybean and sunflower*, " Natural Resources Research" 2005 No. 14, p. 65-76.

[7] S. L. Brandt-Williams, *Handbook of Emergy Evaluation. A Compendium of Data for Emergy Computation Issued in Series of Folios*, Center for Environmental Policy Environmental Engineering Science, University of Florida, Gainesville 2002, p. 1-37.

trical energy coming from different sources[8], measurement of the concentration of the information flow in the cities[9], emergetic assessment of CO_2 emission impact on the climate changes[10].

The basis of this method is the assumption that the energy contained in the source or provided as a result of a service determines their values, i.e. "ecological price".

The aim of the study was the quantitive assessment of the efficiency and environmental sustainability, as well as the mutual relations of prices determined on the basis of monetary and emergetic measures as well as the development of the carbon dioxide balance in the crops of wheat, rape and sugar beets.

Methodology

Data sources

The economical data used in this work are mean values for Wielkopolska Region in years 2006-2008[11] in terms of outlays for the crop. The source of meteorological data are the measurements made in the Research Station of the Institute of Forest and Agricultural Environment PAS in Turew. The radiation balance and evapotranspiration quantity were calculated according to the scheme described in the work[12]. For the calculations there were taken into the account the time intervals in which positive radiation balance occurred.

Calculation basis

Emergy E_m of the specific product or service is the sum of exergy E_{xi} of all inflows „*i*" used directly or indirectly for their production. It is expressed by the formula:

$$E_m = \sum_i \tau_i E_{xi} \quad (1)$$

where τ_i is solar transformity of independent inflow constituent "*i*". Transformity is the amount of energy per unit of exergy of the component „*i*".

[8] M.T. Brown, S. Ulgiati, *Emergy evaluation and environmental loading of electricity production systems*, "Journal of Cleaner Production" 2002 No. 10, p. 321-334.
[9] Ch. Shaoging, Ch. Bin, *Assessing inter-city ecological and economic relations: An emergy based conceptual model*, "Frontiers of Earth Science" 2011 No. 5, p. 97-102.
10 M. J. Lennon, E. Nater, *Biophysical aspects of terrestrial carbon sequestration in Minnesota*, Minnesota Terrestrial Carbon Sequestration Project, 2006.
[11] *Kalkulacje rolnicze*, Wielkopolski Ośrodek Doradztwa Rolniczego, Poznań 2007, 2008, 2009.
[12] E. Miedziejko, L. Ryszkowski, A. Kędziora, *Produkcja entropii w różnych ekosystemach krajobrazu rolniczego*, in: *Bioenergetyka ekologiczna, Koncepcje i zastosowania praktyczne*, Wydawnictwo Werset, Lublin 2007, p. 68-81.

The transformities used in this work were calculated on the basis of the model processes in the global environment[13].

The emergy of solar radiation, wind, nitrogen, carbon dioxide, degraded organic matter of the soil, fuels and mineral fertilizers was calculated using the method described in earlier work of authors[14]. Transformity of the amount of labour in years 2006-2008 was calculated similarly on the basis of statistical data[15].

The emergetic calculation also takes into account the value of goods and services estimated on the basis of market prices after determination of global and national emergy use in relation to GGP and GDP. This way, the circulation of money is allocated to the emergy flow and it is possible to balance all driving forces for the sustainable process.

In contrast to the monetary values (economic prices) that depend on subjective preferences of people, ecological prices should be normative coefficients resulting from the models describing the mass and energy flow through natural habitats.

In the emergetic method the ecological prices which are alternatives to the economic prices should be expressed by the value of emergy expended by biosphere in order to produce economic good per unit of specific physical quantity, most often mass or energy.

In order to directly compare economic prices to the prices determined by the use of emergy (environmentally scaled prices) there should be accepted some simplifying assumptions.

Above all the ecosystems studied are the part of Polish territory which in turn is nested in the global system. Therefore the determination of ecological prices of the products studied requires taking into account certain interdependences. This task can be carried out in turn:

1) there should be calculated the emergy consumption on the global scale and there should be set the emergy/money quotient P(seJ/USD) in a given year which means calculating the ratio of emergy consumption in relation to GGP. It constitutes the value of emergy used to produce a unit of GGP (USD);
2) there should be calculated the emergy consumption on a national scale in a given year (taking into account imports and exports expressed by units of emergy with the consideration of P(seJ/USD) and there should be calculated national emergy/money quotient P_1(seJ/USD) as the relation of emergy consumption to the GGP – the amount of emergy used to produce monetary unit (USD) in the national turnover.

[13] H.T. Odum, *Environmental Accounting, Emergy and Environmental Decision Making*, J. Wiley & Sons, inc., New York 1996; M.T. Brown, S. Ulgiati, *Emergy Analysis and Environmental Accounting. Encyclopedia of Energy 2,* 2004, 2, p. 329-353; M.T. Brown, S. Ulgiati, *Updated evaluation ...*, 2010 No. 221, p. 2501-2508.

[14] Ibidem.

[15] *Rocznik Statystyczny Rzeczpospolitej Polskiej*, Wydawnictwo im. E. Romera S.A., Warszawa 2006, 2007, 2008.

3) emergy/money quotient of the national currency P_1'(seJ/PLN) should be determined by using the comparative method. Since the purchasing power of the currency determines its „driving force", it was assumed that it is an analogue of exergy in the formula 1, so E_x(PLN) or E_x(USD), whereas emergy/money quotients of both currencies are analogues of transformities. As the value of emergy used to produce GDP does not depend on the type of currency (USD) or (PLN) in which the monetary flow is expressed but depends on its purchasing power and emergy/money quotients of both currencies P_1(seJ/USD and P_1'(seJ/ PLN), formula 1 indicates the correlation:

$$E_x\ (PLN)\times P_1'(seJ/PLN) = E_x(USD)\times P_1(seJ/USD) \qquad (2)$$

Therefore the emegy/money quotient of the national currency is expressed by the following formula:

$$P_1'(seJ/PLN) = P_1(seJ/USD) \times E_x(USD)/E_x\ (PLN) \qquad (3)$$

In years 2006-2008 the relation of purchasing power of both currencies in the national turnover was E_x(USD)/E_x(PLN) = 3.102; 2.769; 2.962 and calculated emergy/money quotient was P_1 = 2.01TseJUSD; 1.74TseJ/USD; P_1 = 1.47 TseJ/USD respectively[16].

The values of market and non-market goods expressed in the environmentally scaled prices can be calculated by dividing the emergy used by P_1'(seJ/PLN).

It is proposed that the values of scaled prices obtained on the basis of emergetic calculation should be described as EmPLN, as the analogy to designations EmUSD functioning in the world literature.

The data were analyzed on the basis of emergetic indices[17] defined in the Table 1.

[16] E. Miedziejko, *Termodynamiczna analiza wykorzystania zasobów środowiska w latach 1995-2006*, in: *Zasoby i kształtowania środowiska rolniczego. – Agrofizyczne metody badań*, eds. B. Dobrzański jr, A Gliński, R, Rybczyński, Wydawnictwo Nauk RFNA, Komitet Agrofizyki PAN, Lublin 2009, rozdział 1, p. 9-28.

[17] M.T. Brown, S. Ulgiati, *Energy-based indices...*, op. cit., p. 31-69.

Table 1.
Emergy indices for crop efficiency and sustainability

Indice	Symbol	Definition
Used emergy	Y	R+MR+SR+N+MN+SN
Renewable Emergy Fraction	P_R	$\frac{R+M_R+S_R}{Y}$
Emergy Yield Ratio	EYR	$\frac{Y}{M_N+S_N}$
Environmetal Loading Ratio	ELR	$\frac{N+M_N+S_N}{R+M_R+S_R}$
Emergy Index of sustainability	EIS	$\frac{EYR}{ELR}$
Emergy Investment Ratio	EIR	$\frac{S_N}{Y}$
Emergy Exchange Ratio	EER	$\frac{Y}{E_p}$

Y – total emergy consumption, R – renewable crop emergy: solar irradiation, kinetic energy of wind, water, nitrogen and carbon dioxide, N – non-renewable emergy of organic matter of the soil, M_R – renewable energy of seeds, M_N – non-renewable emergy of fuels, fertilizers and plant protection chemicals, S_R-renewable emergy of labour, S_N-non-renewable emergy of financial outlays, Ep-emergy obtained from the crop sale.

Results and discussion

Emergy consumption

A very important achievement of the emergetic method is a quantitative comparison of qualitatively different inflows to the crop habitat. Figure 1 presents quantitative comparison of the emergy taken from different sources in crops of wheat, rape and beets. As we can see, renewable inflows in the form of solar radiation, kinetic wind energy, stream of atmospheric nitrogen and carbon dioxide absorbed are very small in comparison to the chemical energy of water. Among resources taken from the habitat, the largest share has the consumption of emergy in the form of soil organic matter, which is particularly important for the beet crop. It turned out that non-renewable energy taken during the fuel burning is significantly smaller than the emergy taken during soil organic matter degradation. Especially large share characterizes non-renewable emergy of ferti-

Figure 1.
Crop emergy resources

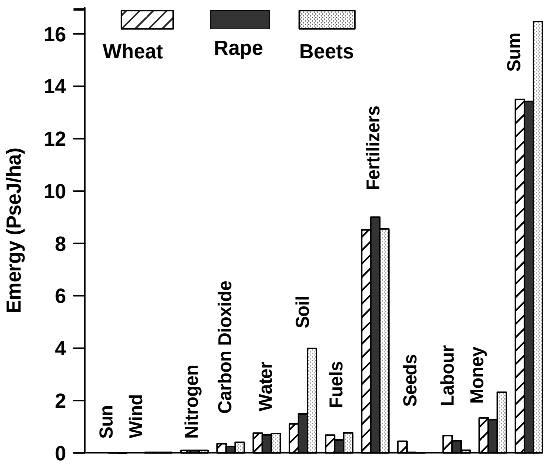
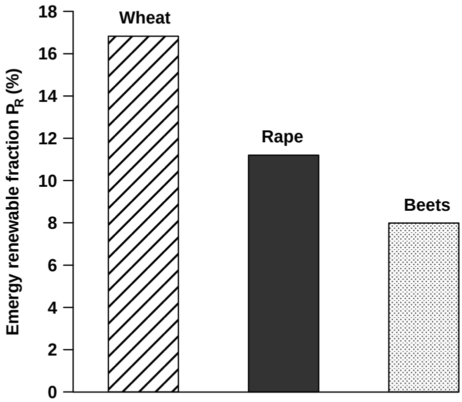


Figure 2.
Dependence of the renewable emergy fraction on the type of the crop



lizers. The renewable emergy of seeds is very small, similarly to emergy of labour. Non-renewable emergy of financial outlays is comparable to non-renewable emergy of degraded organic matter taken from the crop habitat.

The share of habitat renewable emergy in whole crop emergy consumption has been compared on Figure 2. The renewable emergy fraction used in Wielkopolska Region in wheat is comparable to cultivar performed in Argentina[18] and Italy[19]. Particularly low is emergy renewable fraction P_R used in sugar beet cultivar.

[18] M. C. Ferreira, op.cit.
[19] S. Ulgiati, C. Cialani, *Environmental and thermodynamic indicators in support of fair and sustainable policy making. Investigating equitable trade among Latvia, Denmark and Italy,* Pro-

As results of the crop cultivar was obtaining the mass: m = 6 t/ha (wheat), m = 3 t/ha (rape) and m = 48 t/ha (sugar beets). Since the exergy calculated on the basis of chemical composition was E_x = 100.7 GJ/ha; E_x = 68.97 GJ/ha and E_x = 198.8 GJ/ha and the calculated emergy consumption was Y = 13.5PseJ/ha; Y = 13.4PseJ/ha and Y = 16.47PseJ/ha there were obtained yield transformities: t = 134kseJ/J; 194.3 kseJ/J and 82.8kseJ/J for wheat, rape and sugar beets respectively.

For these values of emergy density is r = 2.25 TseJ/kg (wheat), r = 4.47 TseJ/kg (rape) and r = 0, 34 TseJ/kg (beets). It should keep in mind that transformity is a measure of emergy placed in a given product and is an indicator of "ecological price".

After dividing by P_1'the value of production expressed in environmentally scaled prices is 3979, 5123, 6623 EmPLN. The market value in economic prices was 6888PLN; 3498PLN and 3769PLN. The difference in prices scaled by using emergy method (EmPLN) and monetary price (PLN) is a measure of non-market environmental services. Therefore as a result, in the crop model described the values of non-market environmental services in the creation of profit from the crops of wheat rape and sugar beets is 53%, 60% and 48% respectively. As we can see, taking into consideration prices of market services and the value of production conditioned by supply and demand of agricultural products, the non-market environmental services in the rape crop were used the most effectively. Moreover the market value in economic prices was 173%, 68% and 57% environmental price for wheat, rape and sugar beets respectively.

Assessment of crops sustainability

In Figure 3. there are Emergy Yield Ratio of crops defined as the relation of emergy accumulated in product to the non-renewable emergy taken from the external environment

Form the definition of the Emergy Yield Ratio it results that reverse of EYR-1 equals the number of units of emergy taken from the outside per unit of emergy taken from the habitat. It is 3, 4 and 2 for whet, rape and sugar beets respectively.

The EYR reveals to what extent the crop environment can compete in providing emergy. It means that for the collection of habitat emergy the most effectively was used the external emergy in beets crop. Due to the fact that this was non-renewable emergy collected during the degradation of soil organic matter, the ELR coefficient was particularly high (Figure 4).

The environmental pressure in the cultivar model is characterized by the Environmental Loading Ratio (ELR) which is equal to the ratio of the P_R fraction

ceedings of 2[th] International Conference on integrative Approaches towards Sustainability, Riga, Latvia, 2005.

Figure 3.
Comparison of emergy Yield Ratio for crop analyzed

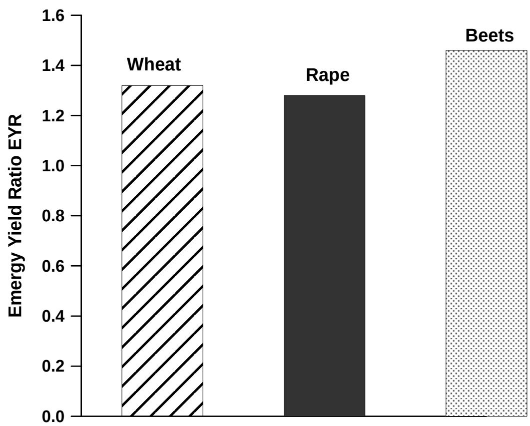
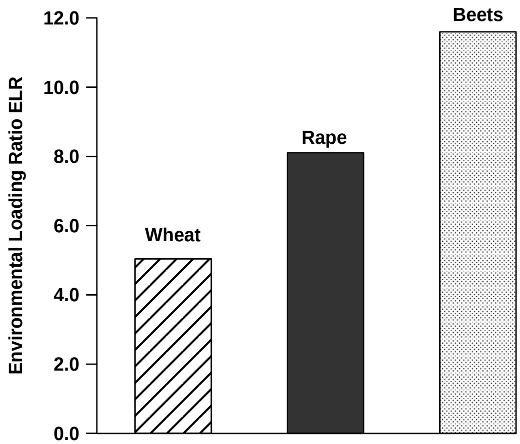


Figure 4.
Dependence of the Environmental Loading Ratio ELR on the type of the crop

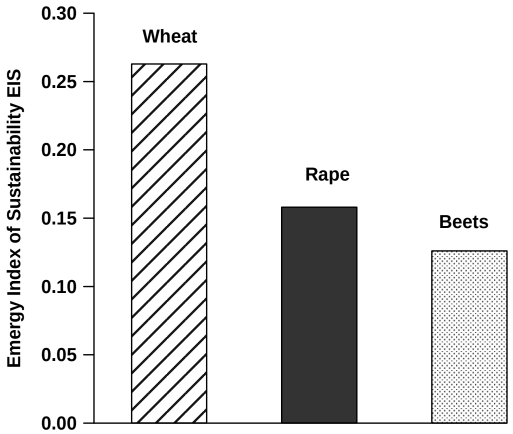


of renovable to the fraction R_N nonrenevable sources, respectively in the total emergy consumption. The Figure 4. reveals that ELR is three times bigger in the beets crop than in the wheat crop and 1.5 times bigger than in the rape crop.

Received values are greater that obtained in Argentina, greater than the average for all cereals in U.S.[20] and close to the values obtained in Latvia for all agricultural production with a predominance of wheat. In order to improve the ELR

[20] S. L. Brandt-Williams, *Handbook of Emergy Evaluation. A Compendium of Data for Emergy Computation Issued in Series of Folios*, Center for Environmental Policy Environmental Engineering Science, University of Florida, Gainesville, 2002, p. 1-37.

Figure 5.
Dependence of the Emergy Index of Sustainability on the type of crop.



a great changes in the system of farming can be recommended based on existing data basis[21].

Generally we looking for the best production model there is a large EYR and little ELR. This feature assesses Emergy Index of Sustainability (EIS), which quantitatively specifies the yield of process per unit of environmental loading.

Crops were carried out with the usage of large amount of mineral fertilizers and small amount of work due to that fact they were characterized by small index of sustainability (Figure 5).

For the model of cultivar in Wielkopolska Region emergy evaluation reveals that EIS is much smaller than this, which is characterized by cultivation of cereals in Italy, Latvia and Brazil[22].

This situation is not surprising, taking into consideration the lack of economic sustainability on a national scale[23] in Poland.

The share of investments (EIS) means a number of emergy units which should be invested in crop in order to collect a unit of crop emergy. On the basis of Figure 6 data the calculated values are 4.6, 7.1 and 8.6 for wheat, rape and beets respectively. Therefore the biggest investment efficiency was obtained in wheat crop.

At agricultural products prices in years 2006-2008 the emergy included in the yield are 4.3, 4.2 and 3.2 times bigger in relation to the emergy achieved for

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[21] J. Jankowiak, I. Małecka, *Uproszczenia uprawowe w zrównoważonym rozwoju rolnictwa*, Wydawnictwo Prac Instytutu Ekonomiki Rolnictwa i Gospodarki Żywnościowej, Program Wieloletni (6) 2008.

[22] S. Ulgiati, C. Cialani, op.cit.; E. Ortega, S. Ulgiati, *Expanded energy analysis of soybean production in Brazil*, Proc. 4th Bien. Int. Workshop" Advances in Energy Studies", Unicamp, Campinas, Brazil, 2004, p. 285-299.

[23] Ibidem.

Figure 6.
Comparison of Emergy Investment Ratio in crops analyzed

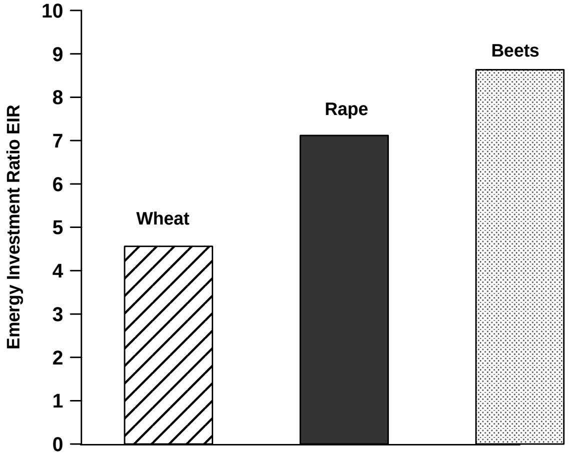
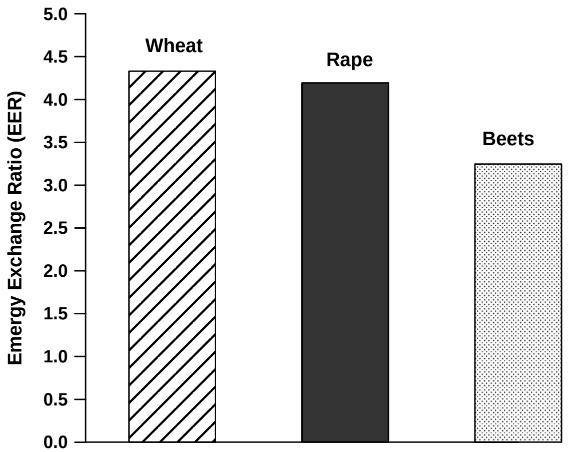


Figure 7.
Dependence of the emergy Exchange ratio on the type of crop



the money from the yield sale (Figure). If the sale had been done in emergetically scaled prices it would have turned out that this ratio would have been 0.58, 0.68 and 0.52 for wheat, rape and beets respectively. It means that on average a half of emergy included in yield is not taken into consideration in the market value as it results from non-market environmental services.

A comparison of emergy scaled prices with prices currently in force

On basis of emergy calculated you can express the value all the resources used by dividing the assigned them emergy (Figure1) by emergy/money quotient

Figure 8.
Emergy scaled prices for resources used

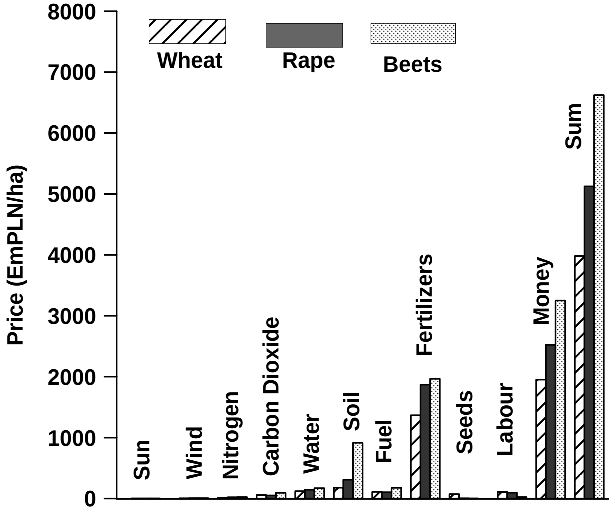
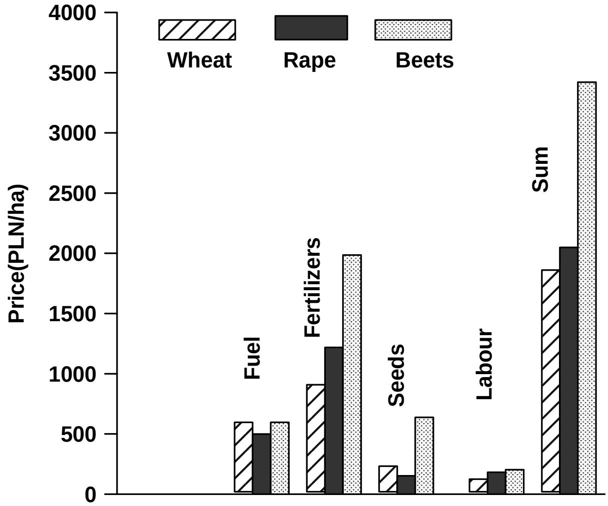


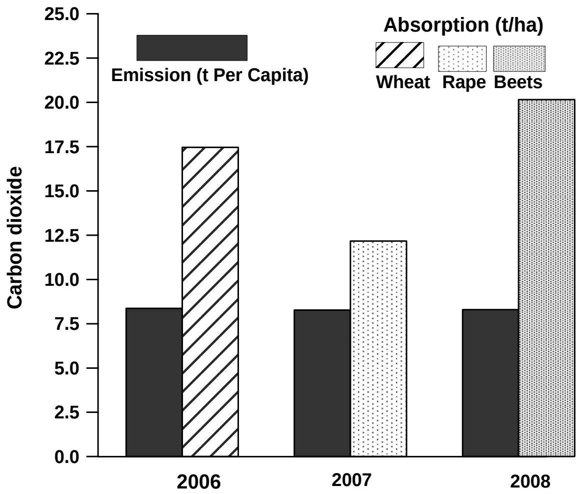
Figure 9.
Typical monetary prices for cultivar studied



of the national currency (P_1'(seJ/PLN). Therefore with the use of emergetic method it is possible to determine values of non-market environmental services such as transpiration, soil organic matter supply, nitrogen and carbon dioxide collection as well as emergy resources commonly analyzed. The results these calculations are shown on Figure 8. The relevant applicable prices are shown in Figure 9.

In comparison to the prices scaled with emergetic method in general market prices of fuels, work and seeds are too high and prices of fertilizers are similar.

Figure 10.
Net balance of carbon dioxide absorption in plant cultivar with comparing to the emissions per capita in Poland



The balance of carbon dioxide

In the crops studied there occur both carbon dioxide emission in the process of soil organic matter degradation and under the impact of burning of fuels used in agrotechnics and its absorption in the process of photosynthesis. It is known[24] that the unit of area of wheat crop as a result of soil organic matter degradation emits 13t/ha and a unit of the area of beets 22t/ha of carbon dioxide. The mean standard values in units (t/ha) calculated on the basis of published data[25] for carbon dioxide emission are: 0,35; 0.33; 0.51; as result of the fuel burning and

[24] M. Zieliński, *Efekty produkcyjne i ekonomiczne gospodarstw zbożowych sekwestrujących CO_2*. „Roczniki Naukowe STRiA", 2011, XIV, p. 219-223.

[25] L. Bakken, K. Refsgaard, S. Christensen, A. Vatn, *Energy use and emission of greenhouse gases from grassland agriculture systems*, Proceedings of the 15th General Meeting of the European Grassland Federation. Wageningen 1994, p. 361-376; M. J. Lennon, E. Nater, *Biophysical aspects of terrestrial carbon sequestration in Minnesota*, Minnesota Terrestrial Carbon Sequestration

1.13; 1,13; 3.02 due to organic matter degradation for wheat, rape and sugar beets respectively. The amount of CO_2 absorbed was determined on the basis of the value of the mass of transpired water.[26]

In the crops studied the balance of carbon dioxide was positive. The comparison of the stream of carbon dioxide absorbed in the wheat, rape and beets crops presents Figure 9. To show the potential role of the environmental services in stabilization of climate, the stream of carbon dioxide was compared to the stream of the carbon dioxide emitted by statistical citizen of Poland.

As we can see, the unit of the wheat crop area absorbs the same amount of carbon dioxide as 2 statistical citizens of Poland emit during the year. The unit of area of sugar beets compensates the emission of carbon dioxide of 2.4 statistical citizens and rape 1.5 of emission per capita.

Ecosystems services are therefore also diversified. In this case the highest value has the beets crop and the lowest the rape crop.

Conclusions

1. Emergetic method allows replacing the receptor system of values based on people preferences with the donor system of values based on the evaluation of goods and environmental services.
2. Emergetic researches allow obtaining a consistent balance of environmental resources and the assessment of their use on the basis of physical and economic data applied to the thermodynamic theories.
3. Although cultivation methods used in Wielkopolska Region do not indicate full compatibility with the principle of the environment sustainability, they compensate effectively emission of carbon dioxide resulting from the consumption of non-renewable energy sources. The factor that causes a lack of sustainability is intensive use of fertilizers.
4. The emergetic method can be used to estimate market values of the environmental services usually omitted and to express them in clear and understandable features. It can be a useful tool for the popularization of knowledge and behavior directed on environment protection.

Project, 2006; J.R Siche, F. Agostinho, E. Ortega, *Energy net primary production (ENPP) as basis for calculation of ecological footprint*, “Ecological Indicators” 2010 No. 70, p. 475-483.

[26] Ibidem.