Definition:

$$\frac{Embodied\ Energy}{Energy}$$

Description:

Benefit: Energy content can be used for an integrated evaluation of crops. Generally, the type of energy should be specified to distinguish between use as fuel or use as food and feed. For use as animal feed, further definitions are required to determine if lignocellulosiccrops qualify. Crops with high per hectare yield will show high efficiencies in this impact area.

Resource: The use of energy usually refers to inputs of fuel or electricity. Solar irradiation is not considered because it is not a stressed resource, but also because the amount of this natural input would dwarf out all other energy inputs. Furthermore, energy from human or animal labour is usually not considered, although some studies explicitly include it (Arodudu et al., 2017).

Correlation with soil management

[5] Integrated farming techniques (balancing N fertilization and adopting minimum tillage) improves energy use efficiency of a maize based rotation system compared to conventional farming
[10] Lower tractor implementation, as well as human and animal labor, surface irrigation and reduced tillage improve the energy efficiency of biofuel production systems
[17] Reduced tillage improves energy use efficiency
[38] Controlled traffic system showed lower value in winter wheat production, but higher value in summer maize production
[58] Biofuel production from sugarcane, sweet sorghum and oil palm is efficient (highest energy yield per hectare). Reduced tillage could reduce energy use and increase energy efficiency. For cereals, planting legumes in rotation, may increase energy efficiency. Energy ratios can be improved by using crop residues as fuel
[125] Conservation management (including the use of organic compost, cover crops, and reduced level of tillage) are more energy efficient than conventional systems
[152] Mixed organic farming produce food with high energy-use efficiency. Improved farm management and technologies can increase resource-use efficiency and maintain high yield performance. Energy use efficiency of agro-forestry systems was higher than for arable farming in both the organic and conventional systems
[186] to improve energy efficiency, several technological and organizational procedures may be applied, e.g. reducing distances between fields, reducing the amounts of transported goods by preliminary treatment, efficient machinery for tillage operations
[199] Results showed a positive and additive effect of water and nitrogen application on Water Use Efficiency, reflected by yield enhancement

[214] In Brazil, biodiesel addition into diesel is mandatory and soybean oil is its main source. Energy balance showed linearity with yield, whereas for EROI, the increases in input and yield were not affected

[248] Small rice-producing farms ranging from 0.61 to 1.0 ha yielded higher energy ratios (4.14) than larger ones

[270] Energy consumption from irrigation process is converted to electricity, thus the corresponding GHG emission caused by irrigation is included into that of electricity

Correlation with soil functions

[152] Organic mixed farming improved soil fertility and soil structure. Grass cover alfalfa of organic arable farming and organic agro-forestry systems is used to increase soil structure, soil fertility, and humus content

Strength & weaknesses pertaining to measurement of this impact area

Embodied Energy: Indicators for embodied energy are generally easy to measure and allow integration of or comparison between benefits from very different crops. However, their information value for questions of nutrition is limited because the provision of amino-acids and vitamins is not considered.

Energy: For this indicator, a number of standard values for agricultural management are readily available. LCA inventories even provide standard values for energy used in precursory processes. If the (fossile) energy input is used as a proxy for greenhouse gas emission, it is necessary to also consider the share of non-energy related GHG emission sources like drained soils or nitrous oxide from fertilizers.

Sample Indicators

Indicator values from		Survey	
Experiment or direct measurement		Statistical- or census data	
Expert assessment		Literature values	
Model		Maps or GIS	
Stakeholder participation		Not provided	

Table 1: No Scale

Indicator	**Unit**	**Indicator values from**
[58] Energy ratio (Bioenergy output (including co-products)/Fossil energy (used in agriculture, transport and processing))	$MJ * MJ^{-1}$	
[85] Energy in harvested fruits/Energy input (farmyard manure energy + chemical fertilizers + machinery and diesel fuel energy)	$MJ * MJ^{-1}$	

Table 2: Field Scale

Indicator	**Unit**	**Indicator values from**
[5] Energy use efficiency (EUE) (Energy in harvested grains/Total energy inputs until field gate (Mechanization + fertilization + irrigation + crop propagation + herbicides))	$GJ * GJ^{-1}$	
[5] Environmental Efficiency of Support Energy (EESE) (Energy in harvested grains + soil organic matter/Total energy inputs (Mechanization + fertilization + irrigation + crop propagation + herbicides))	$GJ * GJ^{-1}$	
[17] Energy use efficiency (Energy content of sunflower grain yield/Total energy input (human labor, machinery, chemical fertilizers, diesel fuel, irrigation, seeds))	$MJ * MJ^{-1}$	
[125] Energy use efficiency (Energy in harvested potato/Total Energy input (direct energy (diesel fuel, lubricants) + indirect energy (manufacturing of machinery, fertilizer, pesticides)))	$GJ * GJ^{-1}$	
[152] Energy use efficiency (Energy in harvested biomass – energy in the seed/Total energy input (Direct energy (diesel) + indirect energy (Seed + mineral and organic fertilizers + pesticides + machines))	$GJ * GJ^{-1}$	

Table 3: Farm Scale

Indicator	**Unit**	**Indicator values from**
[152] Energy use efficiency (Energy in harvested biomass – energy in the seed/Total energy input (Direct energy (diesel)	$GJ * GJ^{-1}$	

+ indirect energy (Seed + mineral and organic fertilizers + pesticides + machines))		
[186] Partial energetic efficiency (Energy content of biofuel after processing/Energy used for transportations of products, machines or tools)	$MJ * MJ^{-1}$	,
[186] Partial energetic efficiency (Energy content of biofuel after processing/Energy used after tillage operations)	$MJ * MJ^{-1}$	,
[276] Energy use efficiency (Output energy/Input energy)	$MJha^{-1} * (MJha^{-1})^{-1}$	

Table 4: Regional Scale

Indicator	Unit	Indicator values from
[38] Energy use efficiency (Energy output (wheat grain + maize grain + straw)/Energy input (machine + diesel fuel + labor + seed + nitrogen + P2O5 + K2O + herbicides + electricity))	$MJ * MJ^{-1}$	
[199] Energy Return on Investment (EROI) (Energy output/Energy input)	$MJ * MJ^{-1}$	,
[214] Energy return over investment (EROI) (Energy output flow - energy input flow/Energy input flow (grain yield))	$MJ * MJ^{-1}$	,
[248] Energy efficiency (Output energy/Input energy	$MJha^{-1} * (MJha^{-1})^{-1}$	,
[248] Non-renewable energy ratio (Output energy/Non-renewable energy input)	$MJha^{-1} * (MJha^{-1})^{-1}$	,
[270] Energy output/Energy input	$GJha^{-1} * (GJha^{-1})^{-1}$	,
[271] Energy output/Energy input	$J * J^{-1}$	
[283] Thermal efficiency (Released energy (energy released by the fuel and ignition material)/Useful energy (energy used by the water temperature rising + water evaporating + energy absorbed by the pot))	$kJ * kJ^{-1}$	

Table 5: National Scale

Indicator	Unit	Indicator values from
[270] Energy output/Energy input	$GJha^{-1} * (GJha^{-1})^{-1}$	 , 

Table 6: Global Scale

Indicator	Unit	Indicator values from
[10] Energy return on energy invested (EROI) (Bio energy output (including co-products)/Energy input (direct energy (farm operation + energy for conversion of biomass to energy) + indirect energy (production of chemicals)))	$MJ * MJ^{-1}$	

References

ID	Citation	[1]Soil type/ texture
5	Alluvione, F., et al. (2011). "EUE (energy use efficiency) of cropping systems for a sustainable agriculture." Energy **36**(7): 4468-4481.	Coarse-loamy mixed non-acid mesic Typic Hapludalf; Loamy sand
10	Arodudu, O. T., et al. (2017). "Integrating agronomic factors into energy efficiency assessment of agro-bioenergy production – A case study of ethanol and biogas production from maize feedstock." Applied Energy 198: 426-439.	n/a
17	Baran, M. F. and O. Gokdogan (2016). "COMPARISON OF ENERGY USE EFFICIENCY OF DIFFERENT TILLAGE METHODS ON THE SECONDARY CROP CORN SILAGE PRODUCTION." Fresenius Environmental Bulletin **25**(9): 3808-3814.	Clayey and loamy soil
38	Chen, H., et al. (2016). "Effect of controlled traffic on energy use efficiency in wheat-maize production in North China Plain." Journal of Computational and Theoretical Nanoscience **13**(4): 2634-2638.	Porous and homogenous; Silt loam
58	de Vries, S. C., et al. (2010). "Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques." Biomass and Bioenergy **34**(5): 588-601.	n/a
85	Gökdoğan, O., et al. (2018). "Studies of Energy Use Efficiency on Fruit Production." Erwerbs-Obstbau: 1-5.	n/a
125	Khakbazan, M., et al. (2017). "Energy Use Efficiency of Conventional versus Conservation Management Practices for Irrigated Potato Production in Southern Alberta." American Journal of Potato Research **94**(2): 105-119.	Mainly orthic brown Chernozemic soils
152	Lin, H. C., et al. (2017). "Effects of changing farm management and farm structure on energy balance and energy-use efficiency-A case study of organic and conventional farming systems in southern Germany." European Journal of Agronomy **82**: 242-253.	Cambisol; Loamy to sandy soil

[1]**Soil type/ texture:** If provided, what are type and texture of the soils studied in the paper?

186	Orynycz, O. and A. Swic (2018). "The Effects of Material's Transport on Various Steps of Production System on Energetic Efficiency of Biodiesel Production." Sustainability **10**(8).	n/a
199	Peter, C., et al. (2017). "Impact of Energy Crop Rotation Design on Multiple Aspects of Resource Efficiency." Chemical Engineering and Technology **40**(2): 323-332.	Stagnic Cambisol, Chernosem, Luvisol, Regosol, Planosol, Albeluvisol, Gleyic Cambisol, Stagnic Cambisol; Fine, medium and coarse
214	Romanelli, T. L., et al. (2012). "Material embodiment and energy flows as efficiency indicators of soybean (Glycine max) production in Brazil." Engenharia Agricola **32**(2): 261-270.	n/a
248	Talukder, B., et al. (2019). "Energy efficiency of agricultural systems in the southwest coastal zone of Bangladesh." Ecological Indicators **98**: 641-648.	n/a
270	Wu, H., et al. (2017). "Temporal trends and spatial patterns of energy use efficiency and greenhouse gas emissions in crop production of Anhui Province, China." Energy **133**: 955-968.	n/a
271	Wu, Z. N., et al. (2017). "Water efficiency evaluation of a regional water scheme - Zhengzhou, China, using a water ecological-economic system (WEES) and based on emergy theory." Water Science and Technology-Water Supply 17(3): 674-687.	n/a
276	Yousefi, M. and A. Mohammadi (2011). "Economical analysis and energy use efficiency in alfalfa production systems in Iran." Scientific Research and Essays **6**(11): 2332-2336.	n/a
283	Zhang, Y., et al. (2018). "Assessment of pollutant emissions and energy efficiency of four commercialized charcoal stoves with modified Chinese cooking stove protocol." International Journal of Agricultural and Biological Engineering **11**(2): 202-207.	n/a