



Article Achieving Sustainable Valuations of Biotopes and Ecosystem Services

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Abstract: The results of a broader notion of value for measuring ecosystem services (ESs) are presented, as recently demanded by R. Costanza, with attention to the biophysical, thermodynamic aspects of value. The unifying basis in any ecosystem is the solar energy inflow and the growing efficiency of its use with higher stages of self-organized succession processes. The authors utilize two methods of nonmarket valuation (Biotope Valuation Method, Energy-Water-Vegetation Method) which show the range of the environmental values of nature, from how costly it is for nations to restore the quality of a landscape (biotopes as specific habitats for specific species) to their real abilities to replace the core supporting and regulating services of ecosystems (climatizing service, water-retention service, oxygen production, habitats for biodiversity). The role of natural forests and wetlands as the most effective solar energy users is shown and compared with agricultural lands and other human-altered ecosystem groups. A comparison of ESs value ratios with the welfare-method results of Costanza's team shows much higher importance of natural forests as the best climatic and water regulators in sustainable landscape decision-making. The authors show that it is not the replacement-cost method that overestimates, but rather, preferential methods that underestimate the values of ESs.

Keywords: ecosystem services; life thermodynamics; biotope valuation method; energy-water-vegetation method; land-use changes; economic value

Ecological economics set out 30 years ago to be a redemptive science—when it caved in to the normative framework of neoclassical welfarism—it finds itself at a political and academic dead end.

M. Sagoff, The Rise and Fall of Ecological Economics, 2012

1. Introduction

The human species evolved and spread over the Earth's continents due to the widespread life-supporting roles of natural ecosystems and the effective synergies of their natural vegetation and water. If life and its evolution on the Earth's surface has been thermodynamically self-organized by the giant solar energy gradient [1], the energetic difference between the Sun, the Earth, and outer space (6000 °C \rightarrow 15 °C \rightarrow -270 °C), then the values of ecosystem services [2] should reflect, as the biophysical side of those values, the different energy dissipation capacities of the main types of ecosystems. Natural vegetation types are the most efficient land covers to sustain the climate.

The Sun's energy drives the water cycle, plant production, and other processes in the biosphere; it warms the Earth to an average temperature of around 15 °C or 288 K. The actual direct solar irradiance at the top of the Earth's atmosphere fluctuates over a year from 1412 W m⁻² to 1321 W m⁻²

due to the Earth's varying distance from the Sun [3,4]. The amount of incoming radiation on a clear day (over 8 kWh m⁻², maximum flux 1000 W m⁻²) can be an order of magnitude higher than the amount of incoming radiation on an overcast day (0.78 kWh m⁻², maximum flux 100 W m⁻²).

The difference across distance—i.e., the gradient—is what creates the conditions for the flow to take place. Similarly, in the atmosphere and the landscape, it is gradients of temperature, heat, and air pressure which drive wind and transport water vapor. In 1886, Boltzmann suggested that the energy gradient imposed on the Earth by the sun drives living processes. Gradients are reduced by organisms which, as open systems, persist, grow in complexity, and reflect their ability to gather information to obtain energy. Plants spread their immense surface of leaves and utilize the sun's energy before it falls to the earth's temperature [1].

Odum, in his *Fundamentals of Ecology* [5] and other works, definitively linked solar energy flow to succession. He showed that the self-organized directional succession processes culminate in an ecosystem in which maximum biomass and symbiotic function between organisms are maintained per unit of energy flow [6]. Self-organized processes in autotrophic terrestrial ecosystems tend toward climax vegetation that is characterized by maximal efficiency in solar energy use and by maximal ability to produce life-supporting conditions, keeping nutrients and water inside the ecosystem [7,8]. Ripl proposed a conceptual ETR Model based on the three essential "energy-dissipative" properties of water:

- the process of water evaporation and condensation;
- the process of dissolution and precipitation of salts;
- the process of disintegration and recombination of the water molecule within the biological cell (photosynthesis, respiration).

These three processes are driven by the gradient of solar energy; they slow down in winter when the supply of solar energy is low, and accelerate in summer. Similarly, they fluctuate between day and night.

As the long-term results of self-organized natural processes, natural vegetation types (deciduous leafy forests and wetlands in central Europe) are the most efficient land covers to sustain the climate and the chemistry of planet Earth [9]. Potential suites of natural vegetation, as a result of mutual competition and cooperation of living forms with their nonliving environment, most efficiently produce and control basic conditions for living, providing the climatic (temperature and water regulating), soil-producing, and water- and nutrient-retentive services. In this article, the Energy-Water-Vegetation method systemically proves and quantifies these growing energy efficiencies and better nutrient and water retention processes. Wetlands and wet natural forests are thermodynamic maximizers of the basic process of supporting and regulating life-supporting services.

However, over the period of the Industrial Revolution, and especially over the last hundred years, expanding human populations, and mainly their insatiable and unprecedented self-interested striving for the individual's profits and material wealth, have led to half of the most important world natural habitats being converted for other uses [2]. As mature natural forests and wetlands are being removed and changed mainly into agricultural, urban, and infrastructural areas, basic ESs decrease, and the global climate change problem is exacerbated.

Since the late 19th century, the destruction of natural ecosystems has been supported by the neoclassical welfare concept of economic value as unilateral anthropocentric marginal utility perceived by the human individual. Valuing ESs unilaterally, as based only on benefits to individual humans, has led to systemic undervaluation and false value relations of their real importance, and to the fragmentation of landscapes. Therefore, it is highly important to understand how the monetary values of such ESs are derived.

The written history of setting monetary values of goods and services started with Plato and Aristotle's debates [10], and was strongly reinforced during the last two or three centuries when massive production for anonymous consumers emerged. At the outset of the Industrial Revolution,

in the economic theory of the classical English political economy (Smith, Ricardo, J.S. Mill et al.), the supply-side cost theory of economic value prevailed, defining value as flowing from the amount of labor, materials, and inputs of other factors of production necessary for the creation of a useful product or service. The cost theory of value came from the unilateral supply-side approach stating that, in the long run, costs of production are decisive for economic value, and the concept of *socially necessary costs* linked the value concept to price as a result of comparing demand and supply.

Around the 1870s, Marx's revolutionary labor theory of value and the development of marginalism contributed to the emergence of an alternative, the neoclassical marginal utility theory of economic value. This subjective value of neoclassical economics is determined by an individual's preferences (i.e., his/her utility, wants, and wishes). Neoclassical economics moved the value pendulum to the opposite extreme from the classical focus on costs of production, but it was similarly unilateral, this time being the demand-side, utilitarian subjectivist approach of consumer preferences to economic value setting.

At the same time, since the end of the 19th century and the work of A. Marshall—one of the co-founders of neoclassical economics—it has been known that both aspects (costs and utility) are decisive for revealing the real economic value. As Marshall ironically wrote: "We might as reasonably dispute whether it is the upper or the under blade of a pair of scissors that cuts a piece of paper, as whether value is governed by utility or cost of production" [11] (p. 203) "... the shorter the period which we are considering, the greater must be the share of our attention which is given to the influence of demand on value; and the longer the period, the more important will be the influence of cost of production on value" [11] (p. 204). Marshall hoped to reconcile the classical (cost) and the neoclassical (marginal utility) theories of value. He integrated the cost supply-side approaches, elaborated by the last classicist J. S. Mill, with the demand-side utilitarian approaches, and argued that both are necessary for revealing the proper economic value, while neither theory alone explains it satisfactorily.

Respect for such an integrated concept of economic value is decisive for controlling the general equilibrium between human needs on the one hand, and the energy-labor-material possibilities and costs of their satisfaction on the other. As Daly and Farley wrote in the recent second edition of their *Ecological Economics* textbook: "Value has psychic roots in want satisfaction, as well as physical roots in entropy... any theory of value that ignores entropy is dangerously deficient" [12] (p. 70).

In spite of the clear definition given more than one hundred years ago by A. Marshall, one of the most influential economists of his time, and in spite of clear explanations given by current leading transdisciplinary economists as referenced above, the majority of educational explanations and practical applications of the concept of economic value in measuring ESs stick to the unilateral utilitarian approach, defining economic value in the straitjacket of individualism and subjectivism as only a utilitarian category defined by preferences of the human individual.

This unilateral utilitarian approach could even be taken as more natural than in the case of man-made private commodities and services (where it is the market mechanism that balances human wants against producers' costs), as many important ecosystem services are provided by nature as free public goods, seemingly at no cost.

In the Encyclopedia of Earth, Dziegielewska explains that the economic concept of value provides the foundation for neoclassical welfare economics, which has its roots in utilitarianism. She explains that in the neoclassical perspective, "Economic value expresses the degree to which a good or service satisfies individual preferences . . . Thus, economic value can be measured by the amount of money an individual is willing to pay for a good or service or the amount of money an individual is willing to accept as a compensation for forgoing the good or service" [13].

Similarly, in economic literature, the dominant concept of the economic value of natural goods and services is unilateral, relating only to the preferences of individuals. In an article focused completely on measuring economic values for nature, N. Bockstael, A. M. Freeman III et al. write: *"The economic value of an ecosystem function or service relates to the contribution it makes to human welfare, where human welfare is measured in terms of each individual's own assessment of well-being"* [14].

Such a tendency for a one-sided understanding and practice concerning economic value resembles the practice of the former centrally-planned economies where, consistent with the governing Marxist economic theory, economic practice considered only the costs of production as the decisive factor for the centralized determination of price. The result was that prices of all goods—reflecting the production costs—were relatively low, but there was a never-ending shortage of some highly demanded goods [15].

2. Materials and Methods

In order to achieve more realistic assessments of the real importance of natural ecosystems and their basic ecosystem functions and services, in the Czech Republic, we developed two expert methods of valuing biotopes (by Biotope valuation method, hereafter BVM) and basic supporting and regulating ecosystem services (by Energy-water-vegetation method, hereafter EWVM) that show more completely (systemically in nation-wide framework) the real importance of the natural environment in its diversity and maximal utilization of incoming solar energy.

One of the main goals of this paper is to show the second necessary side—the biophysical, energetic, and entropic cost side—for revealing the real economic value of non-marketed functions and services of ecosystems. In the BVM, that is targeted at biodiversity and habitat protection, for measuring the costs we used the real costs of 182 nationally-representative restoration projects supported from the EU Operational program Environment. In the EWVM, we had to use the replacement cost method, as three measured supporting services (climatizing function, water retaining function, oxygen production) are not yet explicit goals of environmental policy, and are perceived by most people as free public goods. The replacement-cost method was mentioned as an additional technique for ES valuations in the foundational article by Costanza et al. [16]. As summarized by Groot et al., of 665 ES valuation studies, up to now, there have been only 56 studies applying the replacement-cost approach, mainly to regulating services (waste treatment, moderation of disturbance) [17].

In 2001, an international research team was contracted to elaborate the so-called Hessian valuation method of biotopes in a three-year project. The BVM derives from the EU White Paper on environmental liability (COM (2000) 66 final, 9 February 2000). It satisfies the requirements of the EU NATURA 2000 system, and presents biotope monetary values. The BVM is a systematic method for establishing a list of national biotopes and for ranking them according to their capacity as specific environments for living plants with animal species (incl. NATURA 2000). Each biotope type was valued by an interdisciplinary team of ecologists and economists from different scientific backgrounds using a 6-point scale (1–6) according to eight ecological characteristics (matureness, naturalness, diversity of plant species, diversity of animal species, rareness of biotope, rareness of species, vulnerability, and threat to existence). A complete list of biotope point values is available at http://fzp.ujep.cz/projekty/bvm/bvm.pdf.

Biotope point values are derived from the relative ecological significance of the respective biotope, and are converted into monetary terms by the average national cost of restoration measures necessary for a one-point increase, i.e., for maintaining and improving the biotopes as environments for healthy ecosystems and living species. On the side of benefits, BVM has "only" the life nursery function (biodiversity carrier habitat function).

The total monetary value of biotope natural capital in the Czech Republic estimated by the BVM grew in the period 1990–2006 from \notin 712 billion in 1990 to \notin 727 billion in 2000; and, to \notin 740 billion in 2006. Compared to the GDP of the Czech Republic, the stock value of national biotope natural capital was around 7-fold higher in 2000, while in 2006 it was approximately 5 times higher than GDP in 2006. In 2006, the average biotope value of 1 m² in the Czech Republic amounted to \notin 9.4 [18].

Biotope natural capital valuations, performed by the BVM, show the minimal "cost" level of the biotopes and are easily implementable as an instrument for macro-economic environmental accounting. At the micro-economic level, they are mainly targeted at the valuation of environmental damage caused by legal and illegal human activities that intervene in nature, inclusive of damages covered by the EU

Directive on environmental liability (2004/35/EC). The BVM values biotopes as habitats for specific living species; at the same time, they are environments for providing specific ecosystem functions.

A limitation of the BVM is that it is not able to estimate other real benefits (beyond the nursery function) that humans permanently derive and consume in the form of ecosystem functions and services.

The EWVM, developed in 2007–2009 in a project for the Czech Ministry of the Environment [19], shows the growing solar energy losses caused by anthropogenic changes in natural landscapes (by means of systemic valuing four ecosystem supporting and regulating services at the national scale: climatic and temperature regulation, water retention, oxygen production, and biotope valuation).

EWVM offers an ecological and thermodynamic approach to estimate the non-market value of ecosystem functions and services. This EWV approach comes from recognition of the fact that later mature ecosystems are more efficient in the use of incoming solar energy than their predecessors [6]. It draws on Ripl's Energy-Transport-Reaction (ETR) model [7,8] and estimates the main forms of benefits that nature and its autotrophic ecosystems provide in the form of delivering ecosystem services for society (air-conditioning service, water retention service, oxygen production service, sustaining biodiversity). It is worth mentioning that all four functions and services work in mutual synergy, and must be taken as a self-organizing unity, where biomass and oxygen production, climatizing, and water retention services are mutually tied. Odum, in his 5th edition of Fundamentals of Ecology, wrote: *"The energy is not destroyed by the lifting of the water; instead, it becomes potential energy, because the latent energy inherent in having the water elevated can then be transformed into some other type of energy by allowing the water to fall back down to its original level."* [20] (p. 79).

There is a large difference between the distribution of net radiation in living natural ecosystems of high plant biomass which are well supplied with water, and in dry, biomass-poor ecosystems, with far more non-living physical surfaces.

The latent heat flux (evapotranspiration, or ET) represents large "invisible" fluxes of water and energy in the landscape, and consumes several hundred W m⁻². ET of 250 W m⁻² produces 100 mg H₂O m⁻² s⁻¹, which, up-scaled to 1 km², is an evaporation of 100 litres s⁻¹, an order of magnitude more than liquid water outflow from 1 km² and a gradient reduction (air-conditioning) of 250 MW km⁻² [21–23].

The sensible heat flux (H) represents the sum of all the heat exchanges between the surface of a landscape and its surrounding atmosphere by conduction or convection. On dry surfaces, H may reach values of several hundred W m⁻². The H of an overheated surface thus warms air, which rises up in a turbulent motion, creating atmospheric instability. Drainage of wetlands and deforestation bring about a shift from latent heat flux (air-conditioning, temperature gradient equalizing via evapotranspiration) into sensible heat flux (increase of local temperature and turbulent motion of air, strong wind, cyclones).

The ground heat flux (G) is the heat transferred from the surface downward via conduction. Ground heat flux slows down in dry soil, as well as in dry plant litter.

In closed-canopy ecosystems, the maximum net photosynthesis rate [24] may take up as much as 20 W m⁻², with an average rate of about 2 W m⁻². In contrast to biomass production, the decomposition of organic matter results in the release of energy; this process is accelerated by drainage of wetlands [25].

The physical sink of energy depends on the amount of living biomass and its water content. The maximum heat-flux warming of biomass is approximately 10 W m^{-2} .

The cooling process of transpiration is often considered a side effect, rather than a mechanism, to control leaf temperature and that of surroundings (evapotranspiration losses). The amount of water molecules exchanged by plants is at least two orders of magnitude higher than the amount of carbon dioxide fixed in biomass.

Through the substitute cost method (also sometimes called "replacement costs") in combination with incorporated biotope valuation method, we obtained values of four annual ecosystem services for selected natural ecosystems. As can be seen below, from the viewpoint of thermodynamics,

the dominant role of each ecosystem is that it is a giant gradient reducer, i.e., within autotrophic ecosystems, the dominant role is played by ecosystem air-conditioning (climatizing) and water retention services that, within the ecosystem's self-organizing processes and according to real monitored data of energy-material flows, tend to be maximized with climax vegetation.

In the introduction, we expressed a request that ESs values should reflect different energy dissipation capacities of the main types of ecosystems. As shown by E. Odum [5,6], self-organized succession processes culminate in climax natural forests as best solar energy dissipaters and highest energy efficiency users. Forest-driven atmospheric water and energy changes govern (by evapotranspiration, condensation and precipitation) water availability on continents [26–28]. In the following examples and tables, we want to underline that evapotranspiration (ET) is the most significant irreplaceable energy flow in nature, and that the principles for quantifying it have been known since the mid 20th century. Evapotranspiration and short water cycle (SWC) (as drivers of latent heat changes) are key climate controlling components of the water cycle; however, they are very difficult to quantify in time and space. Figures on ET and SWC in the following examples and tables are derived partly from measurements made by authors, partly from the latest ET measurements [28] that generally prove increasing ET and SWC levels in succession phases. Figures are presented as typical "framework" levels according to the long-term experience with the results of different measuring methods applied [29–32].

3. Results

3.1. Deciduous forest ecosystem

For a deciduous forest ecosystem saturated with water, the estimations of services (estimated by replacement cost approach and biotope valuation method) were as follows:

(1) Biodiversity:

L2.3 Hardwood forests of lowland rivers are valued according to the BVM at 66 points per 1 m² [33], which for 1 ha means 660,000 points \times €1.17 per point = €772,200 of stock value (€1.17 is an average national cost of recent restoration projects per one point increase, valid in 2018). With a 5% discount rate (to change the stock into a flow), this means annual services worth €38,600.

(2) Estimation of forest oxygen production:

In the temperate zone, 1 ha of deciduous forest produces around 10 tons of biomass annually (expressed in dry mass). This corresponds to the release of 10.6 tons of oxygen. The production of oxygen has been calculated from the fundamental equation of photosynthesis where the formation of one molecule of 6-carbon sugar is associated with the release of 6 molecules of oxygen, i.e., the formation of 180 g of sugar (cellulose etc.) is associated with the release of 192 g of oxygen. From this stoichiometry, it follows that the production of 10 metric tons of dry mass is accompanied by the release of 10.6 metric tons of oxygen. According to Avogadro's law, one gram-molecule of gas under normal atmospheric pressure and at a temperature of 0 °C has a volume of 22.4 L, i.e., 32 g of oxygen take up 22.4 L. Thus, the mass of 1 L of oxygen is 1.429 g, or 1 kg of oxygen has a volume of 700 L. The oxygen price is the minimal national cost price of 1 L oxygen (as mixed by technical and medicinal oxygen).

10,600 kg/ha × 700 L = 7.42 mL × €0.02 per liter (oxygen price) = €148,400

(3) Forest climatizing (air-conditioning) service:

In the temperate zone, 1 ha of deciduous forest which is well supplied with water transpires around 700 L of water from 1 m² during the growing season; 1 m² of forest saturated with water evaporates around 5 L of water during a sunny day. Whereas photosynthesis (biomass production)

uses less than 1% of the incoming solar energy, by evapotranspiration (latent heat), around 70–80% can be used in water-saturated vegetation. The latent heat of 1 L of water is equal to approx. 0.7 kWh (2.5 MJ). It is necessary to emphasize the double air-conditioning effect of evapotranspiration: first, a tree cools itself and its environment by evaporation of water (solar energy is used as latent heat): second, water vapor condenses on cool surfaces (or in cool air) and releases latent heat. Considering the double air-conditioning effect (cooling during evapotranspiration and warming during water vapor condensation), the annual climatizing service of 1 ha in terms of energy fluxes can thus be estimated at 700 L × 1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) × 10,000 × €0.08 (electricity cost price) = €784,000.

(4) Support of short water cycles and water retention services:

Evapotranspiration of 400 L/m² brings an annual service ($\notin 0.114$ is the minimal national cost price of distilled water offered in bigger volumes): (400 L/m²) × $\notin 0.114$ (distilled water price) × 10,000 m² \notin 456,000.

Total annual services from 1 ha forest: €1,427,000

3.2. Drained pasture

If a natural landscape is drained, as the following account of drained foothill pasture (channel straightening and recessing) shows, its ecosystem services substantially decline:

(1) Biodiversity:

Intensively managed or degraded mesic meadows X T.3 are valued [33] at 13 points per 1 m²; per 1 ha, this means 130,000 points $\times \notin 1.17$ /point = $\notin 152,100$ of capital value; with a 5% discount rate, the value of annual services is $\notin 7605$.

(2) Oxygen production:

5.6 mL O₂ × CZK 0.25–0.73 per liter (CZK 0.50 = €0.02) = €112,000.

(3) Climatizing services:

Around 400 L of evapotranspired water from 1 m² during the vegetation season. Annual climatizing service of 1 ha can thus be estimated at 400 × 1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) × 10,000 × €0.08 (electricity cost price) = €448,000.

(4) Support of short water cycles and water retention services:

Condensation of 150 L/m² of water per year brings: $(150 \text{ L/m}^2) \times \text{€0.114}$ (destil. water price) \times 10,000 m² = €171,000.

Total annual services from 1 ha of drained pasture: €738,605

3.3. Arable land

Non-irrigated arable land for grain and other annual crops production:

(1) Biodiversity:

X4.4 One-year and autumn plants on arable land are valued [33] at 10 points per 1 m²; per 1 ha this means 100,000 points \times €1.17/point = €117,000 of capital value; with a 5% discount rate, the value of annual services is €5850.

(2) Oxygen production:

6.678 mL O₂ × CZK 0.25–0.73 per liter (CZK 0.50 = €0.02) = €133,560.

(3) Climatizing services:

Around 300 L of evapotranspired water from 1 m² during the vegetation season. Annual climatizing service of 1 ha can thus be estimated at 300×1.4 kWh (0.7 kWh cooling, 0.7 kWh warming) $\times 10,000 \times \text{€}0.08$ (electricity cost price) = €336,000.

(4) Support of short water cycles and water retention services:

Condensation of 100 L/m² of water per year brings: $(100 \text{ L/m}^2) \times \text{€0.114}$ (destil. water price) × 10,000 m² = €114,000.

Total annual services from 1 ha of arable land: €589,410

Let us note that due to the high correlation between biomass and oxygen production, we estimated only oxygen production as the typical public service freely offered by vegetation. In the case of agro-ecosystems, the biomass production mostly has some market values, and in the case of natural forests, the biomass production is an important part of soil formation service, which we left unvalued as a consequence of current methodological discussions.

In Table 1, the basic biophysical quantities of evapotranspiration, short water cycle, and oxygen production are assessed for 22 groups of biotopes (and two residual groups) that, in total, cover the territory of the Czech Republic. These biophysical quantities enter into the estimations of four ecosystem functions (life-supporting services) in Table 2. In climate-regulation services, the double air-conditioning effect of evapotranspiration and condensation is estimated by the replacement-cost method through the minimum-cost price of electricity. Similarly, the short water cycle value is assessed by the minimum-cost price of distilled water. And the values of oxygen production are transferred into monetary terms by the minimum-cost price of technical and medicinal oxygen. Finally, habitat services of biotope groups are estimated by BVM biotope point values and multiplied by the actual national value of one point in 2018. The value €1.17 is the new 2018 national value of one point in BVM. This was derived from 182 statistically representative restoration projects realized during the last decade in the Czech Republic, and supported by the EU Operational Program Environment.

No.	Biotope Groups	Area	ET		SWC		Biomass	O ₂	BD
		km ²	Min L/m²/year	Max L/m²/year	Min L/m²/year	Max L/m²/year	Kg/m²/year	Kg/m²/year	points/m ²
1		675	400	600	200	300	1.67	1.78	19
2	Peatbogs	23	300	600	200	400	0.2	0.21	42-66
3	Other wetlands	364	500	700	250	400	2.03	2.17	19–59
4	Ext. used mesic pastures meadows	2601	300	500	150	250	1.05	1.12	33-63
5	Intens. used mesic pastures meadows	5579	300	400	100	200	1.39	1.48	13
6	Degraded mesic pastures meadows	4609	200	400	100	150	0.8	0.85	13
7	Dry closed grasslands	40	200	300	50	100	0.7	0.75	13-84
8	Dry interspaced grasslands	172	100	300	40	150	0.4	0.43	13-84
9	Xeric scrub	426	200	300	40	100	0.8	0.85	10-56
10	Mesic scrub	1959	300	400	100	200	1.06	1.13	33
11	Alluvial hygrophilous scrub	17	400	600	150	300	1.16	1.24	33–56
12	Dry pine forests	298	200	400	100	200	0.9	0.96	40-61
13	Other conifer forests	6050	400	600	150	300	1.56	1.66	36-43
14	Damaged conifer forests	8222	300	500	100	250	1.25	1.33	19-20
15	Leafy forests	6636	300	600	150	300	1.79	1.91	38-72
16	Leafy forests degraded	1632	300	500	100	200	1.28	1.37	19-25
17	Alluvial flooded forests	924	600	700	200	400	2.03	2.17	55-66
18	Solitary trees, alleys	1276	300	500	100	250	1.43	1.52	25
19	Arable land: cereal, root-crops	27,605	200	300	50	100	0.9	0.96	10
20	Arable land: fodder, durable stands	141	200	400	50	200	1.98	2.11	10
21	Areas without vegetation	2938	1	200	0	50	0	0	0
22	Rock biotopes	113	100	300	50	150	0.2	0.21	40-56
23	Other (semi) natural biotopes	3780	400	600	150	300	1.51	1.6	26-84
24	Other anthropically influenc. biotopes	2787	200	400	100	200	0.96	1.02	0-23
	Czech Republic total	78,869							

Table 1. 22 Biotope Groups in the Czech Republic According to Their Biophysical Functions.

ET = evapotranspiration; SWC = short water cycle; BD = biotope point values per m² [33].

No.	Biotope Groups	Area	Ecosystem Services (€/m ² /year)				Total of Four ES		
		km ²	Climate Regul. s.	SWC	02 Production	BD	Relat. Value €/m²/year	Total Value bln €/year	
1	Water bodies, courses	675	56.0	28.5	24.9	0.5	110	74	
2	Peatbogs	23	50.4	34.2	3.0	1.4	89	2	
3	Other wetlands	364	67.2	37.1	30.4	1.0	136	49	
4	Ext. used mesic pastures meadows	2601	44.8	22.8	15.7	1.2	84	220	
5	Intens. used mesic pastures meadows	5579	39.2	17.1	20.7	0.3	77	431	
6	Degraded mesic pastures meadows	4609	33.6	14.3	11.9	0.3	60	277	
7	Dry closed grasslands	40	28.0	8.6	10.5	1.2	48	2	
8	Dry interspaced grasslands	172	22.4	10.8	6.0	1.2	40	7	
9	Xeric scrub	426	28.0	8.0	11.9	0.8	49	21	
10	Mesic scrub	1959	39.2	17.1	15.8	0.8	73	143	
11	Alluvial hygrophilous scrub	17	56.0	25.7	17.4	1.1	100	2	
12	Dry pine forests	298	33.6	17.1	13.4	1.2	65	19	
13	Other conifer forests	6050	56.0	25.7	23.2	1.0	106	641	
14	Damaged conifer forests	8222	44.8	20.0	18.6	0.5	84	690	
15	Leafy forests	6636	50.4	25.7	26.8	1.4	104	691	
16	Leafy forests degraded	1632	44.8	17.1	19.2	0.6	82	133	
17	Alluvial flooded forests	924	72.8	34.2	30.4	1.5	139	128	
18	Solitary trees, alleys	1276	44.8	20.0	21.3	0.6	87	111	
19	Arable land: cereal, root-crops	27,605	28.0	8.6	13.4	0.2	50	1387	
20	Arable land: fodder, durable stands	141	33.6	14.3	29.6	0.2	78	11	
21	Areas without vegetation	2938	11.3	2.9	0.0	0.0	14	41	
22	Rock biotopes	113	22.4	11.4	3.0	1.2	38	4	
23	Other (semi) natural biotopes	3780	56.0	25.7	22.4	1.0	105	397	
24	Other anthropically influenc. biotopes	2787	33.6	17.1	14.4	0.3	65	182	
	Czech Republic total	78,869						5664	

Table 2. 22 Biotope Groups in the Czech Republic According to Their Provision of four ES.

Clim. s. = climate-regulation service, expressed by litres of evapotranspired and condensed water, double air-conditioning effect (evapotranspiration and cooling effect, condensation and warming effect, both latent heat changes of 1 litre of water = 1.4 kWh); $1/\text{m}^2/\text{year} \times \text{€0.08}$ (electricity cost price); SWC = water retention service of the short water cycle; $L/\text{m}^2/\text{year} \times \text{€0.114}$ (cost price of 1 litre of distilled water); O_2 production= O_2 (kg/m²/year) × 700 (kg changed to litres) × €0.02 (cost price of 1 litre of oxygen); BD = habitat provision service valued by biotope valuation method [33]. Exchange rate € = CZK 25; 2018 point value = €1,17; Source: [18] and figures up-dating.

4. Discussion

If the real economic value is governed by both the utility side of human needs (psychic roots) and the cost-of-production side (biophysical roots of changed entropy), then the real economic value of traditionally free ecosystem services can be revealed only by using "both blades of the value scissors". As for the utilitarian demand-side valuations, the first well-known example of ecosystem service monetary valuation at the global level is from Costanza et al. [16]. It is an example of valuation that derives ecosystem values on the basis of people's willingness to pay for their individual services. These authors estimated the total value of 17 annual services of 16 world biomes in the range of US \$16–54 trillion, with an average of US \$33 trillion per year, which was approximately double (1.8-fold) the annual world GDP (US \$18 trillion). In this original article, the authors also write about the replacement-cost method as one additional way to think about the value of ES (what it would cost to replicate them in a technologically produced, artificial biosphere) [16]. Similar results were published recently [34], showing that in 2011, the world ecosystem services were US\$145 trillion per year, and the global GDP around US \$75.2 trillion, which means global ecosystem services were estimated to be 1.9-fold greater than the annual world GDP.

Alternatively, Boumans, Costanza et al. [35] evaluated major ecosystem goods and services for eleven biomes of the biosphere using the GUMBO model of the biosphere; the value in terms of ecosystem contributions to supporting both conventional economic production and human well-being was estimated to be about 4.5 times the value of the Gross World Product (GWP) in the year 2000.

The Common International Classification of Ecosystem Services (CICES) does not take most supporting services into account, arguing that these are intermediary services and their incorporation into the utilitarian economic value system would mean double counting [36]. By neglecting the importance of supporting ecosystem services, CICES interpreters refuse to take into account the fate of around two thirds of incoming solar energy, mainly the information regarding whether solar energy is changed into sensible heat or latent heat fluxes. With this rejection, they also deny the importance of

natural vegetation and water, and in the end, they reject the real integration of ecosystems (or ecology as the economy of nature, as defined by E. Haeckel in 1866) with human socioeconomic systems.

At the same time, it is precisely these ecosystem functions and services of support and regulation (generated on continents, mainly by natural forests) that are most seriously threatened by human activities and behavior, and are most quickly vanishing from the Earth's biosphere. These services, with their indirect use values, are of critical importance for sustaining humans and other animal species, and more generally, for the sustainability of life on the Earth. Let us mention, e.g., the formation of the ozone layer, cleaning of air and water cleaning, formation of soil, control of the structure of the atmosphere, mitigation of temperature extremes, and all other supporting and regulating services delivered as free public goods.

Due to the real absence of the majority of supporting and regulating ecosystem service values in the subjective value systems of most human individuals, the application of preference-based valuation methods necessarily produces false relative prices (thus giving a false mirror for human decisions in landscape), and also produces systemic undervaluation of their real importance for human survival and for sustaining their threshold minimum ecosystem networks.

For an approximate estimate of the level of undervaluation by the utilitarian valuations, the Biosphere 2 experiment can be used [37]. As is known, this experiment was the most ambitious project to create an artificial ecosystem ever undertaken, with 8 people trying to survive for two years in a 3.15 acre sealed greenhouse. The difficulty of the task was demonstrated in 1991–1993, when scientists operating the US \$200 million experiment in Arizona discovered that it was (after about five months) unable to maintain life-supporting oxygen levels for the eight people living inside. Biosphere 1, i.e., the Planet Earth, performs this task daily at no charge for over 7 billion people. If Biosphere 2 needed a US \$200 million investment for eight people living there for two years, then the natural capital of the global ecosystem could be estimated (for 6.6 billion people at the beginning of the 1990s) at least at the value level of US \$82.5 quadrillion (82.5×10^{15}). Let us note that at the beginning of the 1990s, the world annual GDP reached approximately US \$16 trillion (16×10^{12}), i.e., was five thousand times lower than the estimated natural capital value of global biosphere. If we transfer, similarly to Costanza et al. [16] (p. 258), the dimension of natural capital stock into the dimension of the annual flow of world ecosystem services (using a 5% discount rate), then the annual value of world ecosystem services would be USD 4 quadrillion (4 \times 10¹⁵), i.e., 250 \times higher than the annual world GDP. From this ambitious and expensive experiment, where investment costs were uniquely high (and operation costs are not calculated), it is clear that the estimates of world natural capital, based on replacement (substitute) costs method (costs of creating artificial ecosystem), might be at levels two orders of magnitude higher than double the annual world GDP.

According to our EWVM national estimation results, based on the rate of efficiency of solar energy dissipation by different ecosystems and on the replacement costs of individual ecosystem services, the total amount of four annual ecosystem services on the territory of the Czech Republic is about CZK 143 trillion (143×10^{12}) . Compared to the annual GDP in 2015 (4477×10^9) , four annual ecosystem services were around thirty two times bigger. It is understandable that the ecosystem service values achieved and presented in the above table are not economic values; rather, they show an upper bound of costs humans have to pay in order to substitute, technologically and imperfectly, four basic natural ecosystem services.

However, the relations among values of individual ecosystem services are much more important for real economic and political decision making than absolute value figures. Thus, Costanza et al. estimated that, globally, floodplains in 2011 were 8 times (65 times in 1997) more valuable than temperate forests, and that lakes and rivers in 2011 were 4 times more valuable than temperate forests (28 times in 1997). In 2011, even grasslands were 1.3 times, croplands 1.7 times, and urban lands 2.1 times more valuable than temperate forests. Even tropical forests are less valuable than urban land [34] (p. 156). Huge differences and huge changes in time disclose the subjectivity of those mainly utilitarian ecosystem service values and how disconnected they are from the real thermodynamic

efficiency of ecosystems. A positive fact for non-market valuation is that in measuring the regulating services, cost-based methods dominate [17]. It is worth adding that in their recent article, Costanza et al. [38] call for a broader notion of value that could overcome the weaknesses of the mainstream economic approaches to nature and ecosystem service valuations. We believe our article can help to open up this more sustainable pathway.

A similar comparison of four basic ecosystem services (climatizing service through evapotranspiration and condensation, water retaining service, oxygen production, and biodiversity service) which represent the majority of supporting and regulating life-supporting services for the biotope groups of the Czech Republic, shows that ecosystems of the most effective, relatively most natural landscapes (wet deciduous leafy forests, wetlands) are around 10 times more valuable than bare lands, around 2.8 times more valuable than arable lands, and 1.7 times more valuable than grasslands and agricultural lands with perennial crops. At the same time, we fully respect that other ESs are also important and necessary for human survival, and other types of landscapes are more valuable when it comes to providing provisioning and cultural ESs. Cultural ESs are especially important in the protection of biodiversity, and there are some trade-offs between biodiversity goals and energetically maximizing succession trends.

Drainage of 1 km² is associated with a daily shift from ET to sensible heat of tens of MW. In the Czech Republic, 10,000 km² of agriculture fields with small flood plains and wet meadows were drained during the period of central planning, which caused a decline of ET (and an increase of sensible heat) of some 100,000 MW. The effect of drainage of the world's wetlands should be evaluated in this way [22]. According to Mitsch [39], during the past 200 years, about 400,000 km² were drained in USA.

Reporting only global average temperature ignores the main effects of climate change, i.e., gradients which may drive torrential rains, cyclones etc. Similarly, persisting only with the dogma of the greenhouse effect alone results in ignoring the most important functions of natural forests and wetlands through their direct effect on climate and water cycling, and hence, enables further drainage and deforestation [40].

If agroecosystems dissipate around 50% of the full potential generated by the most mature natural vegetation of wet leafy forests and wetlands, that means we should transform current agricultural "deserts" into the web of agricultural fields, ponds, and native forests dominated by native trees.

What do these relations among thermodynamic efficiencies of different ecosystems mean for shifting agricultural and other human-changed landscapes onto a path of sustainable development? They clearly show that farmers, urban planners, and other landscape managers should start to restore the most natural ecosystems (leafy forests, wetlands) into all vacant places where agricultural production is not dominant or is of low efficiency due to, e.g., the impacts of aging of soils (for successful reforestation techniques used to recreate natural forests see [41]). The same landscape revitalization measures should be focused on brownfields and other abandoned areas. Demand for such public-good measures comes from the first priority objective of the 7th EAP (to protect, conserve, and enhance the EU's natural capital), and must be stimulated using national and EU public funds.

5. Conclusions

Since the beginning of the Industrial Revolution, the concept of economic value has been explained predominantly in a one-sided way, relying either on production costs in the period of classical economic theory, or on marginal utility since the 1870s. Such simplifying approaches do not correspond to the broader character of economic value, as argued by Alfred Marshall or by contemporary ecological economists Herman Daly and Joshua Farley, and recently also by Robert Costanza et al. [38]. Economic value, as an instrumental concept, must in all cases come from the comparison of the supply-side production costs (or the growth of entropy) and the demand-side use values. As we are warned in the passage from M. Sagoff quoted at the beginning, with the application of welfarism to ecosystem

service valuations, the previously very promising field of ecological economics has been driven to a dead end [42].

Based on the utilitarian demand-side, WTP methods, Costanza et al. [16] estimated the world's annual ecosystem services as 1.8-fold greater than the annual world GDP (US \$18 trillion), and later, as 4.5 times the value of the Gross World product (GWP) in the year 2000. Pilot estimation of the annual ecosystem service values in the Czech Republic, based on the real energy and water flows in different vegetation types and on the replacement-cost method, assessed the four annual ecosystem services at a level 32 times greater than the annual GDP of the Czech Republic.

If viewed as complementary, these two main methodological approaches (preference methods, replacement cost methods) show the range of annual ecosystem service monetary values, from how people value these life-supporting services to what their real abilities are to replace them technologically. So, the real economic value of the main ecosystem services of the biosphere should be estimated within the range of about five to thirty times the world annual GDP. These thermodynamically real economic values can bring about a radical shift in our perceptions of the gravity of environmental degradation. It is not the replacement-cost method that tends to overestimate the actual values of supporting and regulating services of ecosystems as utilitarian economists argue, see [43] (p. 33), but rather, the utilitarian perceived preference methods that underestimate the primary functions and services of nature, delivered as free public goods. But mainly, they are producing false criteria for landscape managers. Damage to life-supporting ecosystem services must be properly internalized (at least at the level of biotope values) in order to help inform the public about the urgent need to restore the basic environmental conditions for human health.

With growing environmental consciousness among the human population, and with growing efficiencies of technological trade-offs, a clear convergence can be expected in future valuation results of both methodological approaches.

Only by accepting the real double-sided concept of economic value can humans turn the fight against nature into the new era of real cooperation with her.

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