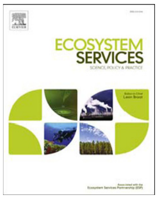
Ecosystem Services 25 (2017) 195–200

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser



A physical economic model of ecosystem services

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ARTICLE INFO

Article history:
Received 27 October 2016
Received in revised form 17 April 2017
Accepted 24 April 2017

Keywords:
Chemical bond
Oxygen
Carbon
Carbon cycle
Work

ABSTRACT

To make full use of the power of economics, ecosystem services accounting can show how work done can be understood from the carbon cycle and compared with the economic actions represented in the Circular Flow of the Macroeconomy. The comparison is useful in fitting data from both fields on the one spreadsheet to assist in economic and environmental management. This requires some review of concepts originally formed before the industrial revolution discoveries of modern science. Though labor and capital are conventionally considered as distinct, the concept of "work" is shown in a simple case study to be a unifying concept derived from the factor, "force" which may be biological or mechanical, almost invariably fueled in purposive action by the combustion of a carbohydrate (food or organic fuel) or hydrocarbons. Adapting from Odum's "fractal cascade" of usable energy, 30,000 solar photons pass through a hierarchy of 5 phases to deliver work done by the breaking 2 carbon-hydrogen bonds. For the Earth in 2015 the increase in broken C–H bonds over those reconstituted naturally was 18×10^{38}, emphasizing a unidirectional trend to higher costs, rather than any hoped-for recovery of business cycle.

1. Introduction

Ecosystems services can be better appreciated by economic policy makers through building on their economic model. The model central to economics is the Circular Flow of the Macroeconomy (Samuelson and Nordhaus, 2009), the basis for GDP and National Income. It may be useful for the public and policymakers to see economic activity and the money that makes it go round as a cog in the natural carbon cycle. The essential driver of consumption and production, it can now be observed in hindsight, is purposive combustion, and tracking the system that forces carbon into and then out of bonds with oxygen makes a statement of accounts of activity for both economy and the ecosystems it interacts with. The model is scalable, from a very small ecosystem up to the global economy.

Every human action has a physical basis, cost and consequence. Economic activity represented in dollars can simplify and short cut the details, but also overlook within limited boundaries of space and time, through ignorance or intent, the inviolable reality of the First and Second Laws governing matter and energy. Though the actual details of activities become incomprehensibly complex, there exists a scientific pathway in any process that cannot be papered over by financial magic. Economics, which was founded on practical examples of simple activities prior to the onset of the industrial revolution, can benefit by revisiting foundational models armed with the science subsequently available.

A case study of a primitive agricultural scenario analyzed from the basic building blocks of physics and chemistry leads to a fresh perspective applicable at scales from a small community up to the global drawdown of ecosystem services. In remote southwest China, in the tight spatial boundary of a karst pothole landform with a watershed profile of less than 3 square kilometers, the natural ecological systems and human interaction were analyzed.

Beginning where HT Odum left off in 1997 (Odum, 2007), and with the benefit of the subsequent two decades in which to apply a critical re-assembling of two centuries of science, a pragmatic appreciation of what it takes to use or protect ecosystem services emerges. In the case study, as simple as but more realistic and detailed than Smith's deer and beaver trade (Smith, 1776), or Quesnay's farm produce and village handicraft table (Quesnay, 1758), the cost of compensating to protect or to draw on an ecosystem is reduced to an equation in physics.

The first published economic table by Quesnay in 1758 focused on activity powered by humans and draft animals. Natural surroundings were simply assumed – the entire focus was in transactions between economic actors measured in money. At that time, evidence of the existence of atoms was yet to be observed (Dalton, 1808). This Short Communication disassembles the building blocks of science back to that period and reviews the physics and chemistry afresh, aimed at what we now need to know in a more complex world. The very tight ecosystem is analyzed in a

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http://dx.doi.org/10.1016/j.ecoser.2017.04.007
2212-0416/

way that can be extrapolated to the global overview, introducing a scientific, objective, universal currency that cuts through the maze of units measuring energy and emergy to allow government strategies to be set out on the one spreadsheet.

2. An ecosystem with an entirely closed watershed of 3 square kilometers

The karst topography of south west China includes hundreds of square kilometers of rugged peaks interspersed with potholes that are completely ringed by steep rock slopes and cliffs. Many of the hollows have at the bottom a flat layer of fertile sediment. Even with subtropical monsoon climate, rain disappears into underground caverns within hours allowing for only hardy drought-resistant stubby vegetation. It is clearly not farmland of first choice and was only taken up as turf wars over a thousand years ago began to push minority ethnic groups from lowlands.

The first distinct and vital service from this ecosystem is protection and peace to grow just enough to live. In a pothole of five houses studied, initially via a China-Australia development cooperation program (Coulter, 1992), oral legend depicts an entry and settlement 13 generations ago and backed up by etched names on a central wooden structural column. There is a division of labor between growing dry arrowroot bulbs as the staple food on the flat field, and fetching water up from a cavern. They are all full time jobs. There are four men growing crop and one special for carrying water. There are no women. These men may be destined to be "dead twigs" with no offspring, a consequence of the 30 years of One Child Policy that resulted in a shortage of women. Hence there is earnest competition trying to be economically successful and find a wife, and hence choice to specialize. Their view of work and exchange is characterized by their figure of speech, "scratching at the door (of existence)". There is no surplus and no way to be generous. The exchange is basically water and dry arrowroot and the exchange rates are jealously bargained depending on conditions of supply and demand. The physical dimension of lifting water is glaringly obvious and a dominant factor in supply.

3. Energy, work and force

The term "energy" can represent many ideas when applied to economic activity, and needs reviewing, along with associated terms. The example comparing hunting two different kinds of animals (Smith, 1776) quantifies both cost and worth in hours of labor. Subsequent economists elaborated on The Labor Theory of Value (Ricardo, 1817; Marx, 1867) and since the oil crises of the 1970's some analysist have quantified economic activity in various units of energy. Economists are invited to be cautious of the term, "energy", and consider the useful overlap of meaning between "labor" and "work". The conceptual building block of physics named "work" was defined in terms of a load lifted up a vertical shaft a certain distance against the force of gravity. $W = Fd$ (Coriolis, 1829). It was originally measured in foot pounds and in IS units in kilogram meters, or newton meter, or joules. The force, in an 1826 English mine or a 2016 Chinese cavern, is gravity acting on objects, and the force on 16 l of water carried by a 60 kg man is 74.5 N (taking one newton as the force experienced by 102 g). The work done lifting the water 7 m up a ladder to the farmland surface is 5.2 kJ. The exchange rate of how many grams of arrowroot he expects for delivering water one time is based directly on the physical reality of the work done in lifting water.

The water is taken free from the natural ecosystem at the bottom of the cavern and the carrier "produces" 76 kg m of water at a "work cost" of 5.2 kJ. Depending on conditions of the farmer's need for water and his store of produce, this work is exchanged for a certain amount of arrowroot. Typically the water carrier must make 15 trips a day for the exchange of 650 g of dry arrowroot. This may seem to resonate of the Labor Theory of Value, but the emphasis is on the cost experienced by the supplier and not a value influenced by demand. Furthermore, in this case the work is human labor, but in the original definition in physics the source of the force could be human, or draft animal, or steam engine. Watt promoted the sale of his steam engine by boasting it could beat the average work of a horse (1 horsepower), estimated to be able to raise a load at the rate of 180 pounds through an elevation of 181 feet in one minute for the duration of a 4 h workshift. In retrospect "labor" and "value' are misnomers. Instead of "labor" pitted against "capital", the term "work" can be inclusive of human labor and the mechanical work done in industry. Instead of "value" measured at a price which may be subject to fickle demand, the "cost" is much more a reflection of reality. This Work Theory of Costs is applicable to modern markets.

In the work formula, the force applied – by man, draft animal or machine, almost always can be traced to a food or fuel whose essential starting constituent is the electromagnetic force from the breaking of a chemical bond (Coulter, 2002). Combustion, when the oxygen-oxygen bond is broken, is the essential driver of economic activity. It maintains and drives the human body using carbohydrate foods. It was broken by wood fire, as the primary stove and furnace fuel until the early eighteen hundreds, then in hydrocarbons the C–H bond delivered the modern global economy. The C–O bond in carbon dioxide is about double the strength of the C–H bond that resides in foods and fuels, both carbohydrate and hydrocarbon. Extra strength within the new molecule allows the possibility of unneeded force released for work to be done externally, providing heat and motion that can be "harnessed" for human purposes.

When an oxygen molecule (traveling in the air at over 500 m/s) collides with a molecule containing carbon bonded to hydrogen, the carbon bonds with oxygen to form a tighter bond about twice as strong. Some of the electromagnetic force in the original bond is no longer required and the excess released in 3 dimensions. At the macro- observable scale this is heat, and/or spark, noise, expanding at a slow rate in starch or near instantaneous rate (gunpowder). The expansion is in 3 dimensions and so how that force is harnessed to move macroscopic objects in one direction seems to invariably lead to what we observe as major inefficiencies, even the cubed root of the initial release of the force.

There is a paradox between the perception of economic actors, who work hard to harness energy, and chemists who assign it a negative value. Chemical bonds hold our world together, and exchanges of chemical bonds include breathing, eating and all biological growth and manufacturing any product. Chemical bonds need to be discussed. Chemists see no problem in displaying their results to show that bond strengths (in kj/mol) in the products (right side of equation) are greater than the original reactants. For example 4 bonds in methane (4×413) combust with 2 bonds in oxygen (2×495) to produce 2 very strong bonds in carbon dioxide (2×799) plus 4 bonds in water (4×467). Economic actors harness the 824 released for their benefit (ie a positive number) such as heating or driving force but it appears to chemists as $2624 - 3466 = -824$. This is set out in the way displayed by chemists in Table 1. In further ongoing research, the undiscovered, unchartered reasons for bond strength are being explored. Revelation of this phenomenon may allow ecological economists to better account for ecosystem services.

In this case study, the starting point to conduct carbon-hydrogen bond accounting is the water carrier's daily consumption of 10 MJ of carbohydrate, estimated to contain 250×10^{23} carbon-hydrogen bonds. From there the "fractal cascade" can be calculated beginning with a daily dose of solar photons to fix C–H bonds in the foliage biomass, produce 650 grams of arrowroot consumed,