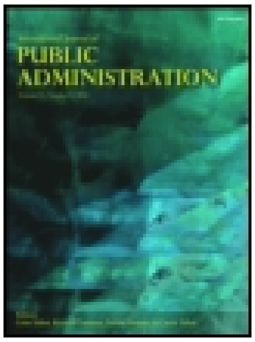

International Journal of Public Administration

ISSN: 0190-0692 (Print) 1532-4265 (Online) Journal homepage: https://www.tandfonline.com/loi/lpad20

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INTERNATIONAL JOURNAL OF PUBLIC ADMINISTRATION
https://doi.org/10.1080/01900692.2019.1645691

Biophysical Economics as a New Economic Paradigm

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ABSTRACT

Global civilization is experiencing social and economic turmoil. Human are experiencing deterioration of environment and uncontrollable declines in GDP. Traditional economic theory has been continuously advancing yet seems unable to predict these crises or provide adequate public policies to address them. A biophysical version of economic theory uses mass and energy flows as well as environmental constraints to describe the delivery of goods and services. Ongoing development in biophysical economic theory may provide some new guidance. In this review paper, Authors analyze the progression of historical economic arguments, explore their assumptions and their development and compare them to the currently developing biophysical economics framework which, instead of focusing on investment, debt, and growth, focuses on sustainable energy and mass flows to deliver goods and services to civilization.

KEYWORDS
Biophysical economics; economic paradigm; energy

Introduction

Economic theory in its infancy created descriptions of how humans distribute scarce resources to unlimited needs (Skouras, 1981). Over 1000's of years, these descriptions of choice processes expanded to reflect the objectives of a wide variety of groups embedded in a wide variety of social contexts, and physical systems that varied greatly over time. Every time the group make-up changed, every time the social community and the group it was embedded in changed, every time the physical attributes of the physical environment changed, the economic descriptions of how decisions were made changed.

The first descriptions were of how family units (hunter and gatherer) selected their actions. These calculations are still being taught in public school home economics classes. As groups got more abundant, more complex (leadership, ownership, distribution of labor, agricultural units and industrial units) and spread over longer distances (sea routes) and included different cultures and values which in turn formed alliances with competitive advantages (socialization of labor, economies of scale and protection of trade) economic descriptions got more complex. Table 1 shows part of this progression of evolving economic theory.

Different people assess economic issues differently, forming different kinds of economic theories. It was identified three aspects of the economic theory' history development: economic ideology, economic schools, and economic problems. Economic theory development experienced four stages, as shown in Table 1.

Economic activities have been existing since ancient times and called "housekeeping" economics. It consisted of simple economic thought, and as production class, named "family-units." In the sixteenth century, western European countries entered a capitalist society. New economic ideology emerged, especially Mercantilism and Physiocracy, appeared at that time. Mercantilism regarded money or gold as wealth, which guided government to protect overseas business and expanded capitalism (Haley, 1936). Physiocracy regarded land and agricultural products as social wealth in France. Physiocrats valued production process and advocated economy to develop freely (Ware, 1931). As capitalism developed, a new form of economic theory replaced Mercantilism and Physiocracy. The classic economic theory focused on economic growth, regarding production as playing the leading role and emphasized market as an invisible but powerful hand. Adam Smith published "Wealth of Nations" in 1776, which marked the establishment of the new classical economic theory. In this book, he discussed such essential points as labor theory, labor' division, as well as monetary theory development (Maynard, 1937). Later, David Ricardo and Karl

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Table 1. Stages of economics theory development.

Stages	Major economic thought	Times
Beginning	Physiocracy and Mercantilism	1400–1600
Formation	Classical Economics: Labor theory of value	1650s–1870s
Development	Neo-Classical Economics: Marginal Utility theory	1870–1930
Reformation	Keynesianism: governmental macroeconomic regulation and control	1930–1950
	Pos-Keynesianism: the combination of market and government regulation	1950–1970
	Neoliberalism: Monetarism, Supply-side Economics, Institutional School	1970–1980
	New Keynesianism: New Growth theory	1980–now

Marx inherited Adam Smith's view. Also, Tomas Robert Malthus, Say, and Moorer expanded the classical economic theories at that time. Subsequently, neo-classical economic theory substituted classic economic theory, considering human satisfaction and marginal utility as the main aspects of the theory (Marshall, 1920). Unfortunately, the capitalist society leads to overproduction and economic crisis during the 1930s, resulting in deep conflict between the owners of capital and the working class. Later, Keynes explained the State Intervention Theory in his book "The General Theory of Employment Interest and Money" (Dickey, Winant, Smith, & Adam, 1993). It was the first significant step in Macroeconomic theory development. After the economic stagflation in the 1960s, Keynes' theory faced a deep crisis. However, further neoclassical synthesis accepted Keynes' views and emphasized to combine marketing mechanism and government macro-control (Blanchard, 1991). We consider the Monetarist School, supply-side economic theory and institutional school as Post-Keynesian (Kregel, 1979), where Samuelson and Solow provided major contributions. There are additional theories that have come from the West, such as value theory, utility theory, production equilibrium theory and others. However, none of them were able to predict the 2008 financial crisis accurately. Theories that could predict whether the global economy would be in crises or recovering became essential. Indeed, preventing of civilization's collapse is not even on the agenda of neoclassical economics. A new theory may be required. It may be the theory with an accent on the biophysical point of view.

Literature review

The origin and development of biophysical economics

Alfred Lotka (1922) focused on sustainable/collapsing biological systems: islands with grass and rabbits, and islands with grass, rabbits and wolves. He monitored grass production and related it to rabbit populations without wolves and with wolves. This work forms one basis for understanding the dynamics of human civilization on Earth which in a way is also an island. Frederick Soddy, Fred Cottrell, M. King Hubbert, Nicholas Georgescu-Roegen, Howard T. Odum, Robert U. Ayres, and Charles A.S. Hall studied changes in earth's resources and how they affected civilization/nations/industry's viability or sustainability. Biophysical economics and ecological economics were the umbrella name given to their work. However, each had its connection between the behaviour to deliver services and the physical parameters of the natural system.

Ancient Chinese philosophy is a storehouse of knowledge and can form a solid foundation for understanding and open new ways of biophysical and economic research. The traditional Chinese philosophical work of the *Tao Te Ching* argues "Man takes his law from the Earth and the Earth takes its law from Heaven, and Heaven takes its law from the Tao. The law of the Tao is the "law of Nature" (Lao, 2015). Thus, natural way of development of biophysical economic science could be the way, based on Chinese traditional philosophy.

Kenneth Boulding's classic *The Economics of the Coming Spaceship Earth* predicts the transition from "frontier economics" (growth without resources limits), to "spaceship economies" where resource limits predict no growth. Earth is where growth in welfare can no longer be fuelled by growth in material consumption (Rome, 2015). Economics was recast (Czech & Daly, 2014) including biology and ecology, physics and chemistry. Thus, American marine biologist Rachel Carson describes the damage and impact of pollution caused by the human development of her book "Silent Spring" (Carson, 1987).

In 1972, the "Declaration of United Nations Conference on Human Environment" stated that "for the benefit of this generation and future generations, the natural resources of the planet must be protected through careful planning or proper management (Weiss, 1992). Sergei A. Podolynsky, a Ukrainian precursor of today's ecological economists, already proposed an energy balance of the agricultural production in 1881 (Burkett & Foster, 2008).

Biophysics was formally developed in the 18th century by the agrarian school, represented by Frenchman François Quesnay and his disciples. The agrarian school believes that natural resources are the first principle of economic development, and the land is the source of material wealth. They also outlined the physical constraints of agricultural productivity (Eltis, 1975; Murphy, 2008). Later, Frederic Soddy, a chemist, discovered that bad banking (monetary practices) would lead to war in his book "Wealth, virtual wealth and liability". He considered wealth as physical property based on thermodynamics, and that debt, when overissued, could lead to bankruptcy (Weiss, 1992). After the First World War, Howard Scott and Hubber at the Alliance of science and technology performed empirical analysis concerning employment and found energy a better predictor of civilization development rather than monetary units. (Howard, 2011). Sociologist Fred Cottrell emphasized that surplus energy played an essential role in our community and considered how it represented a crucial supplement to labor (Fred, 1956).

Nicholas Georgescu-Roegen felt economics should use physical, chemical and biological process at the foundation (Georgescu-Roegen, 1986).

Howard T. Odum added the Max Production Principle (MPP) as the dominant active element in Darwin's evolution theory. MPP also applied to Lotka's dynamics when multiple predators required the same prey. In 1973 he put forward the concept of net energy as the best determinant of a species success (Odum, 1983).

Robert Costanza supported Odum's view, analyzing the relation between direct and indirect investment creating the concept of embodied energy. That is if it is used a truck to deliver your goods, the goods reflect the energy to run the truck and build the truck including the steel and mined the ore . (Costanza & Herendeen, 2005).

Culter J. Cleveland explained the relationship between energy and the economy – published in Science (Cleveland Costanza & Kaufmann, 1984). Charles A.S Hall created Energy Return on Investment (EROI) to analyze the relative utility of a source of energy (coal mine or oil well) to support of a human activity, and its power to advance human welfare. (Hall & Charles, 2011). Robert Ayres explained that to do work a gallon of low entropy gas (very ordered) was transformed into a unit of high entropy hot air (very disordered). This fact supports an application of the second law of thermodynamics. He used this to discuss the different uses of low entropy sources. Gasoline to heat homes vs. run trucks. (Ayres, 1991). To summarize, Biophysical Economics promoted analysis based on the services created by the physical and ecological inputs. These changes in entropy were mostly ignored or were considered based on their acquisition costs in dollars.

Professor Ugo Bardi at Florence University found that the ancient Roman Lucius Anneaus Seneca already showed that civilizations grow slowly and decline rapidly (Bardi, 2011). Peter Turchin explained that one requires at least one hundred years in one circulation for sustainable growth because there are approximately fifty or sixty years of stagflation in this period and it needed only twenty or forty years of growth before a recession (Trinacty, 2016). It is the cyclic curve named "Senecal Cliffy" (see Figure 1).

The period 1950 to 1970 was the highest growth for the middle class in the USA. After that the middle class lost ground while the profits increasingly flowed to investors. From 2001 till 2007 it was a "golden age", where people were engaged in consumer success and neglected to consider the costs to nature. After the financial crisis in 2008, there were signs of a recession with lower GDP per person or lower growth. Therefore, the period of high profit and stable production growth was over. Moreover, fossil fuel started to play a significant role after the industrial revolution. At this point, Authors refocus on the physical character of energy under environmental and economic pressure.

Biophysical economics definition and principal

Biophysical economics definition

The word "Biophysical" first appeared in 1892 (Hunter, 2007). According to the Webster dictionary, "biophysical" means that science utilizes physical methods and explain issues according to a natural point of view. Charles A.S Hall in the book "Energy and wealth of Nations" explains that the Economy is a system and must support sustainable processes through producing energy input and output, distributing and consuming goods and services. Economic growth depends on energy acquisition and

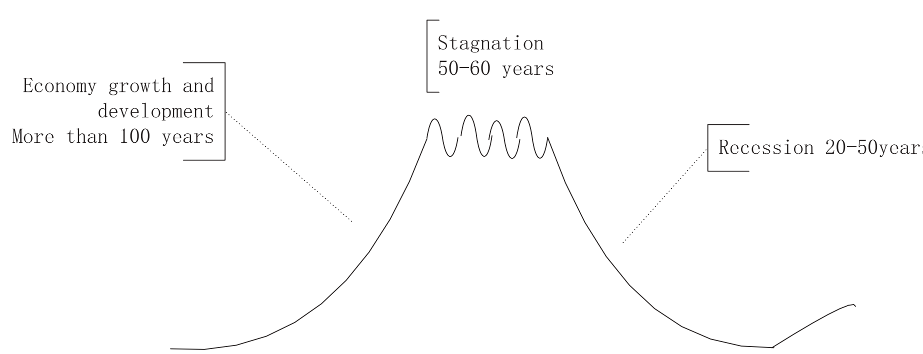

Figure 1. "Senecal cliffy " cyclic curve.

utilization (Hall & Klitgaard, 2012). The generalized definition of Biophysical Economics is that it is a scientific focus on how material and energy transform to maintain human survival and promote social development. Biophysical Economics means economic study related to energy.

Most economic researchers had an anthropocentric view in the past (Callicott, 1984). In contrast to that, the essence of Biophysical Economics actually removes anthropocentrism and regard the economic system as a system in which energy and material flow sustain to act as different elements and agents influence each other. Figure 2 shows the western traditional economic system in contrast to the Biophysical Economic System.

Biophysical economics principles

Scientific consistency principle. Economics under Biophysical view follows scientific laws such as physics, chemistry, and biology. Carnot and Clausius improve thermodynamic law. Ostwald quotes laws of thermodynamics into economic areas (Ostwald, 1907). The first law of thermodynamics is the thermal equilibrium, which states that energy would never disappear nor perish while it transforms into another form. The second law of thermodynamics is energy capacity conservation. It means the Earth' total amount of resource is limited and an automatic process in nature is irreversible. There is a loss of energy during conversion. It represents the decline of energy quality and grade. However, entropy material of energy resources in the World is irreplaceable. Meanwhile, it must be payed attention to high entropy material such as discharged waste.

Biological symmetry principle. Feynman described the nature symmetry phenomenon in 1965. The geometry is symmetrical, the same as human and animals. Similarly, the economic system follows the symmetric principle. However, the cognitive framework of western mainstream economics is asymmetrical. Classical economics, Neoclassical economics and Keynesianism have different points of view, and all devote significant contribution to temporal society at that time. However, they focus on price and make hypotheses concerning supply and limited resources. They all emphasize the demand-side and neglect the supply side. Biophysical Economics on the other hand concentrate on the product, especially energy.

Max power principle. This principle is put forward by Odum and is proposed as the fourth law of thermodynamics. It contains two kinds of meanings. One is the maximum efficient use of energy, and the other is maximum effective energy conservation to sustain system development (Odum, 1983).

Metabolism principle. The word "Metabolism" comes from Greek. It means changes and transformation (Fischer-Kowalski, 1998). Moleschott wrote the book "The Life Cycle" in 1857 and said that life is a transformational phenomenon from energy, material and environmental processes. Biological metabolism is a collection of organisms dealing with material processes. Energy metabolism means a collective system dealing with energy processes. Ecologists hold the opinion that the metabolism process expressed as a cycle of ecological system and nutrient, is the same as the energy and pollutant metabolic cycle process.

Carrying on capacity principle. Ecology firstly quoted this principle. Odum defines it as the maximum potential number of organisms surviving in an environment

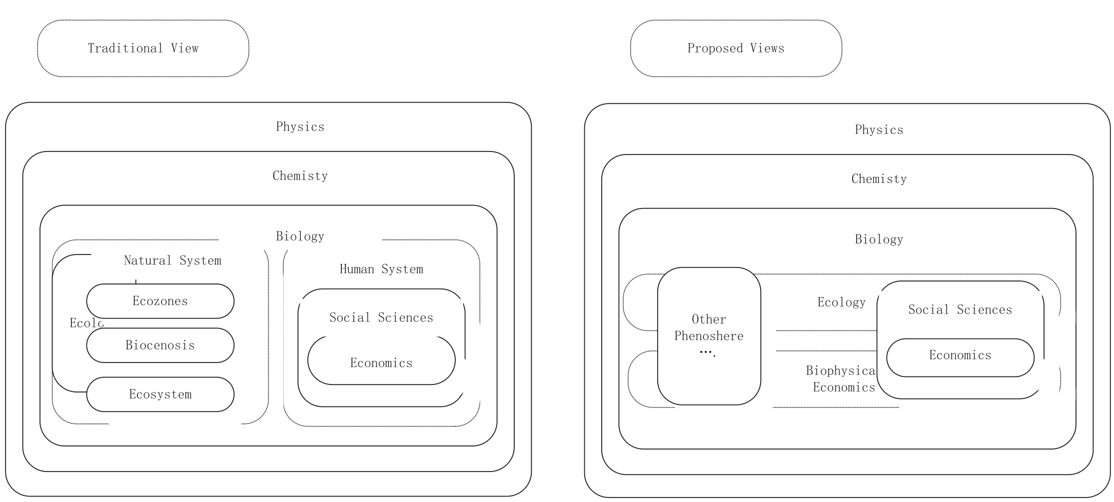

Figure 2. Different views on the economy.

(Odum, 1969). Catton limited environmental carrying to capacity in 1986, and then scholars expanded its notion as the maximum amount of human effort carried out without damaging the environment of the region. That means the ecosystem needs self- sustains and regulates capacity and support social, economic development.

Sustainable development principle. Herman Daly considered sustainable development as a state of stable physical wealth and permanent population. It means the low birth rates equal to the low death rates, so the longevity of people's life is an important factor for social sustainability. The steady condition represents a sustainable development (Daly, 1991). For example, one child per family is the path forward for humankind. However, one child per family will not assure that lower population will grow enough, and people need social control over the number of global annual births to prevent civilization collapse. A viable population that births would have to equal deaths. One child per family would depopulate the community. Thus, society must find ways for sustainable development to try to sustain the population at a sufficient level and try to support the population at the level that will not decrease. Authors definite sustainable development as complying with three conditions:1) the final state where the wellbeing and number of individuals is constant. 2) the level of development that allows the "have nots" rise to the level of "haves" without exhausting the environment's ability to support them. 3) given population current level of overshoot, only rapid decline trend can proceed to a viable future.

Biophysical economics' content

Biophysical Economics covers the process of economic activity. The economic system is a complex and open ecosystem that is assessed with a biophysical and an economic view. Nicholas Georgescu-Roegen considers that the economic system is a process using various production factors to convert energy into the material to sustain existence and development while producing a large amount of waste (Georgescu-Roegen, 1986). The whole means of economic sustainability behavior can be seen in Figure 3. Charles AS. Hall tries to connect the flow of energy and mass through the system to the flow of money through the system. Biophysical Economics describes the relationship between the economy and energy. The mainstream economists focus on financial flows while Biophysical Economists pay attention to material and energy flows. They argue that those are essentially two aspects of the same question (see Figure 4).

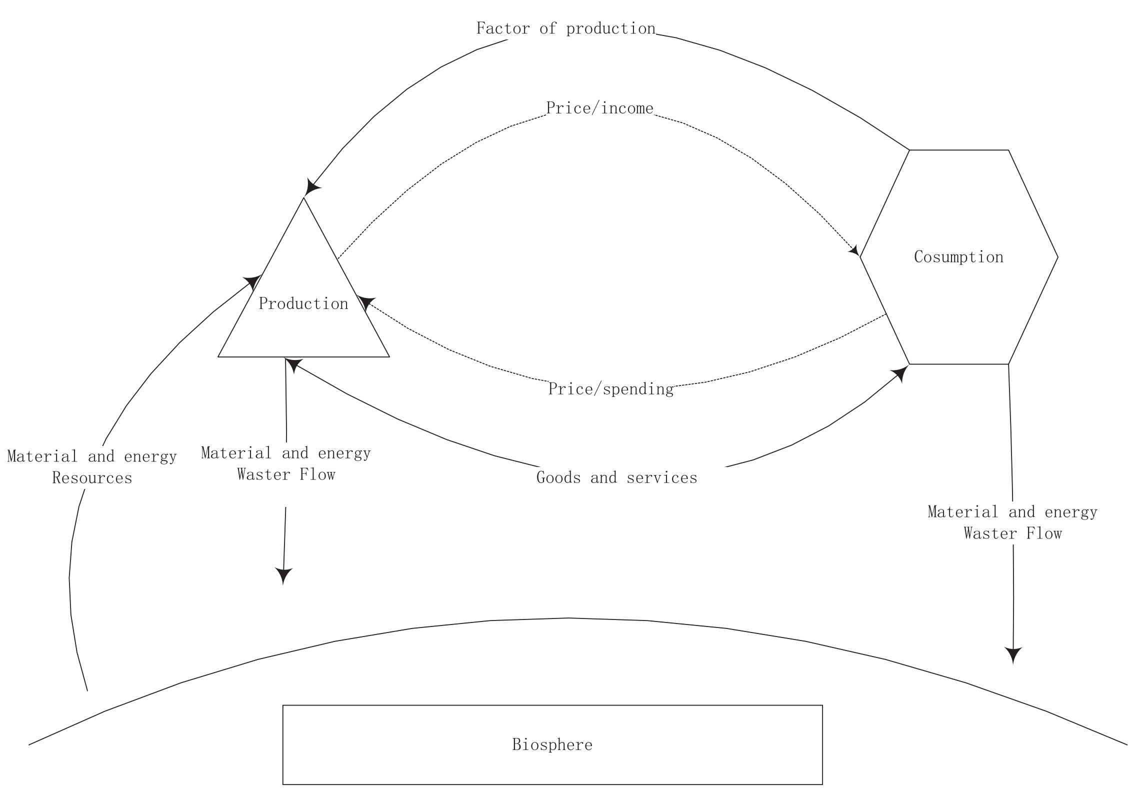

Figure 3. Energy and economic activities.
Sources: Charles A.S Hall "Energy and the Nation of Wealth"

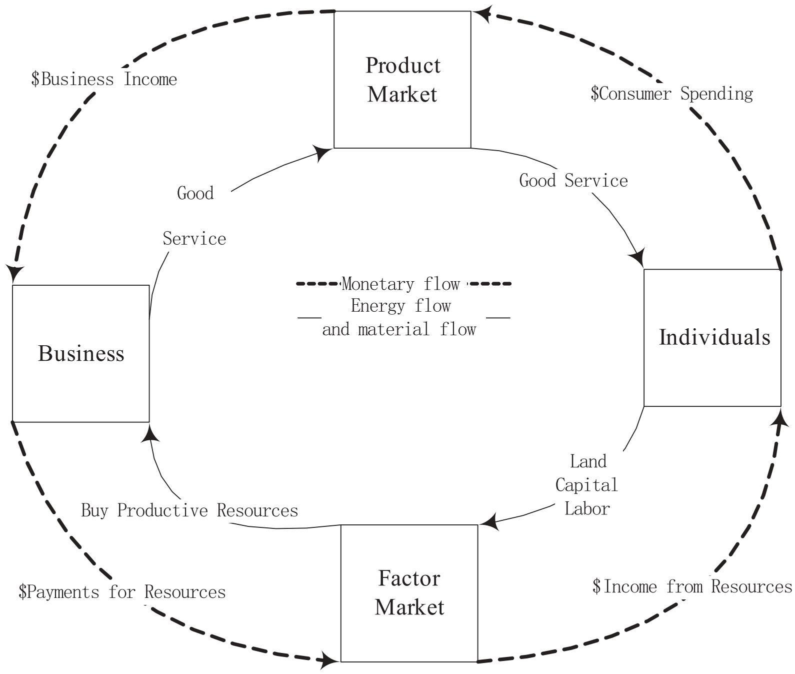

Figure 4. Monetary flow and energy, material flow in economic activity.

Biophysical Economics illustrates the laws between energy and economic development, where Energy is the economic driving force. The developing worldwide history is also the history of energy development and utilization. Energy quantity and energy quality affect the speed and quality of economic development. The amount of energy, especially fossil fuels, has been increasing since the industrial revolution. The contradiction between supply and demand for energy resources is a common question. Energy consumption promotes economic growth. Only net energy consumption can boost economic growth under the Biophysical Economic view, and energy structure affects economic development. For example, in China, total energy production has been growing since China started promoting the reform and opening-up policy in 1978. China's total energy production has surpassed the United States as the largest producer since 2007. Figure 5 shows the correlation between production, consumption, and GDP.

Biophysical Economics reveals the utility of energy and environment. Climate change poses a major threat to species and people's livelihood. At the same time, it endangers the Earth's ecology and human survival. Taking action to solve this issue could promote sustainable economic growth and social sustainability. Meanwhile, climate change decisions also can improve public health and quality of human life. Developed countries have completed the process of industrialization and modernization by consuming fossil fuels excessively since the Industrial Revolution. At the same time, fossil fuels were limited worldwide. Nevertheless, nowadays the World is in an accelerated period of industrialization and urbanization. Energy demands are increasing every year. Therefore, the amount of greenhouse gas keeps growing.

Similarly, energy exploration exacerbated the problem of insufficient water resources. Water resources and energy are fundamental materials for human survival, economic development, and social progress. The total water and energy demands are rising against a background of increasing global population and shortage of resources. Energy consumes large amounts of resources in the production process, including energy resource and water. Meanwhile, water in production and utilization is needed to absorb energy. Water resource has a dual relationship with energy; they constrain each other. Figure 6 below shows the relationship between energy and water resources). For example, China is a significant coal producing country and has a huge coal consumption. It consumes a large amount of water in the coal production process. Scholars calculated the water energy consumption intensity from 2007 to 2012 based on the China Statistical Yearbook. The correlation coefficient of coal with direct water consumption is 0.6 cubic meters per ton of raw coal, and the total water consumption coefficient was 2.02 cubic meters per ton of raw coal (Yu, Xin, Chen, & Zhuo, 2016). Besides, water consumption exacerbates the deterioration of the ecological environment, especially as it relates to energy production and consumption.

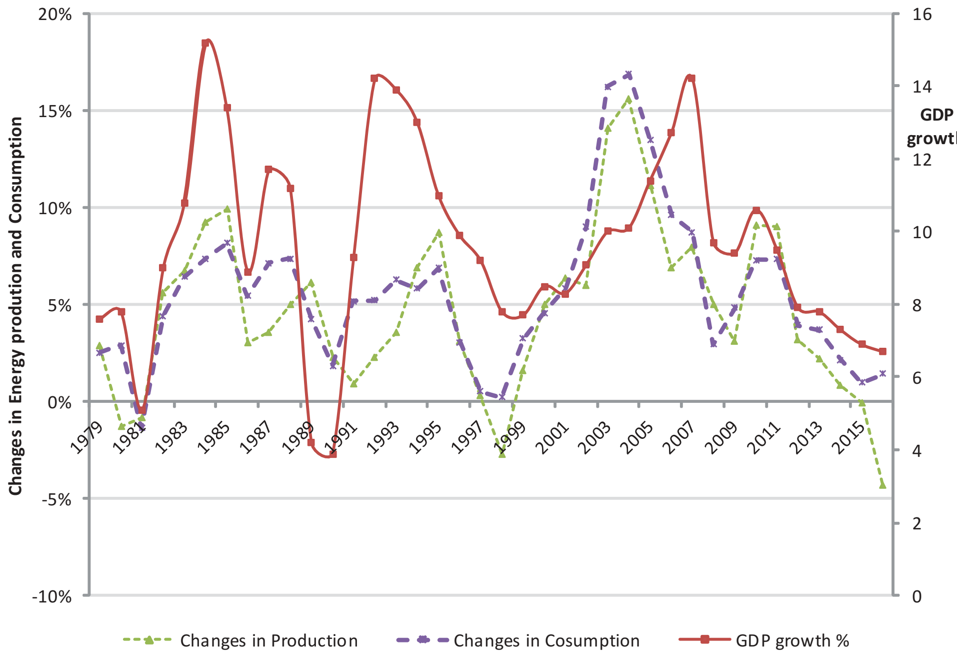

Figure 5. The correlation among production, consumption and the GDP in China.

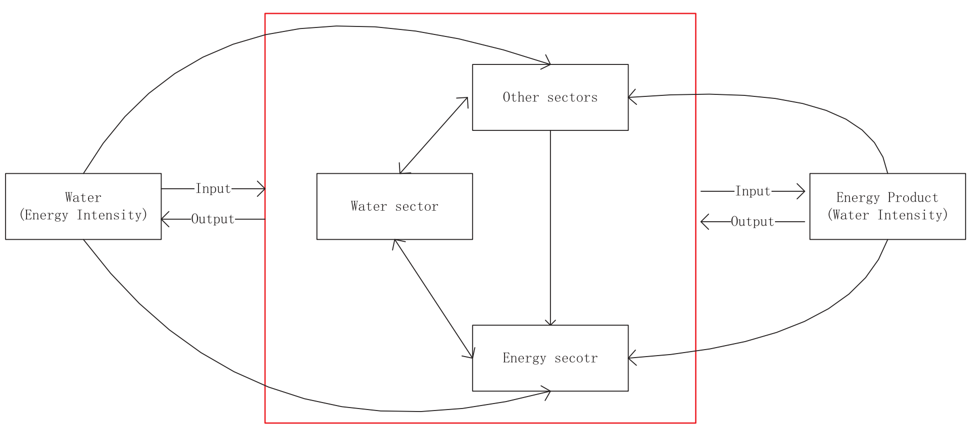

Figure 6. The relationship between energy and water resources.

Biophysical Economics indicates the relation between energy and society. Wilhelm Ostwald, the winner of the Nobel Prize in Chemistry, published his essay "Energy", in which he regards that the foundation of all changes in society is a transformation from primary energy to useful services. Moreover, the larger the available energy coefficient during the transition, the higher the progress of society will be. Maslow divided human needs into six levels, as is shown in Figure 7. He discussed that the lowest level of needs is the pursuit of material living, and the highest level is the need for self-actualization. Energy plays a vital role in meeting humankind needs at different levels throughout the process (Bach, 2015).

The methodology of biophysical economics

Energy Return on Investment (EROI)

Odum H.T, an ecologist in America, wrote the book "Energy, ecology, and economics" in which he first refers to the EROI concept (Odum, 1973). EROI concept was introduced by Cleveland C.J. et in 1987 (Cleveland et al., 1984; Guilford, Hall, O Connor, & Cleveland, 2011). In 2009 Charles A. S. Hall created the formula of EROI which meant energy return to society and society must use energy to achieve goals (Hall & Klitgaard, 2012). EROI's calculation method proposes a variety of outputs and inputs variables converted into heat equivalents directly. Murphy defined the standard EROI calculating process which was output energy

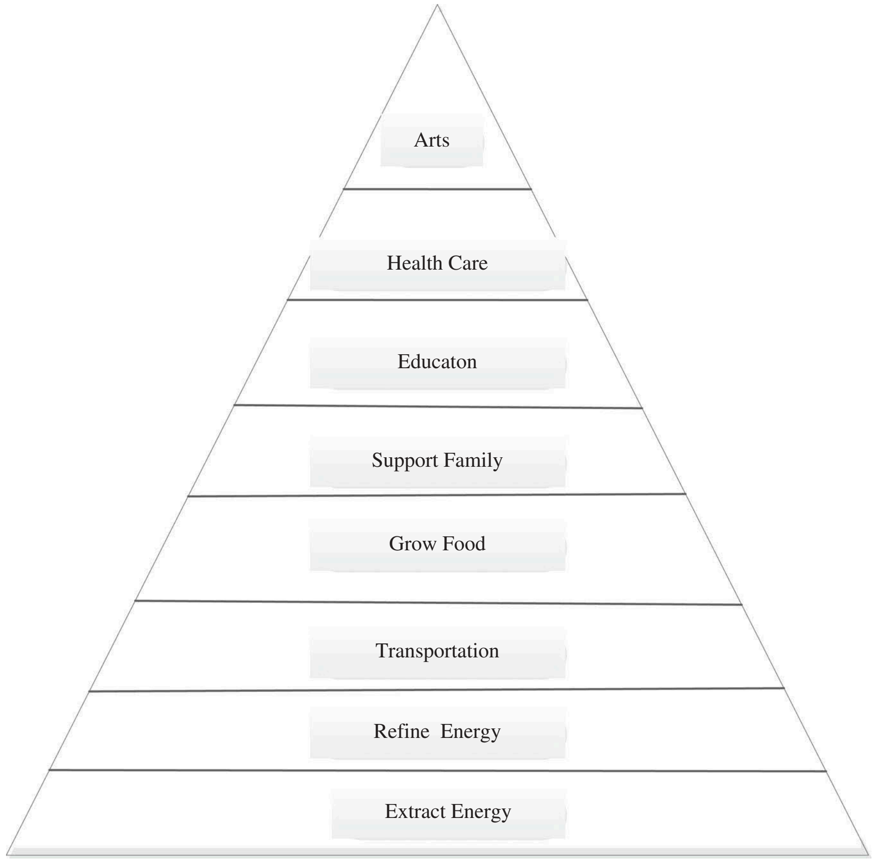

Figure 7. The Maslow pyramid under biophysical view.
Sources: Jessica G. Lambert. Life, Liberty, and the Pursuit of Energy: Understanding the Psychology of Depleting Oil Resources; Karnak Books: London, UK.

divided by the sum amount of direct inputs and indirect inputs of energy (Henshaw, King, & Zarnikau, 2011; Xu, Feng, Wei, Hu, & Wang, 2014). The formula is as follows:

$$EROI_{mm,d} = \frac{\sum E_i{}^O}{\sum E_{d,i}^I} \quad (1)$$

Where $\sum E_i^o$ represents energy outputs as the sum of the amount of energy; $\sum E_{d,i}^I$ represents the sum of direct and indirect inputs.

Other available methods

Odum created the emergy analysis formulation in the late 1980s. He considered energy could be expressed by emergy value (Liu, Wei, & Jin, 2014; Odum, 2002). The carrier of energy was fossil energy or another form of energy resource. Generally, power comes from solar. Energy conversion rate assigns weights of different energy types to measure the process of energy production and consumption.

Energy efficiency is the way how society uses its primary energy resources to meet human needs successfully. Energy efficiency relates to the natural and economic sciences, social development, and other aspects. Technically, energy efficiency is the indicator to examine the levels of the energy parameters. Economically, energy efficiency refers to using less energy to produce the same amount of services or useful output. The energy calculation process includes energy mining, transportation, processing, conversion, final consumption, and other links. Table 2 shows the link for the energy efficiency equation.

In the energy processing stage, energy efficiency and energy consumption intensity are reciprocal (Shi, 2010). The technology, economic structure, economic development mode, energy consumption structure, consuming pattern and government management are the main factors of energy efficiency.

William E. Rees, the Canadian ecological economist, proposed "ecological footprint" in 1992. It is the metric that measures how much nature society has and how much environmental resources people use. It measures the environment assets that a given population requires

Table 2. Energy efficiency equation.

Item	Formula
Mining stage	Energy recovery efficiency = production/ geological reserves
Energy processing stage	Intermediate Efficiency = Energy Output/ Energy Input = 1 − Energy Loss/Energy Input
Energy end-consumer stage	Energy Efficiency = Intermediate Link Efficiency *Terminal Utilization Efficiency
Energy efficiency in the economic system	National Economy Energy Efficiency = GDP/ Total Energy Consumption
Industry energy efficiency	Energy Efficiency = Value Added by Industry/ Energy Consumption by Sector
Energy system	Energy System Efficiency = Energy efficiency in the middle of the chain *Terminal utilization efficiency

to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions (Rees, 1992). In 1996 Mathis Wackernagel continuously improved the concept and proposed the ecological footprint calculation model and calculated organic production area to measure the sustainable development (Wackernagel & Yount, 2000).

The ecological footprint is calculated as:

$$EF = \sum\nolimits_{i=1}^{n} w_i(cc_i) = \sum\nolimits_{i=1}^{n} \left(\frac{ac_i}{p_i}\right) \tag{2}$$

The formula of ecological carrying capacity is:

$$EC = \sum\nolimits_{i=1}^{n} w_i(ep_i) = \sum\nolimits_{i=1}^{n} \left(\frac{ae_i}{p_i}\right) \tag{3}$$

Where, i stands for the type of consumer product or creature; cc_i stands for the i kinds of consumer goods production footprint; ac_i stands for the total consumption of consumer goods; p_i for i production of biological products per unit area yield; ep_i for$i$production of biological resources footprint;ae_i for i total resources of biological production; w_i for i consumer products or biological resources land type productivity weight; EF stands for total ecological footprint for a region; EC stands for regional ecological capacity supply.

The third available method is the entropy analysis evaluation. Entropy represents the degree of disorder in molecular dynamics under thermodynamic conditions. Clausius proposed "calorific value entropy" in 1865. Shannon proposed the concept of "information entropy" in 1948 (Glasenapp, Frieden, & Cruz, 2015). Entropy analysis is a mathematical method based on actual weight and the information impacted by various factors. According to the definition and the principle of entropy, the system may be in several different states, the probability of each state occurring is p_i (i= 1, 2, 3,…), and the system entropy is a kind of system state in uncertainty metrics. The higher the entropy is, the more chaotic the system would be, and the higher the uncertainty of the factors is. Expressed as a formula:

$$E = -\sum_{i=1}^{n} p_i \ln p_i \tag{4}$$

Result

According to the contents, the principles and the methods of Biophysical Economics, it was summarized the research framework of this discipline as Figure 8.

From the framework, authors conclude that Biophysical Economics focus on energy which is the agent between ecology and economy. Nowadays, Biophysical Economics, a single new paradigm based on energy constraints and sustainable conditions, synthesizes into a richer understanding of the inherently complex systems. It implies studying and managing the world in an integrated way and takes full advantage of human accumulated knowledge and understanding of both the natural and the social parts of the system.

It is taking China, for example. After completely abandoning Chinese traditions in China's first Enlightenment, which began in the May Fourth Movement in 1919, China began to accept the process of Western modernity, including anthropocentrism, leading to unbridled pursuit of GDP and consumerism. Such ultimately resulted in China not only facing serious environmental problems, but also social severe problems (Niu, Ning, & Liu, 2015; Zhang, Sun, Cheng, & Niu, 1999).

Nowadays, China has become a global hotspot as it has replaced Japan as the world's second largest economy. At the same time, the term "ecological civilization" was officially proposed by the Chinese government for the first time at the 17th Congress of the Communist Party of China in 2007. Ecological Civilization reflects an essential change in the Party's understanding of development (Xu, 2018). Rather than emphasizing economic construction as the core of development as it did in the past, the Party authorities have come to realize that development, if sustainable, must entail a list of elements including the right relationship between man and nature.

Discussion

One can compare biophysical economics and mainstream economics under the following five questions. First, what is the origin of wealth? Second, how are the wealth and income allocated to branches of the economy? Third, what is the balance mechanism between supply and demand? Fourth, what are the decisive factors for economic growth? Fifth, what is an adequate

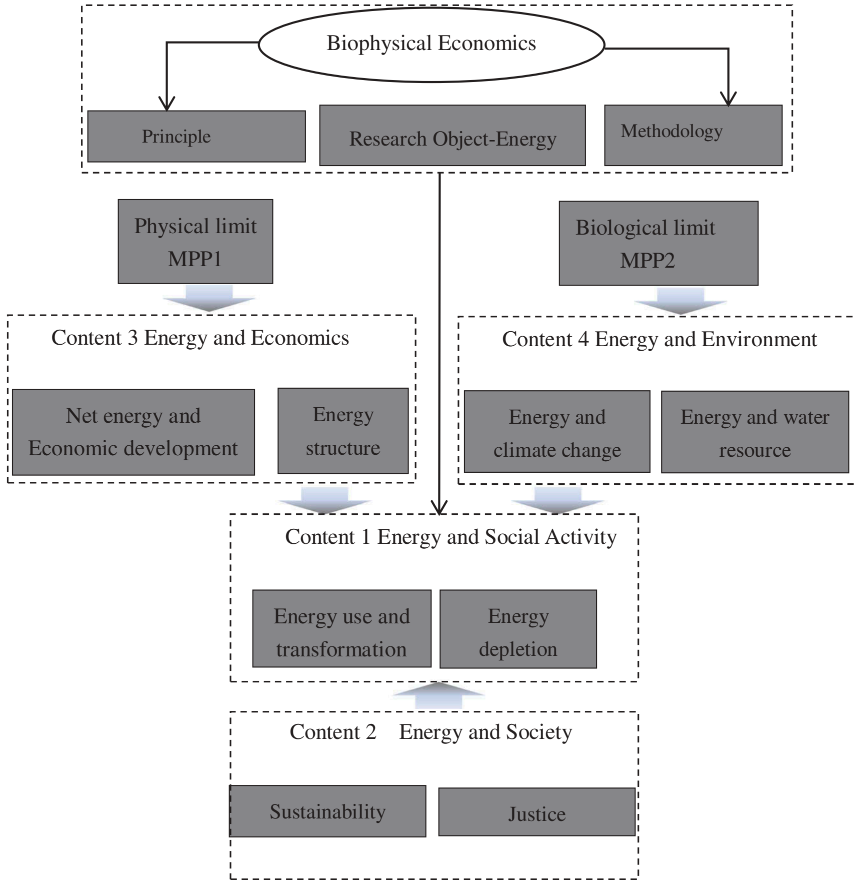

Figure 8. Biophysical economics framework.

role of the government in the economy? To answer these questions, Charles A.S. Hall, one of the father-founders of Biophysical Economics, believes that each issue is mostly energy-related as is shown in Table 3 (Hall & Klitgaard, 2012).

The energy factor in economic production is different under the view of Biophysical Economics researchers. Specific production factors such as land, capital, labor, technology influence economic growth. For example, land as a production factor acquires energy from the sun. Large-scale machines in the production process use power too. However, mainstream economics holds a point of view that classic economics is teleology. Assuming that the rationality of people and limitations of resources as well as unlimited demands, energy is only a commodity or attribute of a commodity.

Table 3. Comparison between biophysical economics and mainstream economics.

Content	Traditional Western Economics	Biophysical Economics
Wealth root	Land, Labor and Capital	Energy
Distribution Mechanism	Market	Resource Constraints
Hypothesis	Rational People	Base on Nature
Economic Determinants	Labor and Capital	Energy
Government role	Macro-control	Environmental Protection Mechanism

Macro-economic textbooks postulate that GDP is determined by rented capital, rented labor, and technological efficiency according to the most straightforward Cobb-Douglas production function (Passy, 1978). However, from a biophysical point of view, useful energy is another essential factor in addition to capital and labor. German economist Reiner Kummel indicates that the output elasticity of energy appears to be larger than its cost (Luz, 2011). In other words, "without energy, there would be no economies because there would be no goods or services produced or moved from place to place or through markets" said Charles A.S. Hall (Hall & Klitgaard, 2012).

The issues of energy prices, energy supply and demand are discussed from the perspective of the energy market. Herun proposed the relationship between energy supply and demand on the standpoint of energy price changes. Biophysical Economics considers resources and environmentally bound. Herun's interpretation of a "biophysical economics constraint cycle model" is shown in Figure 9

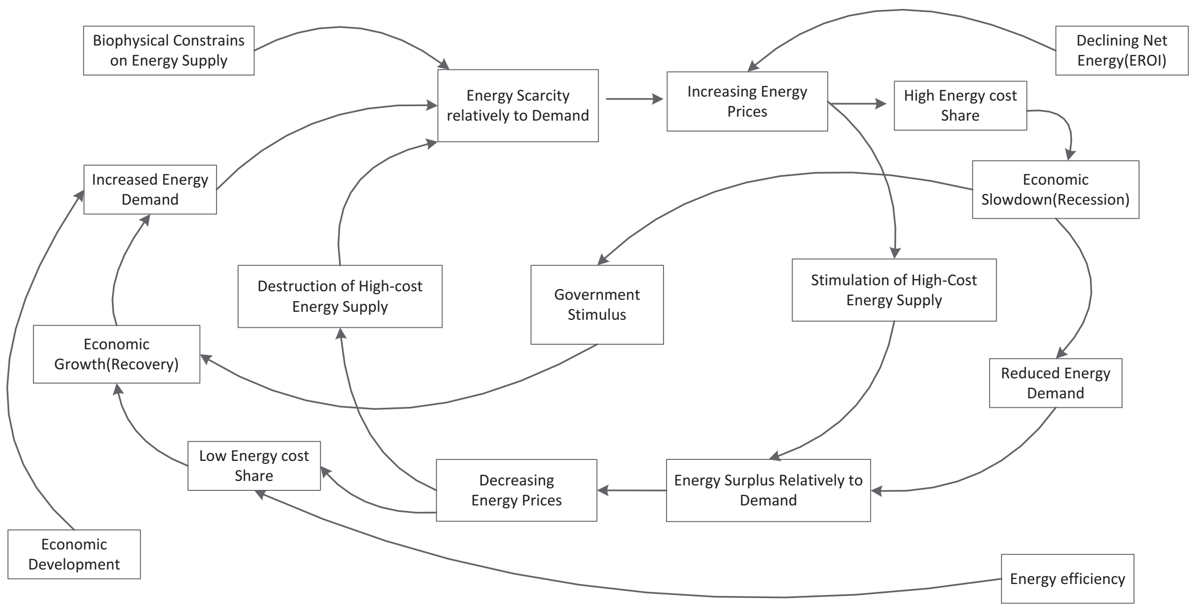

Figure 9. Biophysical economics constrains cycle model.

(Heun & Wit, 2012). According to the model, there are three levels of circular dynamic relationships. The first level of circular relationship considers the dynamic cycle of the energy market from the production and supply level. It mainly regards energy prices interaction between supply and demand. If energy is in scarcity (energy supply is less than the need of the market), the rise of energy prices and the high-cost energy projects were put to balance the energy supply and market demand. Then energy surplus leads to be lower prices; the original high-cost energy projects were closed; energy supply and demand tend to keep balanced until producing a new dynamic cycle. In the second cycle, it considers the impacts of the energy demand on the energy market. The increasing energy prices lead to higher energy cost. As a result, the economic slowdown and even the economic recession leads to a lower level of energy demand in the market, which increases energy surplus and drives energy prices lower. The ultra-low energy prices reduced the share of energy costs in the total cost, and the economy starts to recover or even grow. This fact further stimulates energy demand. There is an imbalance in energy supply and demand, and a new recycling mode starts. According to this fact, the third level of the dynamic cycle implies the impact of limited energy supply (Biophysical constraints) and declining net energy.

Conclusion

It was reviewed such economic theories as they developed over time; describing their theses and assumptions. Authors found these models predominantly used GDP growth to allocate capital and labor. The financial crisis in 2008, produced a sudden decrease in GDP growth, which showed these models lacked robust predictive powers. Society need new models to be our guide. Biophysical Economics, which includes nature's constraints on mass and energy flows, might be the extension to economic theory which would have foreseen the 2008 difficulties and might be able to see future difficulties. For example, Biophysical Economics might foresee that declines in energy deliveries this century, could eliminate future increases in GDP with accompanying decreases in production and labor requirements. While environmental economics added to economic theory by including the value of natural capital and natural production's contributions to the creation of human goods and services, Biophysical Economics included the meaning of reservoirs of mass and energy their contributions to the production of goods and services. Moreover, Biophysical Economics focuses on the impact of its waste stream on nature's productive capacities.

Biophysical economics focuses on the trends in energy quantity and quality and predicts that without some new energy delivery system this century's global economic growth will stop. Biophysical economics focuses on using the remaining energy efficient. While the current state of biophysical economic theory is not a complete solution to the economic failures of 2008, it is more human and ecological oriented than the economic theory that proceeded it. Nobel economist Joseph Eugene Stiglitz said "Standard Economics is wrong. Inequality and unearned income kill the Economy. The rules of the game can be changed to reverse inequality." Also, anthropologists Joseph Tainter thinks energy surpluses driving sociocultural and economic complexity, that most commonly increases to solve problems, and compels increase in resource use. In a sense, all of biophysical economics is asking some version of the fundamental questions put forth in *The Limits to Growth* in 1972. Eventually, society have to create additional elements to economic theory that will help design a truly sustainable community and a process to transition to it. Whatever these additions, energy is likely to be a significant descriptor. Consider this paper as voluntary propaganda effort to use a biophysical perspective in developing that theory.

Funding

This research was supported by the National Natural Science Foundation of China (grant No. 71874202/71874201) Russian State Assignment for CEMI RAS on topic "Creating of a system multi-level theory, coordination and co-evolution industrial complexes and enterprises' models for the Economy sustainable development" [AAAA-A18-1180213901].

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