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Understanding the global economic crisis: A biophysical perspective

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ABSTRACT

The recent economic meltdown worldwide has reinforced our understanding of the effects of decoupling economic growth, monetary policy, and resources. Concern for peak oil and suggestions that it may have contributed to the global economic woes as well as over concern for the banking fraud may be adding confusion over the underlying causes and sending a misleading message to the public and ultimately to policy makers. Viewing the economy as simply a circulation of money that can be manipulated to increase spending and therefore consume our way out of the current economic situation, is courting disaster by deluding the public that the solution lies in simple adjustments to the current monetary system. Similarly, emphasizing that energy is the problem and that the solution can be found with another energy source is probably counterproductive in the short run and may be disastrous in the long run. The recent nuclear accident in Japan seriously calls into question increased dependence on nuclear energy and renewable energy sources, in the majority, have low net yields and are unevenly distributed worldwide.

In this paper we frame the economic system as a subsystem of the larger more encompassing geo-biosphere and suggest that within this context, neoclassical economics is unlikely to provide sufficient explanation of the recent economic melt-down. From a biophysical perspective, increasing the amount or speed of money circulation as well as extracting more energy from whatever source is available will only compound the problems and relying on growth as the solution to what ails the global economy is not a desirable nor a tenable solution.

1. Introduction

The G-20 Toronto Summit for International Economic Cooperation, June 2010, resulted in 48 resolutions on international economic cooperation. The second resolution was as follows:

> Building on our achievements in addressing the global economic crisis, we have agreed on the next steps we should take to ensure a *full return to growth* with quality jobs, to reform and strengthen financial systems, and to *create strong, sustainable and balanced global growth* (our emphasis added).

In the 27 pages of resolutions and annexes in support of those resolutions, the term "growth" was used 67 times and the terms "sustain", "sustainable", "sustainability" most often coupled to growth were used 43 times. Even more telling, the terms "resource(s)" while used 17 times never once mentioned natural resources (only referring to financial resources), and the term "energy" was never mentioned at all. Of course we appreciate their effort on behalf of the people of the world as they try to "fix" the world economy. Yet, we are concerned that relying on the same old economic rhetoric and stimulus packages will not fix the problems, but could at this juncture create even more problems. In light of the current global situation new perspectives on developing sound economic policy based on a biophysical approach are urgently needed as suggested in the following paragraphs. A radical change in economic framework, one that is capable of quantifying direct and indirect unpaid contributions of nature to human economies, cannot be avoided. Economies rely on resources and services provided for free by the past and present work of the biosphere. Since such resources are not unlimited and since we cannot change the rate at which they are provided, economies are constrained in quantity and time and cannot grow without limit on a limited planet. Acknowledging the nature of these limits, and adjusting our expectations to them is a mandatory prerequisite for sound economic policy.

2. Emergy synthesis perspective

In this paper we provide data in an accounting system, named *emergy synthesis* (Odum, 1988, 1996; Brown and Ulgiati, 2004; Ulgiati et al., 2010) that incorporates both the monetary economy and the biophysical economy of the biosphere. We use emergy; however, other biophysical accounting systems would likely lead to similar conclusions about the environmental limits to growth.

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Emergy incorporates the environment by accounting for the work done by nature to generate resources (natural capital) and provide ecosystem services. It expresses all resources on a common basis, in solar equivalents (abbreviated seJ, for solar emergy Joules), which makes the work of environmental systems and human systems comparable and analytical insights more comprehensive. It recognizes that the economic system is a subsystem of the larger geobiosphere system that supports and at the same time constrains it by providing flows of energy and material resources that often have no markets and cannot be valued using willingness-to-pay.

The emergy approach has been criticized for being too complex, at times too general, at times uncertain, or not sufficiently developed, as was well elucidated by Hau and Bakshi (2004) who also listed other well known methods that shared similar weaknesses. In addition, Hau and Bakshi provided a well documented list of the strengths and promises of the emergy methodology and suggestions for improvement.

We feel however, we cannot wait until this method is "perfect" in the eyes of its critics to express our concern about the current monetary measures that are suggested as ways to boost growth again. Our analysis of global resources and economies includes measurements and metrics that other approaches do not. For this reason, it sheds light on directions for sound economic policy in light of the current crisis and provides alternatives to the business-as-usual paradigm. The readers interested in further details of the emergy method can refer to the above cited emergy literature as well as to papers previously published in this Journal (Ulgiati and Brown, 1998, 2004; Brown and Ulgiati, 2010).

Since the first papers by HT Odum (1971, 1973, 1986, 1988, among others) using net energy concepts and systems thinking to explore alternatives to neoclassical economics and related monetary accounting systems, the mainstream disciplines of economics and ecology have dismissed it under various critiques that rely on minor deficiencies disregarding the big picture or as Odum used to say, relying on the microscope instead of the macroscope. More important in this pioneering perspective is what Odum often pointed out. . . the fact that mainstream economics did not recognize nor understand the limitations (and opportunities) imposed by ecological realities on human economies (Odum, 1973). He was not the only one, consider the writings of Schumacher (1973), Daly (1991) and Georgescu-Roegen (1971). What each of these thinkers were, in essence, contributing was not a fix to the existing market theories and monetary accounting methods, but instead a complete overhaul of economic theory that recognized and incorporated biophysical realities (i.e., what is now referred to by some as the "ecological economics" framework). Our experience in the academic and scientific arena was that even ecologically concerned economists have been somewhat reluctant to accept biophysical complements to monetary accounts or alternatives to willingness-to-pay valuing systems. We are afraid that the mindset that results from this reliance on monetary theory is just like those attending the G-20 Toronto Summit, namely that growth is always possible. While instead, focusing on ecological constraints and biophysical accounting of resources suggests that unlimited growth on a finite planet, endowed with finite resources is impossible and looking for unlimited growth is the expressway to disaster.

3. Biophysical economy

The biophysical economic system is composed of flows of matter, energy, and information with counter-current flows of money as shown in Fig. 1. The most striking difference between this depiction of the economy and standard text book diagrams of economic system is the driving energies and the environment that, in general, are completely ignored when one only looks at the economy as a circulation of money and goods and services between producers and consumers. From a *biophysical* point of view, energy and other resources drive the circulation of money and no circulation of money is possible independent of resources. Thus in Fig. 1 the circular economy is shown being driven by *flow-limited* renewable sources and *limited* storages of matter and fossil fuels.

Theories of the operation of the monetary economy hinge on the concepts of market, free agents who have preferences and are informed, and the concept of maximization of utility (consumers) and maximization of profits (producers). Often called *neoclassical economics*, the theories and concepts that explain the functioning of the monetary economy are concerned with prices and the "allocation of scarce resources among competing ends". Within the confines of the monetary economy (i.e., the right hand side of Fig. 1) these concepts and theories of how and why it works are accepted by many but also challenged by an increasing number of serious skeptics (see for instance Cleveland, 1991; Dominique, 2001; Hall et al., 2001; Aldolphson, 2004; Hall and Klitgaard, 2006; Gowdy, 2007; Nadeau, 2008a,b; Simms et al., 2010). Whether neoclassical economics is right or wrong about markets and human behavior, or whether it is incomplete or lacks good scientific underpinnings is not the issue; the fact of the matter is that it tries only to explain a portion of the overall economy. . . that portion that is dominated by human markets, and that it is independent of the other portions where resources are generated and cycled.

Neoclassical economics supports the vision that the complexities of the world's market economies with their global integration and such things as collateralized debt obligations, derivatives, and so forth are not subject to thermodynamic limitations; and that the quantity of money can be increased indefinitely through the use of these economic instruments with little or no attention to biophysical realities. Yet it is quite evident from present actions of governments throughout the world who are displacing millions of people, degrading environments, waging wars and creating "economic instruments" all for the continued control of countries and their resources, that the entire circulation of money and all the exotic human monetary inventions and ways of making more money, are ultimately driven by the very fundamental energetic principle that work cannot happen without an expenditure of energy. This energy comes in several forms, the non-renewable chemical energy of fuels and other mineral resources and the renewable energies of the geobiosphere.

4. Evaluating the biophysical economy

The biophysical economy is composed of emergy flows (quantitative evaluation of resource flows in solar equivalents) that are accompanied by monetary flows. Fig. 2 is a simplified diagram showing the total emergy and money circulation in the global biophysical economy in 2008, and data are given in Table 1. The left side of the diagram shows the environmental systems that provide life support and the biogeologic processes that produce storages of non-renewables and slow-renewables. Currently the renewable and slow-renewable environmental portion of the global economy accounts for about 16% (respectively, 15.2 E24 seJ/yr and 1.3 E24 seJ/yr) of the total emergy budget of the planet (105.3 E24 seJ/yr), with human released non-renewable resources accounting for about 84% (88.8 E24 seJ/yr). Without continuous inflows of emergy in the form of matter, fossil fuels, and renewable energy, the monetary economy would come to a standstill.

While renewable emergy inflow to the planet has remained constant over the years, its share of the total emergy driving the geobiosphere has decreased markedly as a percent of the total (Fig. 3). In 1900 the renewable emergy base of the world's economy was about 97% of the total use. By 1925 the renewable base

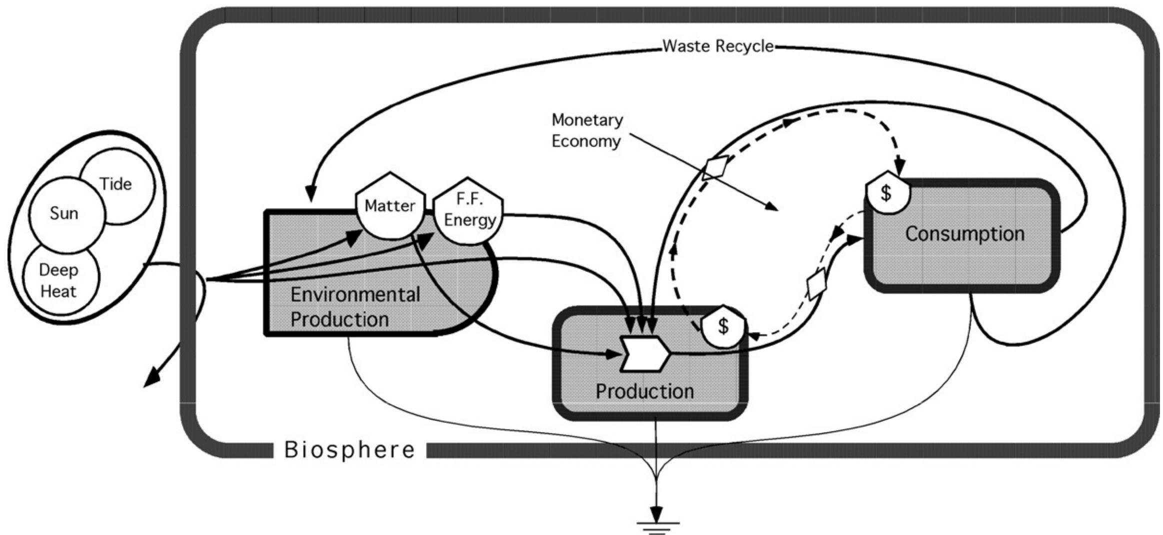

Fig. 1. The biophysical economy. Economic production (center) is a function of renewable energy, materials and non-renewable energy from environmental production and an input of labor (information). The monetary economy represents about 86% of the total emergy budget of the Earth.

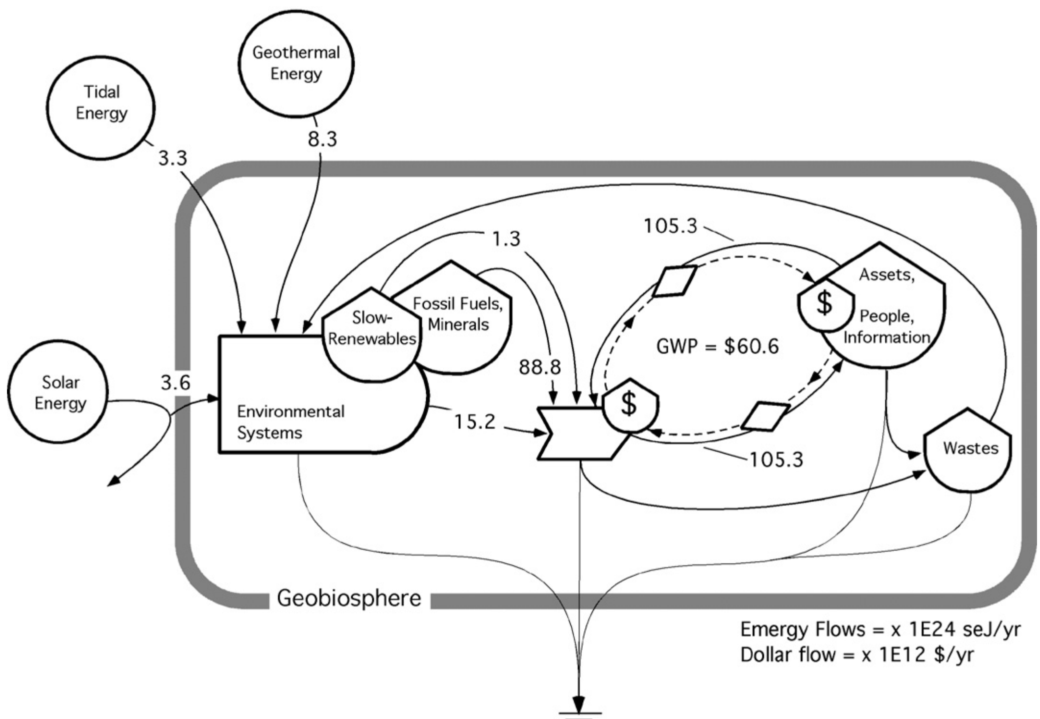

Fig. 2. The global economy. The monetary economy (measured by the Gross World Product [GWP]) is driven by the environmental renewable, slow-renewable and non-renewable emergy. In 2008, total emergy flow supporting the monetary economy was 105.3 E24 seJ/yr and the GWP was $60.6 trillion.

had decreased to 87% of total use, and in 1950 it had comprised 48% of total use. Since mid century, the emergy in non-renewable and slow-renewable sources released by humans has increased so that in 2008 non-renewable emergy use equaled 84% of total use while the renewable and slow-renewable portion of the global biophysical economy equaled only 16%. Bear in mind, that the biosphere's renewable emergy has not shrunk, it has remained constant, the trend shown in Fig. 3 is the result of the overwhelming increase in the use of non-renewable emergy within the human economy.

The monetary economy has increased in size since the industrial revolution and in the last 50 years has come to dominate the biophysical economy. The graph in Fig. 4 shows the change in global emergy and Gross World Product[1] (GWP) since 1900. In the early part of the 20th century non-renewable emergy released by humans was small compared to the renewable flows of the geobiosphere (the horizontal line representing 15.2 E24 seJ/yr). The "great depression" beginning in 1929 slowed the growth of non-renewable consumption for a few years, but World War II quickly made up for the slump. From the end of the war until about 1950

[1] Gross world product (GWP) is the aggregate value of all final goods and services produced worldwide in a given year. It equals the sum of the gross domestic products of all the countries of the world.

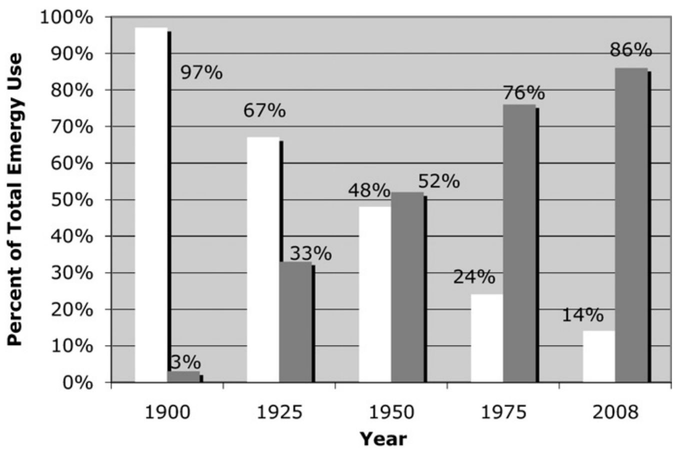

Fig. 3. Changing percentages of total emergy use from renewable and non-renewable sources beginning in 1900 (white bars also include slow-renewable sources, see Figure 2). While 97% of global production was based on renewable emergy flows in 1900, today only about 16% of total emergy use is from renewable emergy sources.

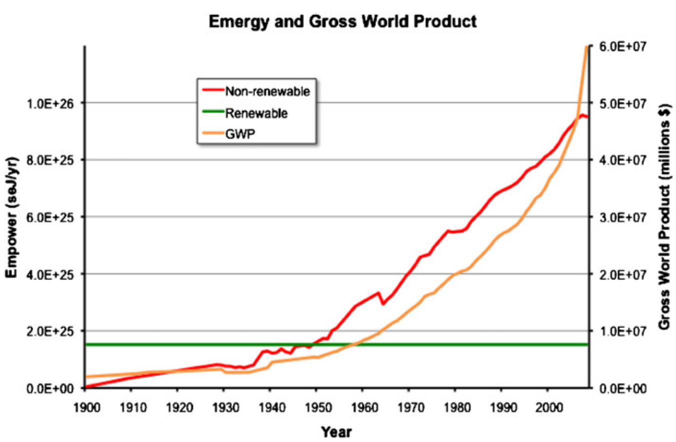

Fig. 4. The growth of global nonrenewable emergy use (red line) and Gross World Product (GWP) (gold line) since 1900. The renewable input to the Earth is constant (green line). GWP data are from Maddison (2006). Historical energy use obtained from BP (2010), historical metals production from USGS (2010a). Metals data were to 1932, prior data generated as a constant percent increase from 1900 estimates. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

increases in non-renewable use rose at about 1% per year, but beginning in about 1952 until very recently the increase in use averaged about 3.7% per year thus the doubling time was about 19 years. Beginning in 2003 the growth in consumption decreased to about 2% and in 2008, consumption of non-renewables actually decreased by nearly 1.5% as a result of contraction in the world economy.

GWP rose at the same rate as global emergy use until the 1950s where it lagged a bit behind emergy use. From the mid 1980s until the mid'1990s growth of GWP was roughly the same as increases in emergy use, about 3.5%. In the first nine years of the 21st century, however, GWP has increased faster than global emergy use, at an average rate of about 4.3%.[2] Since the emergy and monetary economies are linked, increases in money supply that are not accompanied by real increases in the supply of emergy result in

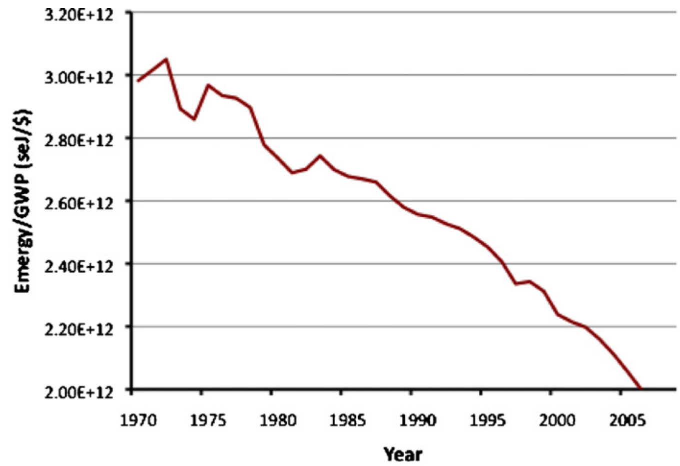

Fig. 5. The change in Emergy per dollar value of GWP since 1970. The 'value' of a global dollar decreased from about 3 E12 seJ/$ in 1970 to about 2.0 E12 seJ/$ in 2006, or a decline of about 33%.

inflation. Thus the difference between the rates of increase of emergy use and GWP represent inflation and since emergy use was increasing at an average rate of about 2.1% during 2000–2007 and GWP was increasing at 4.3%, the difference of 2.2% represents inflation.

The continued increase in GWP in spite of the abrupt change and apparent decline in world use of non-renewable emergy in 2008 is an important sign of what we believe is driving the current world economic crises and should be cause for serious concern on the part of world leaders. Should non-renewable energy and resource consumption remain level or decline and world economic leaders continue to increase money supplies, under the false notion that priming the economic pump will restart global economic growth, the result will be large scale global inflation. It remains to be seen if inputs of non-renewable energy and resources can be increased to match growth expectations of global economies. Overall, the economic policy needed is to match money supplies to resource availability. . . if resources increase the money supply can be increased, if they decline, the money supply should be decreased. In this way we can avoid the inflation that results when money supplies increase faster than resource inputs and more money chases scarce resources.

5. Global Inflation

Fig. 5 is a graph of the ratio of global emergy use and GWP (expressed as dollars) from 1970 to 2008 showing the general decline in the emergy/GWP ratio.[3] The decline is the result of increases in the global money supply without a corresponding increase in the world emergy supply. In essence it is inflation, however since the emergy supply has been increasing, the reason for the inflation is that the countries of the world are increasing the money supply faster than the increase in the available emergy. Countries do this by creating "artificial money" using such methods as deficit spending, revolving lines of credit, or just printing money to boost money circulation.

One conventional way of trying to control the economy when there is a slow down is to increase the money supply in order to increase demand (Fig. 2), which will theoretically increase the

[2] Aggregating the 144 economies of the world into one world economy hides the fact that some economies were not growing in the first part of the 21st century (much of Europe) while others were actually growing at rates equal to or greater than 10% (India and China). This fact does not deny the validity of our concerns since most of the growth these countries experienced was in support of the high standard of well-being of the west (displaced western growth).

[3] The emergy/GWP ratio was calculated for USA and several other countries by Odum (1996) discussing the link between resource availability and inflation. Pillet (1993, 2004, 2006) explored the inter-relationships of emergy and the economy with reference to trade, shadow pricing and externalities.

inflow of resources and energy that drive the system. In the past when resources and energy (i.e., the global emergy resources) were plentiful, this strategy worked (i.e., the great depression, and several recessions since then), however it failed in the early 1970s following the oil crisis when the OPEC nations restricted oil production. In that case, the increase in money supply without a corresponding increase in energy resulted in double-digit inflation in many countries and what was termed "stag-flation" by many economists in the USA. Having never occurred before, stagnant economic growth with high inflation can be easily explained from an energetic point of view (i.e., no increase in emergy driving the economy while money supply increased significantly), which baffled many economists as the increases in the money supply did not work to jump-start the economy as it had in the past.

If emergy supplies are indeed limited and overall availability is remaining relatively constant or declining,[4] then attempts by national governments to grow by "stimulating" the economy with increases in the money supply, will only result in a reoccurrence of the stag-flation of the early 1970s. It may be time to realize the resource constraints on economic growth and begin now to reorient economic theory to more fully recognize biophysical realities.

6. Resources are wealth

The wealth of a nation, as was well recognized in the past by Adam Smith and others, is its resource base. In the distant past when populations were small and the extent of human use of the environment was negligible compared to the size of the environment, wealth consisted of a nation's forests, soils, fisheries and the water and sunlight falling on its landscape. As the fossil fuels increased in amount and came to dominate the energetic base of economies, they allowed the exploitation of mineral resources, which synergistically increased the use of the fossil fuels and in the long run diminished the importance of renewable resources. They were replaced by the energy intense use of non-renewables and in the words of Odum (1971) reflecting on the agricultural green revolution... our "potatoes are partly made of oil".

The wealthy nations have been, are, and likely will be, those that have the power and the ability to secure through various means and political influence, raw resources to drive their economies. History is full of examples beginning with the Roman Empire and continuing through the present, where lands were invaded for resources and strategic minerals (although other non-military wars, most often much more effective, keep being fought to control markets, investments and banking systems; Galeano, 1997). Continuing today, the invasion of Iraq and the continued occupation there and in Afghanistan was driven by the rich resources that each country possesses. We believe that strategic planners recognized the importance of resources yet it seems to go unnoticed by economic planners.

Since money and energy/resource flow in opposite directions (Fig. 1), the use of monetary flows to make public policy and decisions regarding the future of a country is in reality looking at the world backwards. Frequently, sound economic advice in resource rich nations recommends the selling of raw resources and the importation of finished products. Yet under such even monetary trades, the resource exporting country always looses, sending out far more wealth than they receive in finished products (Brown et al., 2009; Ulgiati and Cialani, 2005). Continuing uneven emergy trades at the expense of the developing countries of the world is a recipe for global instability because it keeps the majority of the world's

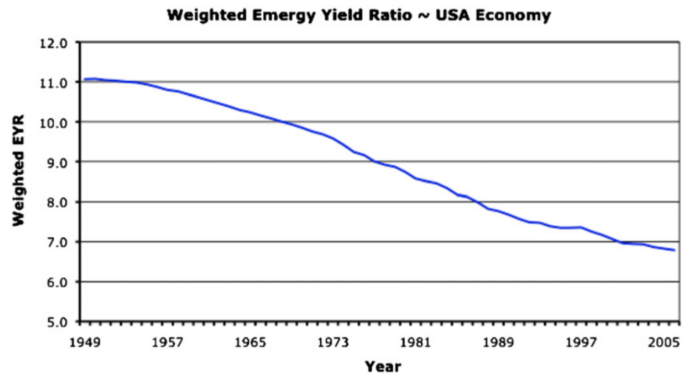

Fig. 6. The change in the combined emergy yield ratio of non-renewable energy sources to the USA economy from 1949 to 2006. Assumptions to create the graph are as follows: emergy yield ratio of coal began at 18/1 and declined at a rate of 3.8% per year to end in 2006 at 7.8/1. The emergy yield ratio of natural gas began at 9/1 and declined at a rate of 5.1% per year to end in 2006 at 6.1/1. The emergy yield ratio of petroleum began at 18/1 and declined at a rate of 11% per year ending in 2006 at 7.73/1. The emergy yield ratio of nuclear has remained constant at 4.6/1. Hydroelectric emergy yield ratio has remained constant at 10/1. The emergy yield ratio for geothermal began in 1960 with a net emergy of 2.66/1 and increased at a rate of 6% per year. Solar PV systems began showing input to the US economy in 1990 with a emergy yield ratio of 1.0 and have increased by 3.0% per year since then up to about 2/1. Wind energy began inputs to the US economy in 1999 with a emergy yield ratio of 8.0/1 and increased at a rate of 8.0% per year from that time, ending in 2006 at 8.6/1. The emergy yield ratio of biomass in 1949 was estimated as 2.0/1 and has increased at a rate of 3.2% per year to end at 3.82/1 in 2006.

population in poverty while the west tries to live an unsustainable lifestyle.

6.1. Net emergy is important

Resource throughput is central to the welfare of human economies yet this is only true if the effort to get the resources is small compared to the return. The concept of net emergy (equal to emergy of resources delivered by a process minus the emergy of resources invested) is central to understanding what can and what cannot be done with resources in relation to human development and sustainability. The ecological concept of "net production" is widely used as a measure of overall development potential in ecological systems. Key to identifying when growth diminishes and eventually stops is when energy costs of sustaining system processes increases and eventually equals productive outputs. The same concepts apply to human dominated systems; when the resource costs of sustaining inflows of new resources (of any kind, not only energy) exceed the return from these new resources, growth stops. Societal infrastructure was built by and its metabolism is still driven by a high net yielding resource base that is unlikely to be available in the future.

A typical case is the oil and minerals that drive our economies. In the past decades their net contributions were large reflecting the fact that they represented millions of years of concentration of biosphere energy. As the easiest and most abundant resources have been exploited, the net yields are declining. Fig. 6 shows the decline in the average Emergy Yield Ratio [EYR = (emergy exploited + emergy invested)/emergy invested] of the USA energy sources since the mid-1900s. As the EYRs from these resources continue to decline, their net emergy yields, i.e., the resources actually exploitable, also decline (consider the costs of the recent BP oil disaster in the Gulf of Mexico and other similar events as further erosion of the net yield of oil) so that growth must slow and eventually stop. Trying to grow the economy when the driving energies are declining (in availability) will result in inflation equal to or worse than the inflation of the 1970s during and following the oil embargo.

[4] Growth of fossil fuel consumption tapered off beginning in about 2000 and declined in the later part of the decade (BP, 2010).

Table 1
Emergy inputs to the geobiosphere including human released resources (2008).

Note	Inflow	Units	Quantity	UEV (seJ/unit)	Empower (E24 seJ/yr)
Renewable inputs					
1	Solar energy absorbed	J/yr	3.59E+24	1	3.6
2	Crustal heat sources	J/yr	1.63E+20	20,300	3.3
3	Tidal energy absorbed	J/yr	1.15E+20	72,400	8.3
			Subtotal renewables		15.2
Slowly renewable inputs					
4	Soils	J/yr	2.05E+19	1.21E+04	0.2
5	Forest biomass	J/yr	7.50E+18	3.80E+04	0.3
6	Peat	J/yr	5.40E+17	5.70E+04	–
7	Fisheries	J/yr	9.36E+16	8.40E+06	0.8
			Subtotal slowly renewables		1.3
Non-renewable inputs					
8	Coal	J/yr	1.39E+20	9.09E+04	12.6
9	Petroleum	J/yr	1.98E+20	1.48E+05	29.3
10	Natural Gas	J/yr	1.17E+20	1.71E+05	19.9
11	Nuclear energy	J/yr	9.72E+18	5.40E+05	5.2
12	Calcium Carbonate	g/yr	1.28E+14	1.30E+10	1.7
13	Phosphate	g/yr	1.58E+14	1.28E+10	2.0
14	Selected Metals	g/yr	1.13E+15	1.59E+10	18.1
			Subtotal non-renewables		88.8
			Grand total		105.3

Notes to EIA, 2010a,b,c; Brown et al., 2010; IPCC, 2010; Sweeney et al., 2008; FAO, 2010; Munk and Wunsch, 1998; Quinton et al., 2010; *Table 1*:

1. Transformity is 1.0 by definition; exergy flow: 3.59 E24 J/yr
2. Transformity is median value from emergy equation for crustal heat solved using equations 1 and 2; median value for exergy release by radioactivity and deep heat from the Monte Carlo simulation was 5.1 TW (1.63 E20 J/yr). The heat generated by crustal sources is not added here to avoid double counting.
3. Transformity is median value from Monte Carlo simulation of the emergy equation for geopotential of oceans. Energy flow 1.17 E20 J/yr (Munk and Wunsch, 1998)

4 Soil loss

Global erosion rate			(Quinton et al., 2010)
Water =	g/yr	2.80E+16	
Tillage =	g/yr	5.00E+15	
Wind =	g/yr	2.00E+15	
Total energy (J) =	(mass)*(1.4%C)*(10Cal/g)*(4187 J/Cal)		
=		2.05E+19	
Transformity=	1.21 E4 (Global average)		(Brown and Ulgiati, unpbl)

5 Forest biomass

Total loss forest land			(FAO, 2009)
Africa	ha/yr	802000	
Asia & pacific	ha/yr	680000	
Central America	ha/yr	57000	
South America	ha/yr	860000	
North America	ha/yr	20200	
Standing biomass			(IPPC, 2010)
Africa	MT/ha	120	
Asia & Pacific	MT/ha	200	
Central America	MT/ha	200	
South America	MT/ha	200	
North America	MT/ha	40	
Total energy (J) =	(Area)*(mass of wood)*(1e6g/MT)*(1.8 E4 J/g)		
=	(Area)*(1e6g/MT		
Africa =	1.73E+18		
Asia & pacific =	2.45E+18		
Central America =	2.05E+17		
South America =	3.10E+18		
North America =	1.45E+16		
Total =	7.50E+18		
Transformity =	3.80E+04 seJ/J		(Sweeney et al, 2008)

6 Peat

Total "mined" peat =	MT/yr	2.50E+07	(2008)	(USGS, 2010)
Energy (J) =	(mass)*(1E6 g/MT)(2.16E4 J/g)			
=	5.4E+17			
Transformity =	1.21E+05			(Sweeney et al, 2008)

Notes to Table 1:

7	Fisheries				
	Total harvest =	MT/yr	3.60E+07	(2008)	(FAO, 2010)
	Energy/g =	0.62Cal/g wet weight = 2.6E3 J/g			
	Energy (J) =	(mass)*(1E6g/MT)(2.6E3 J/g)			
	=	9.36E+16			
	Transformity =	8.40E+06			(Sweeney et al, 2008)
8	Coal				
	Global coal consumption	kg/yr	6.60E+12	(2008)	(EIA, 2010a)
	Energy (J) =	(mass kg/yr)*(21 MJ/kg)			
	=	(6.06E12 kg/yr)*(21 MJ/kg)			
	=	1.39E+20			
	Transformity =	9.1E+04	(Global average assuming 80% hard and 20% soft coal)		(Brown et al 2010)
9	Petroleum			(2008)	
	Global oil consumption	bbl/yr	3.10E+10		(EIA, 2010b)
	Energy (J) =	(bbl/yr)*(6.38E9 J/bbl)			
	=	(3.1E10 bbl/yr)*(6.38 E9 J/bbl)			
	=	1.98E+20			
	Transformity =	1.48E+05	(Global average)		(Brown et al 2010)
10	Natural Gas			(2008)	
	Global NG consumption	cu.ft/yr	1.10E+14		(EIA, 2010c)
	Energy (J) =	(Cu.ft/yr)*(1.06 E6 J/cu.ft)			
	=	(1.10E14 Cu.ft/yr)*(1.06 E6 J/cu.ft)			
	=	1.17E+20			
	Transformity =	1.71E+05	(Global average)		(Brown et al 2010)
11	Nuclear energy				
	Global nuclear production	kwh	2.70E+12	(2009)	(BP, 2010)
	Energy (J) =	(kwh)*(3.6E6 J/kwh)			
	=	(7.69 E11 kwh/yr)*(3.6 E6 J/kwh)			
	=	9.72E+18			
	Transformity =	5.4 E5 seJ/J(Global average for electricity)			(Odum, 1996)
12	Calcium Carbonate				
	Global production =	MT/yr	1.28 E8	(2005)	(USGSb, 2010)
	Quantity (g) =	1.28E+14			
	Specific Emergy =	1.30E+10			(Sweeney et al, 2008)
13	Phosphate				
	Global production =	MT/yr	1.58E+08		
	Quantity (g) =	1.58E+14			
	Specific Emergy =	1.28E+10			
14	Selected metals (Al, Cu, Fe, Pb, Zn)				(USGSb, 2010)
	Global production:			(2008)	
	Al =	MT/yr	3.69E+04		
	Cu =	MT/yr	1.58E+07		
	Fe =	MT/yr	1.10E+09		
	Pb =	MT/yr	3.90E+06		
	Zn =	MT/yr	1.10E+07		
	Total metal prod. =	g/yr	1.13E+15		
	Specific Emergy:				(Sweeney et al, 2008)
	Al =	seJ/g	5.73E+09		
	Cu =	seJ/g	1.02E+11		
	Fe =	seJ/g	1.24E+10		
	Pb =	seJ/g	4.97E+11		
	Zn =	seJ/g	7.46E+10		
	Total Emergy =	(mass of each metal)*(specific emergy each metal)			
	=	seJ/yr	1.81E+25		
	Weighted transformity =	seJ/J	1.59E+10	(Brown & Ulgiati, unpbl)	

6.2. False promise of renewables

While there is much talk of "peak oil" lately, there is little analysis and review of the declining net yields from fossil fuel energy sources that drive our economy. As these limits are felt throughout modern economies, society looks to alternative sources; wind, waves, tides, solar, biomass, bio-ethanol, etc. Renewable energy sources, up to now, have lower net yields than fossil fuels and thus provide false promises to those who are looking for business as usual at the end of cheap oil. It is imperative that the net contributions of proposed new energy sources be evaluated and all costs included. Many of the so-called renewable energy sources are actually consumers of fossil fuels. Take for instance the proposed bioethanol and biodiesel programs, where evaluations over the last decade continue to show net emergy yields of less than 2 to 1 (see for example: Giampietro et al., 1997; Ulgiati, 2001; Rajvanshi, 2010; among others) and confirm similar evaluations of energy return on investment (EROI) (Pimentel and Patzek, 2005; Heinberg, 2009).

The graph in Fig. 6 is a weighted average of EYRs of the different energy sources in the USA, but it is confirmed by studies worldwide. Biofuels EYRs typically are less than 2 to 1 (Ulgiati, 2001) and the same applies to silicon photovoltaics.[5] Other more traditional renewable energies show higher EYRs, for instance hydropower, geothermal and wind range up to 5 or 6 to 1 in other cases investigated (Brown and Ulgiati, 2002). The problem is that their large-scale implementation is offset by several constraints, the most significant of which is the fact that areas suitable for dams and wind farms are limited. The hydropower industry suggests that the maximum potential hydropower development worldwide will increase total hydroelectricity production only threefold (IHA, 2000). The most optimistic projections for wind electricity suggest it will produce only 6.6% of total electric demand by 2050 (WWEA, 2009).

The International Energy Agency's most optimistic projections for the year 2050 (IEA, 2003; so-called Sustainable Development Vision) foresee a doubling of total energy consumption, of which fossil fuels comprise 54.1%, nuclear 11%, biomass 15.7% and other renewables including hydropower 18.9%. These correspond to growth rates of 480% for nuclear energy, roughly 150% percent increase in biomass use, and 370% growth of other renewables. There is a corresponding 34% decrease in fossil fuel use. The next IEA (2008) baseline scenario confirms the more than doubling of energy consumption, in support of the "expected growth in global economic activity in the next forty years". According to that scenario, not taking action would mean that coal would become the dominating fuel (37% of total primary energy use in 2050) and that the global 2050 CO_2 emissions would reach 62 Gt compared to about 14 Gt released in 2005. Oil share would decline from 35% in 2005 to 27%, natural gas from 21% to 20%, nuclear from 6% in 2005 to 4%, and other renewables would decline from 11% to 10%, with hydro remaining constant at 2%. Innovative scenarios (ACT and BLUE) are suggested by IEA, with decreased reliance on fossil fuels (45–59% less than in baseline, although with 34% more natural gas) and increased reliance on nuclear (more than 100% increase, up to about 12% again as in IEA, 2003 scenario) and biomass (about 300% more than in 2005) and other renewables (also more than 300% of 2005). IEA (2008) also estimates that the additional investments needed in the energy sector would be about 2005 USD 17 trillion between now and 2050, ". . . on average around 400 billion per year, roughly equivalent to the gross domestic product (GDP) of the Netherlands, or 0.4% of global GDP each year between now and 2050".

The scenario by the IEA (2003) was produced borrowing from a scenario at the International Institute of Applied Systems Analysis (IIASA) for the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2000). It assumed growth as essential and that it is possible to achieve simultaneously. . .energy security, climate mitigation, and energy access with appropriate policy interventions. The IEA (2008) scenario confirmed the same basic assumptions. The major question here that begs to be answered is how can these impressive increases in the growth of nuclear, biomass, and renewables by sustained on declining net emergy of fossil fuels and the low net yields of the renewables themselves. In addition, there is increasing concern and in some cases, out right rejection by populations regarding nuclear, large hydro-dams, large wind fields and the use of arable and forest land for biofuel production. While some may question these concerns, they are likely to have an effect on future energy policy, by slowing development or requiring additional expenditures of energy to offset environmental problems, thus lowering even further their net yield.

Overall, the entire installed power of renewable electric production systems is so small that it is hard to imagine the huge increases that are needed to meet the IEA's Sustainable Development Vision. Put in numbers, the current and projected contributions of wind, tidal, wave, geothermal and biomass energy are as follows:

(1) Installed wind power is 0.16 TW worldwide translating into a total wind electricity production of 0.03% of world-wide energy consumption (WWEA, 2009)
(2) Total installed tidal power is 0.3 GW which translates into less than 0.002% of world energy use and the best estimates for future energy production are only 0.2% (a 100 fold increase) of current world energy use (Jones and Finley, 2003).
(3) McCormick et al. (2009) estimate that a total wave power of .5 TW can be exploited with the existing technology, which, assuming a 37.5% capacity factor equals about 1.25% of current world demand for energy. However, at present there are no commercial wave power plants operating worldwide.
(4) Present installed geothermal electricity production is 10.7 GW or 0.05% of world energy demand (Bertani, 2003; GEA, 2010;) assuming a capacity factor of 75%. The potential geothermal production has been estimated between 2.3% and 13% of current world demand for energy.
(5) Karekezi et al. (2004) estimate that global biomass use in 2001 was 14% of total global energy use. This figure includes traditional fuel wood, electricity from wood and municipal waste combustion, and other miscellaneous uses. Their estimates for the future use of biomass decrease to 11% in 2020 due to increased recycling and increases in total energy uses.

In summary, the false promise of renewables actually has two related parts. The first part is whether there is sufficient net yield from renewables to drive growth or even a steady state economy without fossil fuels. The second is whether there is enough renewable energy on the planet to drive our complex techno-industrial society. We have shown that most renewables have very low emergy yield ratios (Brown and Ulgiati, 2004), that those that have higher yields are limited by the availability of potential sites and by the quantity of energy that might be generated, and finally that growth always generates non-negligible environmental impacts. Thus, in reality, the concept of "sustainable growth" on renewable energy sources is a false promise that if pursued, can only add to the economic and environmental catastrophes that are beginning to appear.

6.3. Beyond quantity

As long as the dominant economic paradigm is neoclassical economics, then the only course for human civilization is to grow its economy, to grow its population, to grow its consumption, as growth is the first, second, and third commandments of the current economic paradigm that insists that human well being and

[5] The energy-based EROI of photovoltaics was calculated in the range 3–10 with potential for improvement (Fthenakis et al., 2009; Heinberg, 2009), while EYR of photovoltaic is still close to 2:1. A low EYR does not deny that more energy can be obtained from PV modules than was invested in technology, but instead focuses on the global investment of resources (emergy: water, minerals, fuels, environmental services, land, labor & information) that are also needed to reach the result and points out that such investment is not negligible. These resources are supplied by the society and must be accounted for as unavoidable investment costs, diverted from other potential processes.

happiness is linked to increasing income. No amount of tinkering with neoclassical economics can change it into a paradigm that can do without growth. We need an economic paradigm shift, a new paradigm that can accept as a major tenant that continued growth is undesirable and untenable.

Having been taught that "more is beautiful" and "quantitative growth is good", we are hardly able to conceive other values (community values, clean and healthy environment, democracy, shared goods, community care of the young and the elderly, satisfactory relations, and tasty food). The future can still be about growth, but according to other parameters and different measures of wealth. Such changes must be accompanied by appropriate policies that recognize new values as the basis for qualitative, not quantitative growth. We cannot achieve sustainability without redefining and redirecting human wants in ways that are less consuming of natural resources. Since not all wants are needs, it may even happen that in the transition some wants are not fulfilled.

As surprising as it may be, we do not have a word to specifically refer to qualitative growth. As a consequence, the previously proposed terms always bear some "negative" meaning as *de-growth* or *way-down* or *down-sizing*. We also need a semantic revolution to become aware that words are not neutral and have a built-in judgment of value according to the dominating paradigm. An effort is needed to find not only a new thermodynamics and a new economics of sustainability, but also a *sustainability discourse*, i.e., a new mode of organizing knowledge, ideas, experience and language around shared values based on qualitative growth.

6.4. Sustainability and equity

Finally, we have shown that from perhaps this point forward quantitative growth has become impossible or only possible for a small fraction of human kind, while on the other hand qualitative growth is in principle achievable by all and its fulfillment by some is not an obstacle to others. However, in the transition from a quantity to a quality-based growth, we will also have to address the question of how to adjust the current consumptive way of life to make things more egalitarian between the haves and have-nots. Qualitative growth does not fully address this disparity. How do we address it in a way that is sustainable? We need a sustainability discourse that questions the current supply side economic notion that by growing, affluent societies help the poor... i.e., if we get richer, there will be more leftovers for the poor... the trickle down theory of welfare economics.

In a world where economic growth is becoming more and more difficult to achieve, we should recognize that when some economies grow, others are impoverished. While still growing, some national economies keep consuming natural capital and ecosystem services. The growth of population, GDP, number of cars and roads, built environment, food production, number of cell phones, etc., worldwide involves increased extraction and burning of fossil fuels, increased mining, increased soil erosion, increased movement of sediments from land to oceans, increased deforestation, fishing, air and water pollution, decreased biodiversity,..., increased number of environmental refugees, increased political instability worldwide, and finally decreased democracy and respect of human rights in those countries where resources are extracted for export to wealthy countries. How long can this last?

7. Conclusion: growth is not the answer

We worry that the dominant economic paradigm, so fixed in the minds of world population, will result in a politics of "growth at any cost" which can easily translate into further escalations of world tensions. The prevailing world-view of many in the west seems to be that the only way to deal with the current global economic and environmental problems is to intensify the patterns of production and consumption that have produced them. Are we destined to blindly follow the path of many post-hunter–gather societies that experienced a period of rapid increase in resource exploitation and population growth followed by an equally rapid economic and ecological collapse (Tainter, 1988; Diamond, 2005; Turchin, 2005)?

In placing the current economic crisis in a biophysical perspective, we suggest the problem is not just resource availability nor is it finding another energy source to replace fossil fuels. The problem is BUSINESS AS USUAL. Were we to find an alternative energy that provides unlimited, cheap energy, the environmental, social, and economic consequences might be even worse than the consequences of today's limited fossil fuels. Faced with the possibility of unlimited growth, and its coupled consequences, (more people, more pollution, further degradation of human and natural capital, increased exploitation of developing nations, etc.) one can only hope that we fail in our attempts to solve this current crisis so that our focus will turn to living within the planet's carrying capacity. Some suggest that this will happen, no matter what, and thus the real issue is if we want to be part of the solution or continue to be the problem.

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