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EMERGY TRACKING – SAFE TRANSITION FROM A WORLD OF EXPONENTIAL GROWTH TO ONE OF SUSTAINABILITY

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ABSTRACT

This article proposes introduction of an emergy (embodied energy) label to be associated with all technological items sold for more than $100 a piece on the market. This is different from today's energy labels. Whereas the energy labels in use today account for the energy efficiency in using an appliance, the emergy label accounts for the energy efficiency in producing it. The concept of emergy (or energy footprint) as a measure of total production energy is introduced, and a procedure for tracking emergy throughout the production chain of a technological item is proposed.

Keywords: emergy, emergy tracking, grey energy, sustainability

1. INTRODUCTION

150 years ago, at the beginning of the industrial revolution, precious minerals were lying around openly on the surface of this planet. Now we need to dig ever deeper to still discover new sources of minerals, and soon, they will mostly be gone. The planet is reaching its limits to growth, and we have no choice but to transition from a world (an economy) of exponential growth to one of sustainability (Meadows, Randers, and Meadows 2004).

This transition will take place irrespective of what we do. We cannot prevent it. It is the predicament of a species living on a finite planet. However, we may be able to shape the way in which this transition occurs, thereby reducing the pain and agony that invariably will accompany this transition to some degree (Martenson 2011).

We may be asking ourselves, how much energy each of us will have available after the transition. In Switzerland, people are frequently talking about a *2000 Watt Society* (Morrow Jr. and Smith-Morrow 2008). Why 2000 Watt? There are two ways to arrive at this number.

Method one adds up the total annual energy being consumed for whatever purpose by all humans living on this planet, divides that figure by the number of people currently alive, and divides the result by the number of seconds in a year. This results in an average per capita power consumption of 2000 Watt. So, this must be our fair share. We want to grant every human being on this planet the same quality of life, and consequently, highly developed countries, such as Switzerland, must reduce energy consumption so that other nations can increase theirs.

Method two starts with our current energy consumption of roughly 5500 Watt per person here in Switzerland (Swiss Federal Office of Energy 2013; Cellier 2009). It recognizes that, after Fukushima, Switzerland will most likely decide to get out of nuclear power. Furthermore, we all know that the total supply of fossil fuels is finite and consequently, fossil fuels cannot be supplied in a sustainable fashion. If we deduct from our current energy availability the portion that is being generated from nuclear power stations and from imported fossil fuels, the remaining available per capita power is roughly 2000 Watt.

Thus, both the idealists and the realists among us have every reason to buy into the concept of the 2000 Watt Society. Unfortunately, both calculations are deeply and utterly flawed. Let me explain.

What is wrong with method #1? First of all, not every person on this globe needs the same amount of energy. People living at a high latitude or high altitude require much more energy to heat their homes. Also, since the vegetation period is short, they need additional energy to store their food during the long and cold winters. People living on a tropical island can grow their food all year round for immediate consumption, and they don't truly require any energy to heat or cool their homes. Yet much more importantly, the method assumes that we shall always be able to generate the same amount of energy. This assumption is unfounded. If we invest heavily in renewable energy (solar, wind, geothermal), we may be able to generate much more energy locally than we currently do. Unfortunately, we are at the current time consuming world-wide more than 80% of our total energy mix by burning fossil fuels (British Petroleum 2013). When these fossil fuels are getting scarce, the sum of our overall produced energy will drop dramatically. All renewable energy sources combined will be unable to compensate for this drop.

What is wrong with method #2? We need to check how the current 5500 Watt per person have been calculated. The energy balance does not take into consideration any goods that we import or export. Thus, if I buy a car that has been produced in Japan, the energy that went into the production of that car is counted in the energy balance of Japan and not in the energy balance of Switzerland. Method #2 assumes that import/export patterns, with the exception of fossil fuels and nuclear fuel rods, will continue at the same level at which they are now. Yet, what if Japan can no longer produce my car, because the Japanese economy runs out of sufficient energy to do so as it undoubtedly will?

The shortcomings of method #2 are thus related to so-called "grey energy." Although everybody talks about grey energy, there are no solid figures available as to the amount of net grey energy that Switzerland imports. All we know is that it is substantial.

Method #1 does not suffer any inaccuracies due to grey energy not being calculated correctly. If I calculate the total energy generation/consumption planet-wide, there is no grey energy. All grey energy imported into Switzerland is real energy produced and accounted for elsewhere. If one nation is a net importer of grey energy, another nation must be a net exporter. Globally, the total grey energy adds up to zero.

We read frequently these days that China's energy consumption is growing at a phenomenal rate. This is only partly due to an increase in living standard of the Chinese people. A large percentage of the perceived increase in Chinese energy consumption has to do with the fact that China is producing lots of goods for export these days. They have become the largest net exporter of grey energy world-wide.

A country that does not produce anything and imports everything that its people need will look excellent in terms of its energy consumption statistics, and yet, those people may be the biggest energy wasters on the planet. If we wish to calculate fairly and adequately our fair share of energy consumption, we need to get a better estimate of the massive amounts of grey energy that we import and export.

As energy resources become scarce, the international trade both in terms of energy and goods will suffer. The net energy exporters will satisfy the needs of their own constituents first and export less energy, and the nations with large population densities and few energy resources of their own, such as Japan, which in today's world are among the biggest exporters of goods, will become energy starved. Thus, they will no longer be able to produce as many goods for export, but will rather use up the few energy resources that they can master to satisfy the needs of their own people (Brown 2007).

When food gets scarce, governments introduce food budgets. The same happens with energy. During the Second World War, Switzerland was able to feed each inhabitant 1800 calories per day (food rationing), and no buildings private or public were allowed to be heated to more than 16 degrees Centigrade (energy rationing). At that time, Switzerland counted half of its current population, seven times as many farmers, and double the current farm land (half of it has meanwhile been paved over).

Similar restrictions will be imposed again on a world-wide scale once the fossil fuels are depleted. The future looks bleak for countries with high population density and few energy and food resources of their own. The only countries that will fare a bit better are countries with low population density and large reserves of food and energy resources, such as Argentina and Australia. Switzerland currently imports roughly 80% of its energy and 60% of its food. In contrast, Argentina produces roughly five times as much food as the country requires to satisfy the needs of its own population. Argentina still has the capacity of being self-sufficient w.r.t. energy.

2. EMERGY

How much energy am I consuming while driving from home to work in my car? On the one hand, I might count the thermal energy contained in the fossil fuel that I burn. On the other hand, I might focus on the mechanical energy that I consume for propelling my car, a number that is certainly smaller than the former, because some of the thermal energy gets converted to heat (entropy production).

Energy is thus not equal to energy. This dilemma is well known. British Petroleum converts all forms of energy to *tons of oil equivalent (toe)* (British Petroleum 2013). For example, Switzerland gets "punished" with a conversion factor (efficiency factor) of 3 for producing electricity from hydroelectric and nuclear power rather than by burning fossil fuels. For this reason, the Swiss energy consumption statistics (Swiss Federal Office of Energy 2013) show lower consumption numbers than the BP statistics, because the Swiss Federal Office of Energy focuses on the electricity generated rather than converting the energy to toe first.

Howard T. Odum suggested in his seminal publication on *System Ecology* (1983) to convert all forms of energy to *solar equivalent Joules (sej)*, as the sun is the primary source of energy on this planet.

Let us consider the case of a type of biofuel. In order to produce one Joule worth of this type of biofuel, I need biomass containing 10 Joules worth of thermal energy. However, in order to produce this amount of biomass, I require 1000 Joules of solar radiation. The example (Baral and Bakshi 2010) is depicted in Figure 1.

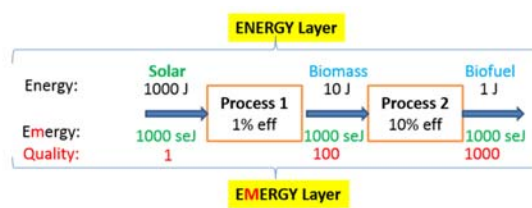

Figure 1: Efficiency of production of biofuel

Whereas BP would consider biofuel a primary source of energy, not assigning any conversion factor to it, Odum takes the analysis two steps further back to the solar radiation needed to generate the biomass from which the biofuel is produced, and therefore would assign a conversion factor (a so-called *transformity*) of 1000 to this type of biofuel.

Although the same technique could be applied to fossil fuels as well, this is probably irrelevant, because with all of the sunshine in the world, fossil fuels cannot be regenerated on a human time scale. These are non-recoverable resources for all practical purposes. Once they are gone, they are gone for good.

Yet in all of this analysis, we have not accounted for the grey energy that went into the production of my car.

I cannot drive my car to work, unless it has been produced first, a process that consumes a massive amount of energy.

The energy that goes into the production of a manufactured good has been coined *embodied energy*, or *emergy* in short (Scienceman 1987). When I buy a new car (when I import a car into my model (Castro, Cellier, and Fischlin 2013)), it comes with an emergy tag representing the total amount of energy that went into its production, including an attributed percentage of the energy that went into the production of the factory, in which my car was produced.

When I calculate, how much it costs me to drive my car around for 1 km, it is insufficient to account for the gas that it uses (although most people do precisely that). I need to factor in taxes, insurance premiums, and maintenance cost, and I should also think ahead and remember that, in a few years' time, I'll need to replace my car by a new one, i.e., I need to put money aside for that future purchase. Thus, I should also factor in the cost of amortizing my car. It turns out that the cost of the gas in all likelihood accounts for less than 50% of the overall cost of driving my car.

Similarly, when I calculate how much energy I am consuming, I need to factor in a percentage of the emergy that came with the car, i.e., I need to amortize my car not only financially, but also energetically. I should also account for maintenance, i.e., I need to factor in the emergy coming with replacement parts and the energy used in the process of repairing my car.

3. EMERGY ACCOUNTING

In order to distribute scarce resources fairly, we need a tool to quantify the amount of grey energy (emergy) that is contained in all of the goods that we consume. This can be easily obtained.

When I buy today a wedge of Camembert cheese in the supermarket, it comes not only with a price tag. It also carries a label that tells me precisely, what that cheese contains percentagewise in terms of fat, proteins, and carbohydrates. If I wish to live sustainably, i.e., without gaining weight, I need to add up my total energy intake in terms of food calories, and balance it against my energy expenditure as dictated by my life style. Thus before eating my Camembert cheese, I should look at the label and decide whether I can afford to eat that cheese or not.

On the other hand, when I buy a new hammer, it comes only with a price tag. There is no label on that hammer telling me how much energy went into its production. Consequently, I have no way of knowing whether I can buy and own that hammer in a sustainable fashion. When I decide to buy a new Japanese car, can I do this without depleting resources of this planet, both in terms of energy and materials?

As our energy resources are becoming increasingly scarce due to depletion of the remaining fossil fuels that currently make up 80% of the energy mix planet-wide, we shall all have to become more energy-conscious, whether we like it or not. At some point in time, our governments will be forced to ration energy. Each inhabitant of a country will be given a monthly energy allowance. At that time, whether or not I can buy my new hammer at the hardware store will depend on two things: whether there is enough money in my bank account and whether there is enough energy credit left in my monthly energy budget.

In order to implement this idea, the hammer will need to carry not only a *monetary* price tag, but also an *energy* price tag, i.e., it needs to exhibit a tag that shows how much energy went into its production, i.e., it needs to document the total amount of emergy that the hammer has accumulated so far.

The producers of Camembert cheese only place a label on the package indicating how much fat, proteins, and carbohydrates are contained in that cheese, because they are legally required to do so. Similarly, no producer of any goods will voluntarily indicate how much energy has been used in the production of his merchandise. They will do so only if this is a legal mandate. It should thus be made a requirement that all new items sold at a price above $100 carry a tag indicating how much energy has been used in their production. The burden of quantifying the energy footprint of each item should consequently be passed on to the producers of these goods.

To the producers, this is not much of a burden. Each producer of goods needs to know how much it costs him to produce his merchandise. To this end, he sums up the cost of all the components that he buys and adds to it the price of producing his sales item.

In a similar fashion, if each component that he buys comes with its own energy price tag, he can sum up all of those partial emergy amounts and add to it the energy consumed in the production of his item. This is the energy price tag, i.e., the amount of emergy that needs to accompany his produced good when sold either to an end user or to the next producer in the chain.

Tools used in the production of goods will need to get amortized both monetarily and energy-wise. The approach is identical in both cases.

Just like in today's markets, producers of goods try to produce their items as cheaply as they can to be competitive on the market, these same producers would also become more energy-conscious in my imagined future market, as producers will have commercial advantage if they can produce their goods in a more energy-efficient way.

Yet, although this measure can be implemented quite easily, it won't happen unless it gets legislated. No producer will voluntarily undertake this effort, and in fact, even if a producer were interested in doing so, he would not be able to, because he would have no way of knowing the energy content of the components that he buys. This only works if the entire production chain labels its goods in this way.

That this is perfectly feasible is evidenced by another labeling effort that was legislated only a few years ago.

When I buy today a steak at my local butcher store, the butcher should be able to tell me exactly where this steak is coming from. He must be able to follow the steak back all the way through the production chain to the meadow somewhere in the Argentinian Pampa where the cow was raised that is at the origin of my steak. How is this possible?

Food safety is of much concern to the people and therefore also to the governments representing the people. In biblical times, the authorities in the Mideast forbade the eating of pork, because they recognized that people often got sick after consuming this type of meat. They didn't have microscopes yet to check for parasites that frequently befall pigs (trichinosis, brucellosis, ascarid worms). In more modern societies, these diseases can be easily recognized, but the potential of food disease is still omnipresent. Consider for example the outbreak of Creutzfeld-Jakob disease (CJD) in recent times.

For these reasons, the EU regulated that all meat products sold within the EU must be traceable back to their origin. As no country can afford to ignore the EU market, all countries meanwhile bought into the concept, and all meat products world-wide are now labeled in this fashion. This was a huge success story that, however, would not have been possible without a large market (the EU) buying into this concept.

Emergy labeling of technological goods is considerably simpler and cheaper than what is already done to meat products today. All it takes is a large market, such as the US or the EU, to buy into this idea.

Although such a tool will be an important asset in fairly distributing the available goods and services in a future energy deprived world, it would offer important advantages already today, as this information could be used by economists in their market models to predict, which technologies will be able to survive in a future energy scarce world.

Also, emergy labeling is important in the context of decision making concerning measures for improving energy efficiency. For example, we may be able to reduce our energy consumption for heating our home substantially by replacing single-pane windows by triple-pane windows. Yet the decision, whether or not to replace the windows in our home, should take into account the (non-negligible) emergy content of the new windows and how long it will take to energetically amortize them. This is rarely done.

The emergy content of an average new house is roughly equivalent to the total amount of energy spent while living in that house for 50 years. Thus, ignoring the emergy content of manufactured goods may lead to decisions concerning energy efficiency that are not meaningful.

4. EROEI vs. total life cycle assessment

Whereas no attempts have yet been made to quantify in practice the emergy content of all types of general goods produced, methodology is already in place to assess the energy-efficiency of producing one particular type of goods, namely energy.

This all started in the oil business. We can ask ourselves: how many barrels of oil can we produce while burning one barrel of oil in the process? This is called the *Energy Returned on Energy Invested (EROEI)*. Some authors also refer to this concept as EROI (Hall 2008a).

Clearly, the EROEI of oil depends both on the location of the oil well (how easy is it to get to it) and on the quality of the crude (how much energy needs to be invested in transforming (refining) the crude oil to a usable product).

The EROEI of oil has decreased over time as the oil that was easiest to produce was produced first. The EROEI of Pennsylvania crude in the 1930s was above 100. The EROEI of today's conventional oil has already decreased to a value of 20 or less (Hall 2008b). The EROEI of unconventional oil and gas, such as shale oil or oil made from tar sands, is much lower, usually around 5 (Wikipedia 2013).

The concept of the EROEI can be easily abstracted to other types of energy as well, and this has indeed been done. Some energy resources have higher EROEI values than others, but most of them exhibit EROEI values that decline over time.

Obviously, when the EROEI of an energy resource passes through one, the game is over, irrespective of how much energy could still be produced in this fashion. At least, it makes *energetically* no sense whatsoever to produce a type of energy that requires spending more energy in the process than is getting generated. It may, however, still make *economic* sense to do so, if the local government decides to subsidize this energy resource, e.g. in order to reduce its dependence on energy imports or for the purpose of local job creation.

The EROEI is, however, still not a conservative measure, because it takes into account only the true (direct) amount of energy expended in the production of energy while ignoring the hidden (indirect) energy that went into the production of the tools used to produce the energy. It does not take into account the emergy content of the tools.

For this reason, researchers such as Charles A. Hall postulate that an energy resource needs to have an EROEI value of at least 5 in order to survive in a post-carbon world (Hall 2008b). The safety margin of 5 accounts for all types of hidden energy cost. However, the proposed margin of 5 is not a very solid number.

Will an energy generation technology, such as photovoltaic solar power, with an EROEI value of somewhere around 6 or 7 using the current generation of photovoltaic panels according to Inman (2013) be able to survive in a post-carbon world? The photovoltaic panels in place would certainly continue to generate electricity for a while longer, i.e., until they die, but new panels may no longer get produced to replace them once this has happened. The reason is that the EROEI of photovoltaic technology does not account for the emergy content of the plants producing these panels. Depending on whether Hall's safety factor of 5 is ample or insufficient, this technology may be sustainable or not.

I am somewhat optimistic in this respect, because the EROEI of photovoltaic technology is *increasing* over time. It suffices to build photovoltaic panels with a life span that is twice as long as that of current generation panels to double the EROEI.

In contrast, the EROEI of shale oil is rapidly *decreasing* (in fact, more rapidly than that of conventional oil), because the most easily accessible deposits were exploited first, and each new well gets exhausted very quickly.

Also, the safety factor needed for sustainability is not constant but rather depends on the technology in use. Hall's factor of 5 represents an average across all technologies. Yet there is no reason to believe that the emergy content of a photovoltaic production plant is the same as that of a shale oil production plant.

It would thus be very useful if all tools used in energy production were to carry an emergy tag. This would allow us to perform a *quantitative total life cycle assessment* of the energy production plant instead of only looking at its EROEI. In this way, we could do away with Hall's safety margin and answer questions about the sustainability of an energy production technology confidently and reliably.

The concept of the EROEI is limited to assessing energy production plants. In contrast, system analysis involving emergy measures is much more general and generic. This type of analysis can be applied to all kinds of human technological processes.

Using such a tool, we would be able to assess ahead of time and in a reliable fashion (through simulation (Castro, Cellier, and Fischlin 2013)) whether a production technology is sustainable or not, i.e., whether it can survive in a post-carbon world. The quality of life of our children may depend on this knowledge.

5. CONCLUSIONS

In this article, the concept of emergy (Odum 1983) was introduced as a means to account for the energy that is "embodied" in a manufactured good, i.e., the energy that went into its production.

The emergy content of manufactured goods has been demonstrated as being able to help us reach informed conclusions about their sustainability in an energy deprived (post-carbon) world.

An emergy tracking procedure has been introduced as a means to form better decisions about the inevitable and imminent transition from an economy of exponential growth to one that is sustainable within the confines of a finite planet.

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