Emergy view on sustainability compared to environmental science textbooks' views on sustainability[1]

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Abstract

Emergy analysis (emergy synthesis) is one of the methods in the sustainability assessment toolbox. In the way it is using stocks and flows of energy and matter it is similar to Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Substance Flow Analysis (SFA). However, Emergy accounting also includes stocks and flows of money and information. In its mechanism of relating to a global baseline of renewable flows Emergy accounting is similar to Ecological footprints in that it is not just revealing which of two alternatives is using more or less of different stocks or flows but also comparing the use to available renewable flows on a global annual basis.

This paper compares, from a modelling perspective, different sustainability approaches covered by Emergy analysis, with more general views on sustainability and sustainable development based on a selection of sustainability textbooks. For the areas not yet covered by emergy analysis, conceptual model approaches are suggested.

The four different approaches of assessing sustainability identified were: 1) the Emergy Sustainability Index (ESI), 2) emergy as a normalizing measure, 3) emergy as a network measure, and 4) the pulsing paradigm. The general aspects from textbooks were presented as three pairs of paradigm views on sustainability: 1) Strong and weak sustainability, 2) Malthusian vs. Cornucopian view, and 3) the "funnel" vs. "cylinder" sustainability paradigm. It was found that the strong sustainability, the Malthusian view, and the "funnel" paradigm were already to a significant extent covered by the existing emergy approaches. The new suggested conceptual models included capital substitution for weak sustainability, ingenuity and innovation for the Cornucopian view, and the choice of presentation to clarify the view for the "funnel" vs. "cylinder" paradigm.

Keywords: ecosystem ecology, sustainable development, capital

1. Introduction

1.1. Emergy accounting

Emergy accounting is one of the methods in the sustainability assessment toolbox. The method is using stocks and flows of energy and matter similar to Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Substance Flow Analysis (SFA). However, Emergy accounting also includes stocks and flows of money and information. In its mechanism of relating to a global baseline of renewable flows Emergy accounting is similar to Ecological footprints in that it is not just revealing which of two alternatives is using more or less of different stocks or flows but also comparing the use to available renewable flows on a global annual basis. The latest global emergy baseline was calculated to 12.0 x 1024 sej/year (Brown et al. 2016).

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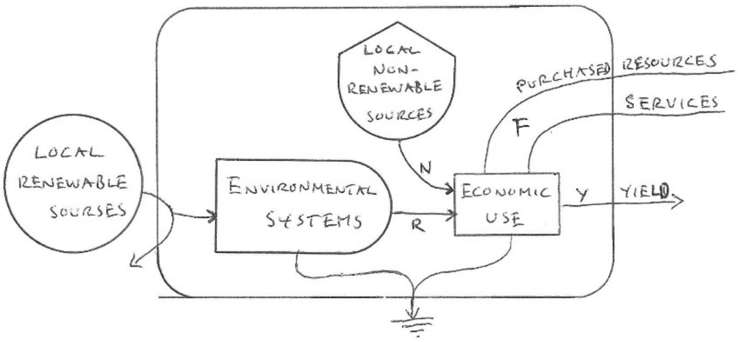
[1] Based on a presentation at the International Society for Ecological Modelling Global Conference 2019, 1st - 5th October 2019, Salzburg, Austria

1.1.1. Emergy and the Energy Hierarchy Principle

Emergy is a measure that emerges when the energy hierarchy principle is applied to natural systems (e.g. forests, meadows, lakes and rivers) or human systems (e.g. cities and countries). The principle postulates that energies in any system will self-organize in hierarchical patterns given time to do so (Odum, 1994, 2007). Emergy is expressed in relation to one type of energy occurring in the hierarchy, almost always solar equivalent joules (sej). In the context of economy, emergy values can alternatively be expressed in a currency related unit, for example Em€ or Em$ (proportional to values in sej). The significance is that Em€ or Em$ measures the contribution different items gives to the whole system, rather than how individuals value different items on the market; a donor value approach rather than a receiver (market) value approach (see e.g. Odum 1996; Grönlund et al. 2015). Emergy accounting use many different indices (Brown and Ulgiati 2004) based on stocks and flows of renewables (R), non-renewables (N), feedback from other systems higher up in the energy hierarchy (F), and the yield or contribution from the system evaluated (Y), see Figure 1. Examples of indices are percent renewable (%R) and Emergy Investment Ratio (EIR=F/(R+N)).



Emergy Yield Ratio : EYR = Y/F = (R+N+F)/F
Environmental Loading Ratio: ELR = (F+N)/R
Emergy Sustainability Index: ESI = EYR / ELR

Figure 1. Emergy indices (after Brown and Ulgiati 2004).

1.2. Sustainability field

Sustainability and sustainable development (in this paper they will be used as synonyms[2]) are important concepts in humanity's strive for long time existence, however also concepts that are debated to some extent (see e.g. Elliott, 2012). There is almost complete consensus that sustainability has three aspects: environmental, economic and social sustainability. Another important feature is the intergenerational equity aspect, expressed by the World Commission on Environment and Development (WCED, 1987) as: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". The three aspects – environmental, economic and social sustainability – is often referred to as the three pillars of sustainability or the "triple-bottom-line". Goodland (1995) depicted the three sustainability aspects with three rings, and sustainable development defined as the area where all three rings overlap. As pointed out by Giddings et al. (2002) the problem with this model is that it gives the picture of a separation between environmental, economic, and social aspects, while a probably more true model is that they are interconnected to a large extent (see e.g. Odum, 1994). A good overview of this sustainability discussion can be found in Palme (2007).

[2] The two concepts can be defined separately, e.g. that sustainability is the end goal and sustainable development are the many possible roads to sustainability (see e.g. Robèrt et al. 2019). However, there is no consensus, or even close to consensus, regarding this, therefore synonyms in this paper).

There are many factors to consider regarding sustainability. Crucial is our ability to assess sustainability, or assess our position in relation to the sustainability goals we want to achieve.

Many claim that the success of the sustainable development concept lies in the varied ways it can be interpreted, and that diverse and possibly incompatible interests can "sign up to" sustainable development. Elliott (2013) referred to this as "constructive ambiguity". Jacobs (1991) identified sustainable development as a "contestable concept" similar to "democracy" or "equality". It has a basic meaning that almost everyone is in favour of, but there are deep conflicts around how they should be understood and fostered.

1.3. Objectives

The objectives of the paper are:

- A comparison of the modelling approaches used in emergy sustainability papers with a more general view based on a selection of sustainability textbooks
- Present conceptual emergy systems models of non-overlapping areas between emergy sustainability models and general sustainability field defined by a selection of sustainability textbooks.

The paper is based on literature studies and some indicative thinking.

Section 2.1 covers the use of the emergy concept in the context of sustainability, first in the older perspective of HT Odum's writings, and then a more recent perspective (Grönlund, 2016).

Section 2.2 tries to capture the more general view of the sustainability concept from four commonly used textbooks in first cycle teaching (undergrad, bachelor's level).

Section 2.3 identifies the overlapping and diverting areas of section 2.1 and section 2.2.

Section 2.4 present possible conceptual emergy systems diagrams addressing non-overlapping areas from section 3.3.

2. Results

2.1. Emergy and sustainability

2.1.1.H.T. Odum's writings

An index search for variations of the words *sustainable* and *sustainability* (sustainab*) reveals that the concept is not mentioned in what can be called H.T. Odum's "modeling books":

- Odum, H. T. (1983). *Systems ecology: An introduction*. New York: John Wiley & Sons.
- Odum, H. T. (1994). *Ecological and general systems - an introduction to systems ecology*. Niwot, CO, USA: Univ. Press of Colorado.
- Odum, H. T., & Odum, E. C. (2000). *Modeling for All Scales*. Harcourt Publishers Ltd.

The concepts, appears, though, in Odum's three other main books:

- Odum, H. T. (1996). *Environmental accounting. Emergy and environmental decision making*. New York: John Wiley & Sons.
- Odum, H. T., & Odum, E. C. (2001). *A Prosperous Way Down: Principles and Policies*. Boulder, Colorado, USA: University Press of Colorado.
- Odum, H. T. (2007). *Environment, power and society for the twenty-first century.* New York: John Wiley & Sons.

In Odum (1996:244) Odum writes under the subheading "Steady Sustainability":

> "In economics, the equivalent to the ecological-climas concept for the global economy is 'sustainability'. However, the steady-state type of sustainability may not be possible because short-term advantage favors consumer that use up accumulated reserves. What is generally observed is pulsing, with small oscillations nested in time and space within larger ones." (Odum, 1996:244)

He then use a little more than one page to describe the "Pulsing Sustainability" under that subheading (figures 13.1, 13.3, and 13.4 in Odum 1996) The title of the Odum and Odum (2001) book, *A Prosperous Way Down*, refers to phase three in the pulsing sequence, see Figure 2.

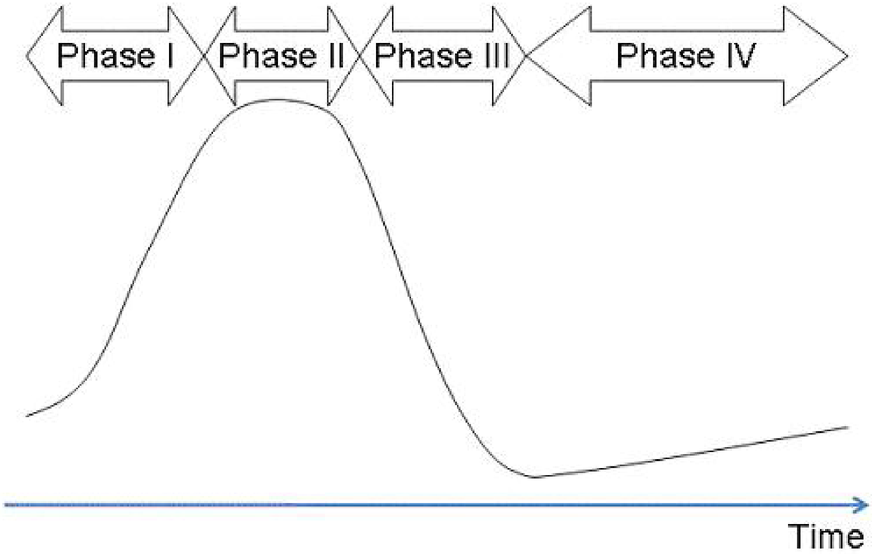


Figure 2. The four pulsing stages, when repeated constituting a long-term sustainable pattern (after Odum et al., 1995).

His last book ***Environment, power and society for the twentifirst century*** use the concept "The steady state misconception" and dedicate one full chapter to *Climax and Descent* (Chapter 13 in Odum 2007).

2.1.2.Four types of use regarding sustainability

Grönlund (2016) gave an overview of how sustainability has been used in the context of the emergy concept. Four types of uses were fourd: 1) the Emergy Sustainability Index (ESI), 2) emergy as a normalizing measure, 3) emergy as a network measure, and 4) the pulsing paradigm.

2.1.2.1. ESI, Emergy Sustainability Index

The ESI was introduced by Brown and Ulgiati (1997) and Ulgiati and Brown (1998) as "…an aggregate measure of economic (large yield) and environmental (low stress) compatibility."[3] It is defined as the Emergy Yield Ratio divided by the Environ-mental Load Ratio (Figure 1). It captures, on the yield side, the contribution of an activity (e.g. forestry or fish farms) to the larger system (e.g. society), and on the stress side the increasing load on the local system (which original state is measured by R) from released local non-renewable recourses (N) and purchased recourses introduced to the local system (F). The ESI measure has been frequently used by many authors, often interpreted in a far more general way than originally suggested by Brown and Ulgiati (1997). An interesting discussion regarding the ESI was

[3] The Happy Planet Index (HPI) has a similar approach, rewarding a good life (estimated by perceived life satisfaction and calculated life expectancy) and low ecological footprint, see http://happyplanetindex.org/ . However, in the ESI all factors used in the index has the same unit: sej/year.

published as Letters to the editor in the journal Ecological Modelling during 2011 and 2012 (Harizaj, 2011; Brown and Ulgiati, 2011; Giannetti (2012). The focus of the discussion was what factors would maximize the ESI. Of course high yield (EYR) and low load (ELR) will do it, but it was investigated in which constellations of R, N and F. The outcome of the discussion was that it was clear that the ESI still needs refining and that it "…does not capture the complexity of the sustainability concept" (Brown and Ulgiati, 2011).

2.1.2.2. Emergy as a normalizing measure

The probably most attracting feature of emergy accounting is its mechanism of normalizing flows to the same unit, not only between energy and matter, but also between energy and money (Odum 1996); this is almost unique among environmental assessment methods. Thus when drawing an emergy diagram (according to Odum 1996 and Brown and Ulgiati 2004), it is not only possible to illustrate flows of energy, matter, information, and money within the same diagram, it is also possible to put values on all of the flows with the same unit: sej (solar emergy joules). From a sustainability point of view it is also interesting that when using the energy hierarchy diagrams of emergy accounting the domains of the traditional triple-bottom-line approach in the sustainability debate comes out naturally (Grönlund et al. 2008), see Figure 3. In each of the three domains it is possible to use the normalized quantitative numbers of emergy regardless of the original units of the flows, be it joules, kg, bits or Euros. In practice this has been done for the ecological and economic sustainability domains[4], but for the social sustainability domain it is still more of a hypothesis, mainly since the social sustainability parts are still problematic in the collection of raw data.

2.1.2.3. Emergy as a network measure

Since emergy is often presented in a thermodynamic (TD) context, the concept is often mistaken for being of the "state variable" measure type. We are also used to talk about flows of energy, so therefore it is easy to assume that emergy is also a flow. However, this is not so clear. Possibly emergy instead should be viewed as properties following the energy flows[5]. It is obvious that emergy accounting has something to do with the network of flows in systems. Looking into any explanation of emergy accounting (e.g. Odum, 1983, 1994) it is clear that the connections and interactions between the parts in the system is the main focus.

The energy hierarchy has been suggested as a new thermodynamic (TD) law since it claims to describe distribution and dynamics of energy in universal terms (Odum 1994). Grönlund and Brandén Klang (2009)[12] and Grönlund (2016) suggested that a problem for this hypothesis to have a breakthrough as an accepted TD law is due to the fact that it expands the classical TD (heat TD, Figure 4a). This expansion is not performed by those who work with the classical TD (mainly heat engine and chemical engineers) but by other research groups who are not used to view their work as TD (Figure 4b). These groups are for example business modellers, computer scientists, and meteorology modellers, working with theories of networks, systems, and complexity (Figure 4b). The expansion also includes new systems ecology measures with a network focus as Environs (e.g. Patten 1992, Patten and Fath 1998), Ascendancy (e.g.

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[4] See for example a collection of international journal publications at www.emergysystems.org or www.cep.ees.ufl.edu/emergy/publications/emergy.shtml

[5] Going deeper into this hypothesis we must also separate the "real" properties following each flow from the estimation we use in the calculations according to the methodology. The "real" properties differ for each individual flow of wood, oil, or mobile phone, since they all have a different background in the history of the flows interacting to create the currently investigated flow. The estimations we use in the calculations are tabulated averages, in a similar way as LCA is performed. The energy values are also standardized values from tables, however, with a higher exactness than is possible for emergy or LCA tables.

Ulanowicz 1997) and Emergy (e.g. Odum 1994) (Figure 4b). A special case is the measure Eco-exergy (Jørgensen 2006) which takes its fundaments much more explicit in the old classical TD but address the new quality aspects[6]. Grönlund and Brandén Klang (2009)[12] suggested that also the Extended Exergy concept (Sciubba 2003) is taking this step by adding money to the classical TD.

Brian Fath points out[7] that exergy, eco-exergy, ascendancy, and emergy – despite they are developed in different contexts – mathematically have a similar approach to include the qualitative aspects: by introducing a compensation factor. The aim of this factor is to capture the information component, not covered by the traditional energy measure[8]. Grönlund (2009) pointed out that a general measure of qualitative information seems to be missing in science. In Figure 5 the three major types of flows known in the universe – energy, matter, and information – are listed. The information category is split into two: money (€, $, or equivalent) and information (bit). In the mid part we can see how these concepts are generally used within science. Energy is measured in joules (J), whether in the form of potential, kinetic, pressure, chemical, or heat energy. Everybody knows, though, that there are specific qualitative aspects for every energy form. If you have 1 kWh (3600 kJ) of hot coffee and 1 kWh of electricity only one of those energy forms can make the electric bulb above you light up due to differences in quality aspects. Two more general concepts have been introduced to correct the energy value according to their qualitative aspects in the system: exergy and emergy. It is interesting that the view on energy by the general public (to the right in Figure 5) is the more qualitative approach, even if it is not labelled exergy or emergy (the general public labels it "energy"). When it comes to matter the situation is the opposite. Both scientists and the general public takes for granted that different materials have different qualitative properties. Only rarely, like for luggage in an aeroplane, we (almost) only care about mass, not different types of mass. The same goes for money. Only small children count the coins: 1, 2, 3, 4, 5 coins. Very soon we learn to add up different qualities (values) of different coins, even if their mass and energy content are very similar. When it comes to information, the general measure is the "bit" (8000 bits = 1 kilobyte). The bit measure is of the same type as the joule, it does not take into account different qualitative aspects of the information. You can probably count how many bits were shouted in a rain forest at night, but you have no idea of the quality of what was said. However, in everyday language the interpretation of the word "information" has a qualitative approach. But, a more general scientific measure of information quality seem to be missing. A candidate may be possible to derive from H.T. Odum's emergy approach. In emergy accounting the joule is renamed emjoule when the network quality aspects are added. In the same way the bit can be renamed embit[9] when the qualitative aspects captured with the emergy accounting approach is added to the information (Grönlund 2009, 2019).

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[6] Readers familiar with the eco-exergy concept know that Jørgensen use the number of genes in an organisms as an estimator for the information content added to the more classical TD based exergy accountings. Compared to the other measures Jørgensen, however, has less focus on the network and more focus on the classical TD math when presenting eco-exergy. In this context it should be mentioned that Odum, Patten and Ulanowicz also stand solid on classical TD, but don't use it as explicitly as Jørgensen when explaining their new network TD measures.

[7] Pers.comm., Montpellier, France, 2016, at the ECOSUMMIT conference.

[8] Literally the information part can be viewed as "burned" away when converting different types of energy values to heat values, e.g. in a bomb calorimeter. Just moving a system out of its context to investigate it in a laboratory, destroys significant amounts of the information aspects, since the system is now "disconnected" from its context.

[9] It is not clear to the author of this paper who coined the term "embit". Mark T. Brown has addressed the topic in several speeches, for example at the emergy conference in Gainesville, Florida (Brown, MT. 2005. Areal Empower Density, Unit Emergy Values, and Emformation. Pages 1-15 in Brown MT, ed. *Emergy Synthesis 3: Theory and Applications of the Emergy Methodology*. Proceedings from the Third Biennial Emergy Research Conference, Gainsville, Florida, January, 2004. Gainesville, USA: The Center for Environmental Policy, University of Florida)

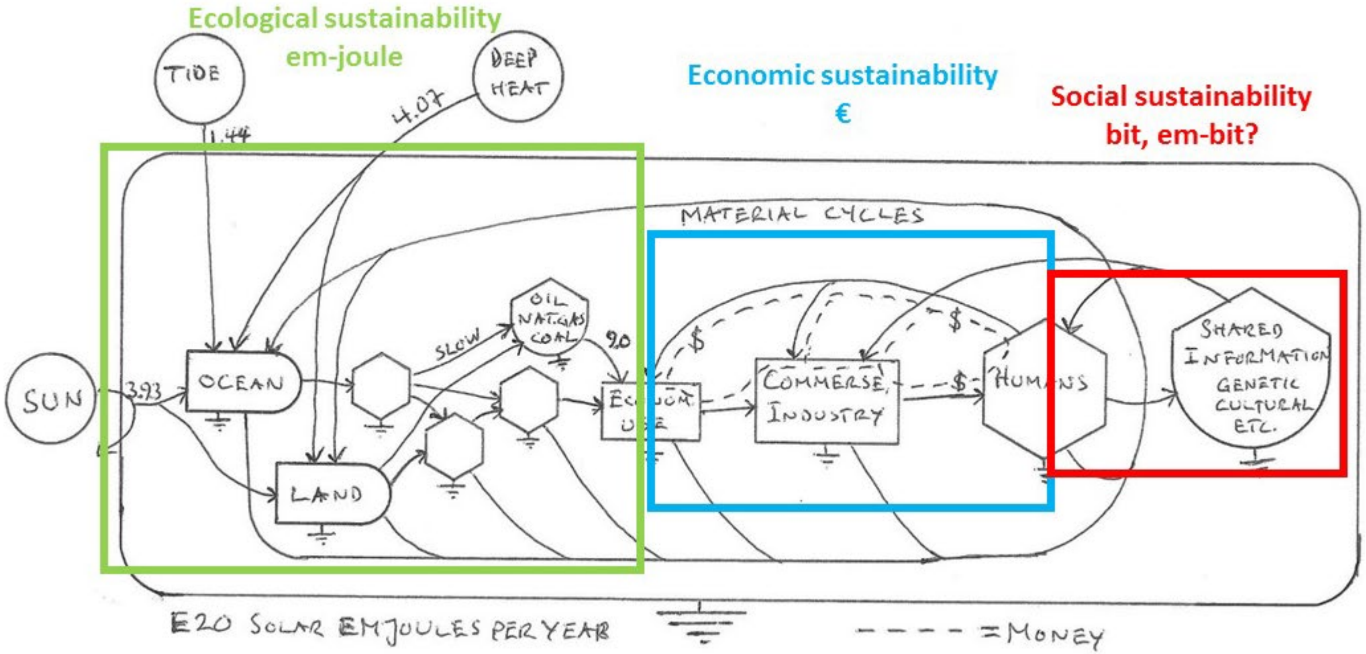

Figure 3. The triple-bottom-line domains in the energy hierarchy (modified from Odum 1996, Figure 3.1, by Grönlund et al. 2008, 2018).

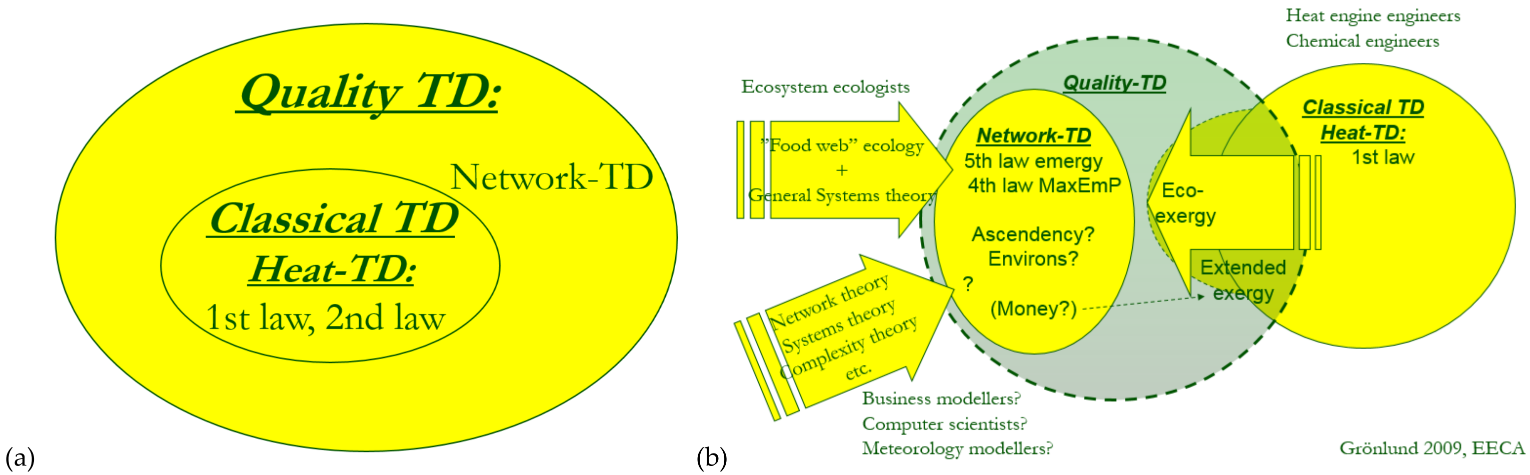

Figure 4. a) A view of the expansion of the field of thermodynamic (TD) from the classical heat TD to quality TD including network TD; b) A suggested thermodynamic classification of the new ecosystem theories emerging. (From Grönlund and Brandén Klang 2009[12] and Grönlund 2016).

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[12] Grönlund E, Brandén Klang A. 2009. *The use in Ecological Engineering of New Ecosystem Theories based on New Thermodynamic Laws*. Powerpoint presentation from the conference Ecological Engineering: from concepts to application, Cité internationale universitaire de Paris, France, 2-4 December, 2009. Östersund, Sweden: Mid Sweden University.

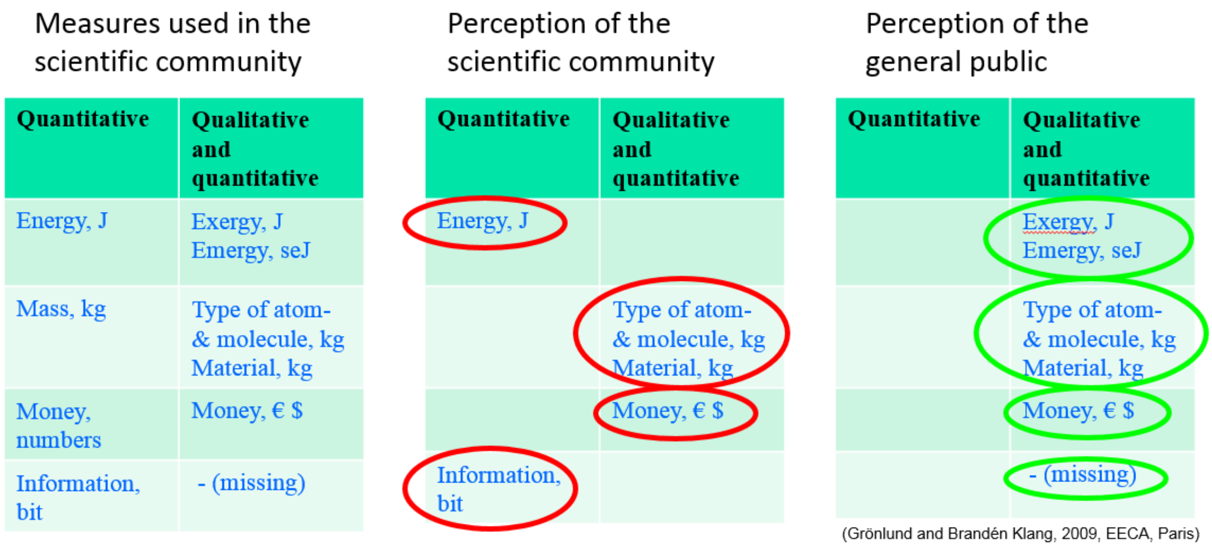


Figure 5. *Scientific perception of the 4 major flow types in the universe. Money can be is considered an information measure, but of a different type than the bit, so therefore they have separate status in this table. (From a presentation in Paris 2009 by Grönlund and Brandén Klang 2009[12]).*

2.1.2.4. Pulsing sustainability

A wanted stable steady state is often intrinsic in definitions of sustainability. However, for example Odum et al. (1995) argue that pulsing is the normal state for systems: the pulsing paradigm. If pulsing is a general systems pattern, sustainability is likely to have different features in different stages of the pulsing cycle. Odum et al. (1995) divide the pulsing pattern into four stages: (I) growth, (II) stagnation, (III) decline, and (IV) slow regeneration (Figure 3). Odum and Odum (2001) gave different suggestions and strategies for sustainability in the different stages. In the pulsing context, during phase I it is observed a wanted outcome of continuous growth. This growth may be considered sustainable if it is part of a pulsing pattern that is sustainable as a whole. Grönlund (2020) looked at 10 sustainability related emergy papers, and found that of them no one included the pulsing approach.

2.2. Sustainability paradigmatic dimensions

All four textbooks studied in this investigation (Caradonna 2014; Elliott 2012; Robèrt et al.2019; Rogers et al. 2008) ascribe opposing paradigms in the view of sustainability or sustainable development. Two main types of such paradigmatic dimensions were identified in the textbooks:

- Strong and weak sustainability – in terms of economic capital
- Malthusians and Cornucopians – in their view on limits or no limits

One of the textbooks had an additional description of the above, called "funnel" or "cylinder" paradigms (Robèrt et al. 2019), which will be described below.

The paradigms are summarized in Figure. 6.

2.2.1. Strong and weak sustainability

Strong and weak sustainability focus on different types of economic capitals. Rogers et al. (2008) use the division of Human, Man-made, and Natural Capital. In short they concluded that: 1) Weak sustainability requires that the sum of all capital be constant or increasing over time. Substitution between the different types of capital is possible. They also point out that "Most of the literature…thinks in terms of weak sustainability…" (Rogers et al.,2008). 2) Strong sustainability on the other hand requires that all of the above capitals be increasing over time, and substitution between the different types of capital is not possible.

2.2.2. Malthusians and Cornucopians

Strong and weak sustainability are often described as related to limits or non-limits. This is not the original definition of these concepts, which is rather related to different economic capitals as described above. The discussion of limits or non-limits are closer connected to the concepts of Malthusians and Cornucipians, where the former group believes in limits of different types, and the latter see "…a future limited only by human ingeniouty…" and a "…future as not resource limited, but limited by humans' inability to get the economic institutions right" (Rogers et al.,2008).

2.2.3. Funnel or cylinder paradigm

Robèrt et al. (2019) describe a similar paradigm situation with the metaphor of a funnel and a cylinder. The funnel give the picture of a decreasing navigation space for companies and organizations due to declining resource availability, and restoration capacity (regenerative capacity), and increasing pressure from population, average resource demand, market competition, regulations etc. Only those companies and organizations that can navigate towards the thought opening of the funnel will survive in the competition and be considered sustainable. In connection to this picture, they present systems conditions that can work as a navigator to steer towards the opening of the funnel. The cylinder paradigm on the other hand do not show any declining resource availability, and restoration capacity. Human actions affect resource availability and restoration capacity, but not to an extent that they are decreasing. The cylinder paradigm is acknowledging that there are limits, but humanity's actions are still far from these limits.

The funnel and cylinder paradigm picture resemble very much Herman Daly's picture of a "full world or an empty world, where in the empty world there are still a lot of resources and assimiliation capacity compared to the human economy, but in the full world the opposite situation exists: the human economy is filling up the world to an extent that resource and assimilation capacity is becoming scarce.

2.3. Gap between emergi-sustainability and textbook-sustainability

Comparing section 2.1 with section 2.2. gives that the following gaps exist in the emergy description of sustainability compared to the textbook approach in section 2.2:

- Strong and weak sustainability are not addressed.
- A cornucopian view is not addressed.
- A cylinder vew is not addressed.

2.4. Suggested emergy modelling approaches for non-covered textbook sustainability approaches

Based on the gaps in section 2.3, some suggested conceptual emergy models are presented below as a beginning of filling these gaps.

2.4.1. Weak and strong sustainability

In Figure 7a a typical emergy system setup is presented. Figures 7b and 7c show the substitution process of weak sustainability, where natural capital is exchanged for financial capital.

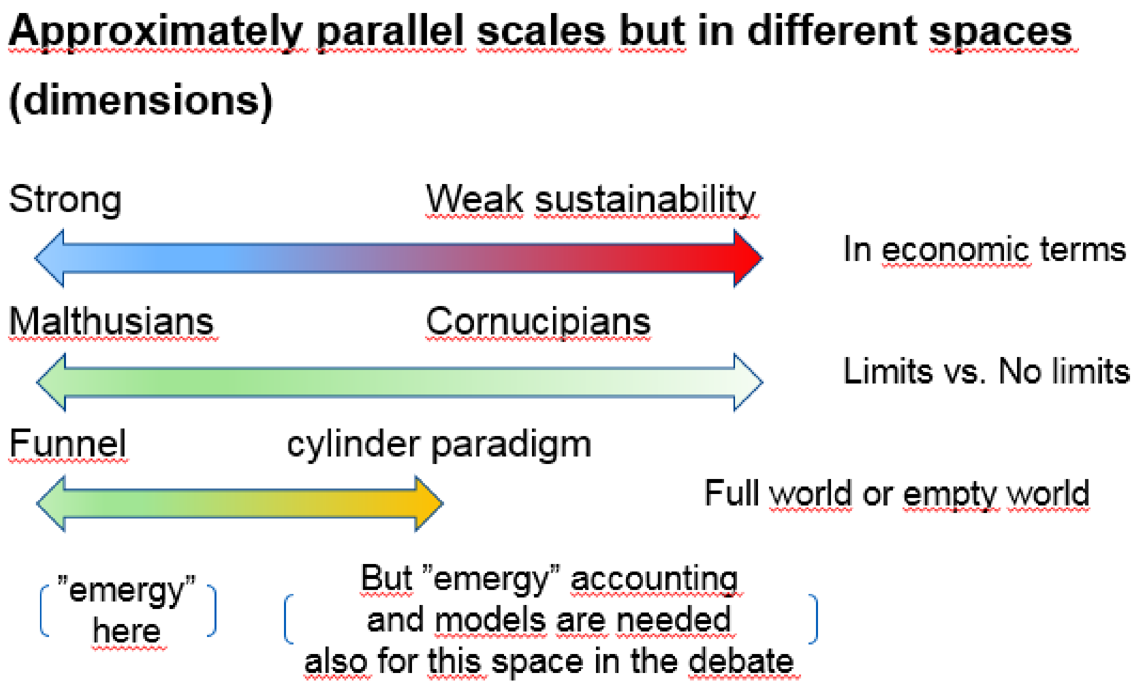


Figure 6. *A summary of the sustainability paradigms found in the four textbooks studied in this investigation (Caradonna 2014; Elliott 2012; Robèrt et al. 2019; Rogers et al. 2008) with the main opposing paradigms in the view of sustainability or sustainable development. Strong and weak sustainability in terms of economic capital, Malthusian and Cornucopian view related to the view on limits versus no limits, and the additional description in Robèrt et al.2019, called "funnel" or "cylinder" paradigms, where the cylinder paradigm acknowledges limits but claim that human actions so far are still far away from these limits.*

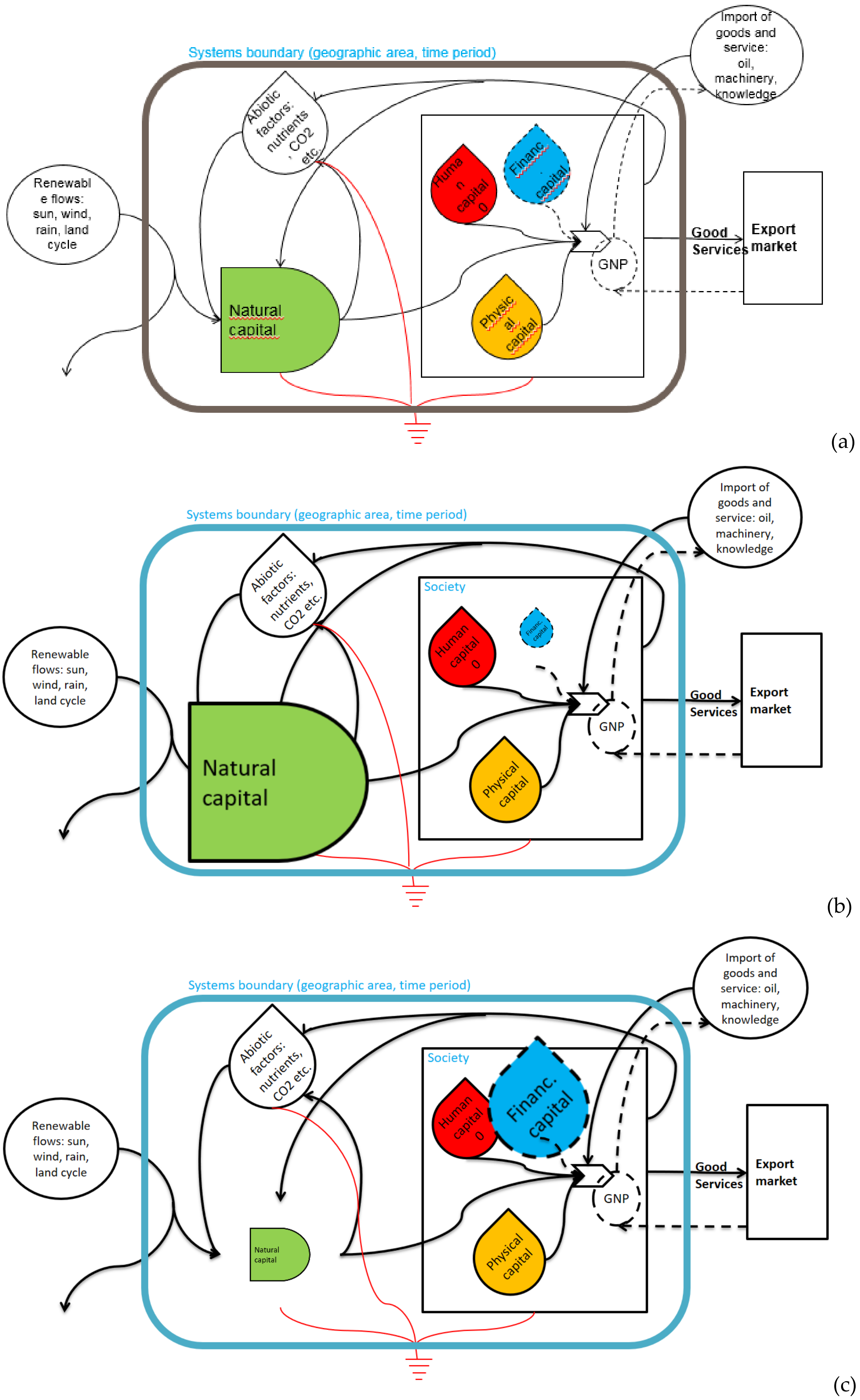
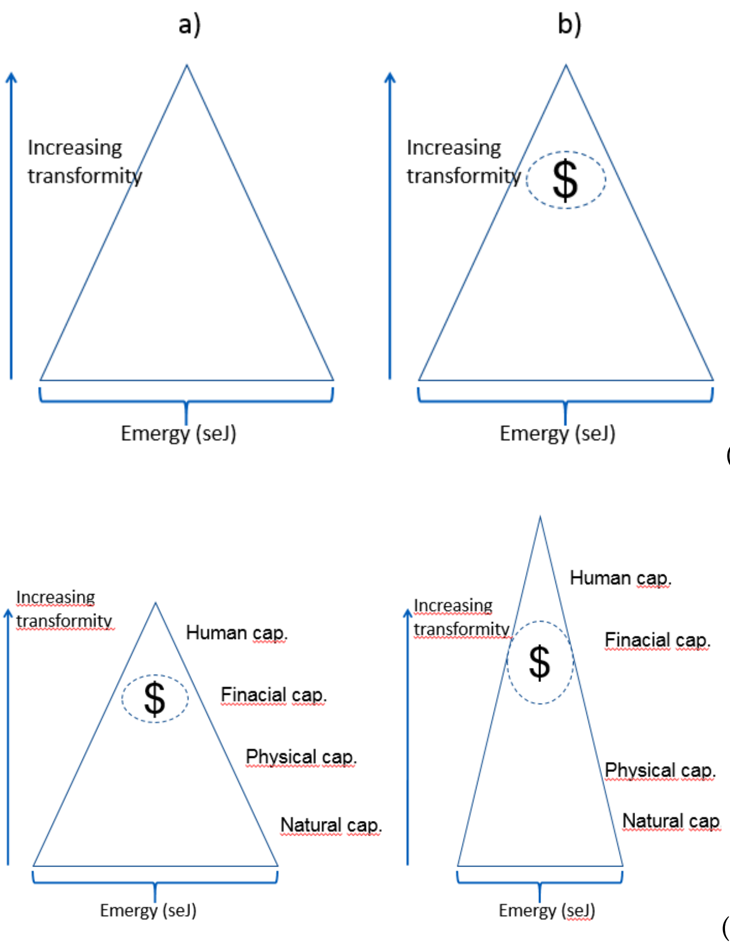


Figure 7. *A hypothetical Weak sustainability substitution where capital can be substituted by each other, in emergy diagram language. a) a traditional generic emergy diagram; b) financial capital is substituted for natural capital; c) natural capital is substituted for financial capital.*

In Fig. 7, a theoretical depiction of emergy is displayed, where the energy hierarchy, usually depicted from left to right, instead be depicted vertically. Transformity is then a measure of the height of the energy hierarchy, and emergy is the width of the basis in the hierarchy. It should be pointed out that energy hierarchies never look like this in reality, since this picture don't include any storages that release or store resources between years. Fig. 7b shows an assumed outcome of the substitution in 6c, where natural capital has been substituted by financial capital. Since financial capital can be found higher up in the energy hierarchy, it is assumed that the height of the energy hierarchy must increase, while the basis will decrease.



(a) (b)

(c) (d)

Figure 8. a) *A simplified energy hierarchy (with no storage interference), where transformity is a measure of how high up in the energy hierarchy an item or phenomenon occurs, and the basis of the hiearachy (triangle) represents the emergy measure expressed in on type of energy, normally solar equivalent joules (sej);* ***b)*** *representing monetary circulation at a certain level in the energy hierarchy;* ***c)*** *hypothetical distribution of human, financial, physical, and natural capital in relation to levels in the energy hierarchy;* ***d)*** *hypothetical weak sustainability substitution of natural capital (low in the energy hierarchy) for financial capital (higher up in the energy hierarchy), similar to the depiction in figure 7c.*

2.4.2. Malthusians vs. Cornucopians

As seen in the gap analysis in section 2.3 the Malthusian view is well covered in emergy literature, but not the Cornucopian view. Since the Cornucopian view depend on ingenuity, it is per definition "not known" yet. It can, though, be included as a modelled part, like were done by the Limits to Growth approach in the 1970s (Meadows et al. 1972, 2002). Figure 9 show an example how ingenuity can be included from the perspective of ingenuity affecting renewable and feedback inflows, ingenuity of efficiency within the existing sources, and not yet discovered sources.

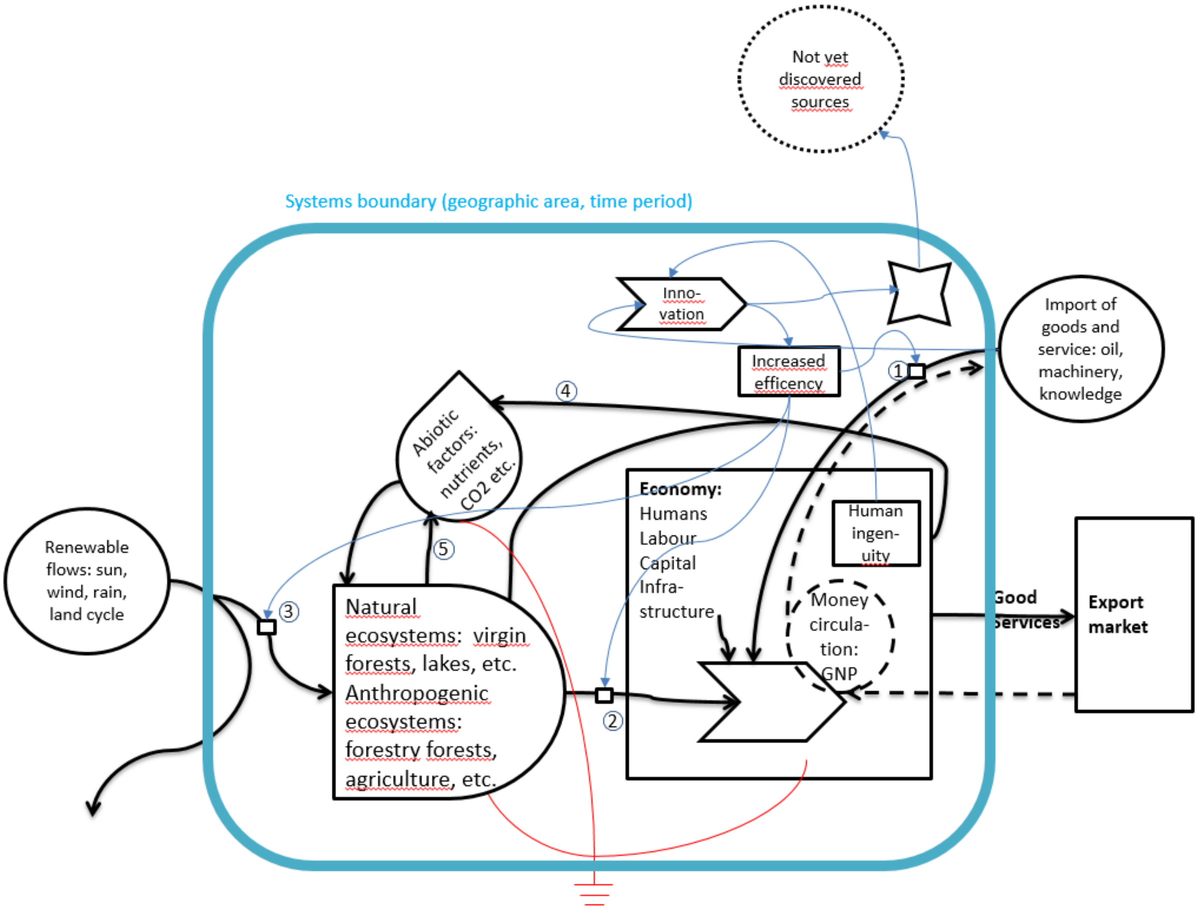


Figure 9. Human ingenuity added to the economy, driving innovation and increased efficiency, which interacts with (1) imported goods and services to increase efficiency in imported goods and services, (2) goods and services from natural and anthropogenic ecosystems, (3) the capture of the renewable flows. (4) and (5) indicates that also the abiotic factors can be addressed by innovation: mineralization flows, releasing and regenerating nutrients, and other abiotic ecological factors as temperature, light etc. The switch symbol in the upper right of the figure depicts innovation that leads to new discovered sources.

2.4.3. Funnel vs. cylinder paradigm

The difference between the funnel or cylinder paradigm will not be visible directly in a traditional systems diagram. In a time diagram of nonrenewable resources the difference will appear though, see Fig. 10. According to the funnel paradigm, non-renewable flows will decrease over time, and maybe also renewable flows will show a decreasing trend, Figure 10, upper left diagram. According to the cylinder paradigm non-renewable flows will not decrease and renewable flows will be stable, Figure 10, upper right diagram.

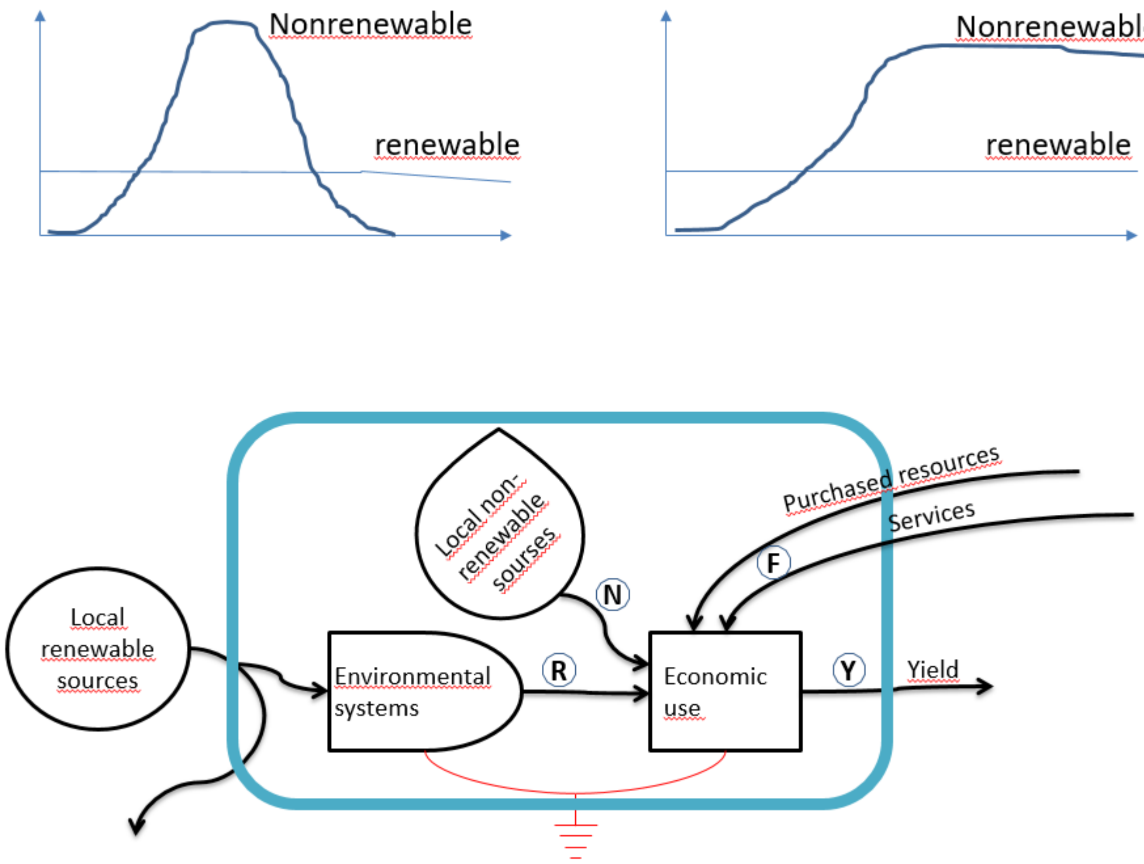


Figure 10. Principal non-renewable (N) and renewable flows (R) with diagrams over time for the funnel paradigm (upper left diagram), and the cylinder paradigm (upper right diagram).

3. Discussion

Sustainability and sustainable development are still not yet fully defined concepts. The view on sustainability from emergy analysis is not crystal clear either. Most promising may be the network track, which, though, need further development in the interpretation part.

The choice of textbooks included in this paper can of course suffer from some bias, as well as the extraction of sustainability dimensions made in this paper. Important aspects from the textbooks not addressed in this paper are for example the concepet of “tripple-bottom-line” and the very common Venn diagram of interlocking circles, often launced under the heading People-Planet-Profit, or People-

Planet-Prosperity. Emergy accountings for different outcomes of Venn diagrams would be an interesting development of this paper. Another interesting further development would be an attempt to quantify the ″ingenouity″ and innovation needed for a weak sustainability approach.

H.T. Odum did not use the concepts of sustainability or sustainable development in his writings to any larger extent. When he did it, the focus was on the pulsing pattern, and especially the downslope of the pulse, among emergy researchers and debaters summed up under the concept of ″a prosperous way down″. However, it must be remembered that Emergy accounting is a method, not a standpoint. Emergy accounting must therefore not be stuck in the ″prosperous way down″ narrative, even though the many mini-model calculations and ″peak-oil″ assumptions talks in its favor of a pulsing behavior and a ″prosperous way down″ narrative.

Regarding the "triple-bottom-line", there are in the literature many interesting emergy investigations published regarding the environmental/ecological aspect. The other two pillars of the "triple-bottom-line" have not been investigated to the same extent with emergy accounting. More of deeper, quantitative investigations regarding economic sustainability or social sustainability would be an interesting development of the emergy accounting field. It must be remembered that most of the Odum statements regarding the socio-economic parts of the ″prosperous way down″ narrative are very, very interesting hypothesis, but not yet backed up by solid emergy accountings. Is there a risk of a Garrett Hardin versus Elinor Ostrom outcome? Where Garrett Harding produced very interesting models based on game theory, but Elinor Ostrom could not find that his modeling outcome where very common in real case studies.

In general a possible standpoint from this paper is to recommend the field of emergy accounting to connect more also to other sustainability narratives. And to have less focus on showing them wrong, instead of investigating what would be needed in the models to make them possible. Again, Emergy accounting is a method, not a standpoint. The results from quantitative accounting investigations can lead to a standpoint, but not easily prove that other standpoints are definitely wrong within the still a little bit shaky field of sustainability.

4. Conclusions

This paper compared, from a modelling perspective, different sustainability approaches covered by Emergy analysis, with more general views on sustainability and sustainable development based on a selection of sustainability textbooks. For the areas not yet covered by emergy analysis, conceptual model approaches were suggested.

The four different approaches of assessing sustainability identified were: 1) the Emergy Sustainability Index (ESI), 2) emergy as a normalizing measure, 3) emergy as a network measure, and 4) the pulsing paradigm. The general aspects from textbooks were presented as three pairs of paradigm views on sustainability: 1) Strong and weak sustainability, 2) Malthusian vs. Cornucopian view, and 3) the "funnel" vs. "cylinder" sustainability paradigm. It was found that the strong sustainability, the Malthusian view, and the "funnel" paradigm were already to a significant extent covered by the existing emergy approaches. The new suggested conceptual models included capital substitution for weak sustainability, ingenuity and innovation for the Cornucopian view, and the choice of presentation to clarify the view for the "funnel" vs. "cylinder" paradigm.

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