ABOUT THE EMERGY CONCEPT

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June 30, 2005

Chapter 1

preliminary concepts

Before introducing the emergy concept, some general energy need to be recalled:

1.1 the energy concept

> Energy is often defined as the ability of a resource to do mechanical work, except when it's present its degraded form: diluted heat. This has often been done because it's useful for industrial processes and because of the stemming revolution of the 18th century.

In fact many different qualities of energy exist. All kinds except degraded heat are able to drive mechanical work but not with the same efficiency. Since all those energy forms are finally irreversibly degraded into heat, heat is the common unit to qualify the energy quantity: thus the energy of a resource is always expressed a caloric joule J content.

Notice that **energy is linked to the exterior of the system (because of kinetic and potential energy) but it's not a systemic property**. The energy conservation law, the first law of thermodynamics allows to calculate quantitatively how one kind of energy type is transformed into an other kind:

$$\Delta En = \Delta U + \Delta Ec + \Delta Ep = 0$$

Where:

En **:** total energy of the system

U **:** internal energy (thermic agitation of the particles, chemical energy, nuclear energy)

Ec **:** kinetic energy (due to the movement of the system in a spatial referential)

Ep **:** potential energy (gravitation, electrostatic potential, elasticity)

However, since several energy qualities exist, energy analysis can't qualify every system. In particular, a trivial co-generative process producing both heat and mechanical work can't be qualified by energy analysis since heat and mechanical work don't belong to the same energy quality.

In order to account for energy quality degradation in a process, entropy or exergy analysis is required. Although entropy is an interesting theoretical concept, exergy is easier to use and is more intuitive since process losses are expressed as exergy destruction rather than entropy production. Anyway, entropy or exergy analysis bring the same information about the process and rely on the second law of thermodynamic.

1.2 the exergy concept

> Instead of energy, exergy is the real proportion of the energy that can drive mechanical work. [1].
>
> Except for special processes like nuclear production of electricity, the specific exergy for open system is defined as:
>
> $$ex = h - T_0 \cdot s + \frac{1}{2} \cdot m \cdot v^2 + m \cdot g \cdot z$$
>
> where $h - T_0 \cdot s$ is the specific Gibbs free energy

This ability to do work doesn't necessarily rely on the heat content but rather to the existence of a gradient between the resource and the environment (temperature, pressure, concentration, chemical potential or any other state parameter). In order to compute such a gradient, **a reference state is required**. That's why scientists have computed lots of standard concentrations of common chemicals within the earth crust (an upper boundary for our systems).

In industrial processes, integral exergy analysis is performed by computing for all matter that inflows and outflows what is its exergetic potential. It's often possible to tabulate such an exergy potential by measuring T_0, h, and sometimes estimating s. Such an analysis is able to show if the process is close or not from a reversible optimum efficiency.

Notice that the exergy variable totaly relies on the existence of a gradient between the resource and it's environment.

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[1] Notice that if the process is a reversible heat gradient to mechanical work transformation, then the proportion of heat able to provide mechanical work is given by the Carnot coefficient

Chapter 2

emergy definition

2.1 the emergy concept

2.2 Odum's textual emergy definition

Thus energy is almost an intrinsic property of the resource (at least potential and kinetic energy rely on a very low knowledge of the environment), whereas exergy attempts to define the usefulness of an energy according to the outside of the system.

Further: we can attempt to define the energy quality according to the environment standard state, but also according to the existing processes. Indeed, **almost all energy transformations in ecosystems have the solar radiation as a common origin**. Then a network of real processes is required to provide the resource and to deal with its by products.

In 1985, Odum defined the emergy to a process as:

> the total solar equivalent available [1] energy directly and indirectly used up to generate a specific form of energy or product.[2]

2.3 Giannantoni's mathematical continuous definition

in [7] page 21, Corrado Giannantoni showed that the definition given by Ogum was perfectly adherent to the time and space continuous mathematical definition of the emergy to a process:

$$Em^*(t) = \int_{-\infty}^{t} \dot{E}x_{eq}(\tau)d\tau$$

where the exergy power is expressed as:

$$\dot{E}x_{eq}(\tau) = \frac{d}{d\tau}\int_{D^*(\tau)} c(x,y,z,\tau)\cdot\rho(x,y,z,\tau)\cdot ex(x,y,z,\tau)d_3$$

where:

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[1] in fact exergy is the more appropriated concept

[2] in [7] page 165, C. Giannantoni explains why one can choose an arbitrary time origin to evaluate the emergy of different processes, especially the solar radiation as a time origin reference

c **:** is a dimensional structural factor depending on the x,y and z spatial coordinates and depending on the time τ.

ρ **:** is the mass density depending on the time and space coordinates.

ex **:** is the specific exergy depending on the time and space coordinates.

This continuous definition might be interesting for further research in emergy, for instance continuous domain applications like satellite GIS map analysis. As a beginning, I personally would be interested in looking if the mathematical definition of Em-power given by Corrado Giannantoni could explain some simple well know continuous self-organizing processes, for instance like the formation of a turbulence in a convection phenomenon where self-organizing structure compete whereas such a system is already mathematically described and also pretty observable, see [8]. Who wants to try?

I should say here however that after an oral discussion and several e-mail discussions, M. Giannantoni didn't convince me neither Serge Kere (an other ECL student) that its emergy continuous definition apply to any concrete system. I've also shown its book to some of my professors (one from electronics and an other from mechanics): they didn't understood. At least this book is not written in a suitable manner...

2.4 discrete pactical definition

In the current stage of development, **emergy users still don't manage to exploit pseudo-continuous (finite elements) data for real systems. So instead of this continuous definition, we will use the discretized definition.** Notice that in an energy network diagram, the emergy equation is discretized this way:

spatial discretization : Useful exergy to a resource only flows through the discrete connected inflowing pathways.

temporal discretization : Along the time, exergy is integrated from discrete processes to discrete processes as we follow the nodes of the graph beginning from the solar radiation until the considered resource. Whenever the independent sources aren't sun radiation, their solar emergy or solar transformity should account for the historic between solar radiation and the entry of our considered system.

2.5 considered systems

2.5.1 emergy deals with open systems

The real systems considered for emergy synthesis are **open systems** :

> a spacial domain (control volume) with imaginary borders (possibly moving) that can both exchange material and energy with the outside.[3]

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[3] Open systems are more general than isolated (no energy neither matter exchanged) or closed (can exchange only energy) systems.

2.5.2 choosing the scale of the system

Emergy efficiency indicators can differ slightly according to the scale of the system because a process can reinforce a small scale environment while damaging a larger scale one (typically true for industrial processes) or even the contrary. However, the maximum Em-Power principle suppose that a general organization can arise and can be qualified by an emergy analysis.

It now seems logical that the control volume should be chosen correctly. On one hand, the larger the system is, the more processes are accounted and thus the global impact of a local human modification are likely to be found. On the other hand, if the system is too large, then lots of unknown data will have to be supposed. The resulting error margin might then hide the pertinent result. So when choosing the system scale, we should account for our current level of knowledge and keep in mind what are the possible pertinent effects of two alternatives for development.

2.5.3 choosing the precision of the system description

The problem is quite equivalent of choosing the correct discretization scale for a finite elements problem. Increasing the precision increases the time and the required complexity to describe the system and to compute the results. Moreover, an excessive precision can exceed our measurements capabilities to describe the system at such a scale.

On the contrary, if the precision isn't sufficient, the result can get dramatically wrong. As in mechanical part can break because of constraint concentration at very small scale, in emergy analysis, you could slightly overestimate the emergy to a resource by adding required emergies that aren't independent!

What scale should be choose is a hard question. What I'm sure is that no coherence and continuity of the results along scales have been demonstrated! Moreover, lots of people consider their process as linear, without accounting for splits, co-productions or feedbacks in their system because it seems that they don't dominate emergy allocation algorithms or their entry data. While this could be excusable for some simple systems, it seems dangerous to systematically proceed this way since it lost both the interest of emergy accounting and its understanding.

Chapter 3

but the emergy methodology still faces lots of problems

3.1 problems relative of the emergy definition

Hopefully emergy could be one day a useful environment accounting methodology, but at the current time, those definitions generate huge problems for any application. Indeed, when we say, that an energy is required to do something, then, it's really subjective:

1. How to prove that without one process, the resource can't be made?
2. If a process is clearly present, is that a proof that it's necessary? because then emery is likely to be an infinite value!
3. In a productive chain, if we stop after a frontier we choose, is there any proof the part we don't account can be neglected or is even finite?
4. If the part we neglect is finite, then is there any proof that it converges at a value in the same order of magnitude as the value we found?
5. Would it exist any universal methodology to choose the borders of the system, thus allowing comparisons of emergy studies?
6. When we choose the discretization scale of the system, what proves us the results we compute are a minimum stable with regard to the scale choice? The consistency or inconsistency of the emergy methodology should be investigated more mathematically with abstract cases and that's not the case!

3.2 problems concerning published emergy studies

May be some thermodynamic criteria and norms could prevent emergy studies from such inconsistency, but my opinion after 10 months of frequenting such studies is that we don't have a good reliability of the results at the moment and in particular:

1. Independent Emergy studies can't be compared because the borders are different and because the assumptions at the entries are different (sources transformities can be very different).

2. If independent studies seems to have similar results, the main reasons are:
   (a) Input transformities probably come from the same Odum's book. However, if you look at the emergy algebra chapter you will see that emergy and transformity are systemic data that you can't take from one system and inject in an other as if it where mass or internal energy!
   (b) Aggregation and Boundaries are probably inspired from the same previous study. This however doesn't proceed of any logical implication...

3.3 problems concerning the way emergy studies are done

As a new scientific field, some critics may be addressed to emergy users:

1. Very low peer review and auto critic.
2. The consistency or inconsistency of the emergy methodology should be investigated more mathematically with abstract cases and that's not the case!
3. You won't find any emergy study rejected as wrong by the emergy community. Then isn't naive to claim that it could be a universal tool?
4. Wide emergy rules disrespecting.
5. Few bridges with classical thermodynamic studies.
6. Low international organization.

3.4 however, some reasons to keep paying attention to emergy studies

However, emergy studies may present some interests because:

1. Judging between two alternatives of the real world will never be something simple. Most of methodologies well define their boundaries, but then the problem is that the boundaries are to small to drive a pertinent conclusion...
2. The emergy methodology is somewhat interesting in the way that people have to put their ideas on diagrams and this really enhance comprehension and communication. This allows knowledge construction and discussion.
3. Even if different emergy studies can't be compared, we can think the an emergy study done by one group as been done with the same sensibility for the various alternatives studied so may be the conclusion has some reliability.
4. Emergy values probably don't mean anything outside of a defined system (that's why it would be so important to archive the whole system like we can do with Emergy Simulator). But on the contrary, the empower concept that measures the level of connective organization of the system is something probably much more relevant.

Chapter 4

practical emergy allocation: the emergy algebra

If we admit that a network energy structure is valid to describe a process (so if we forget the problems linked to the boundaries, the aggregation scale and the causal schema), then computing the emergy to support some resources of the network requires a special energy accounting in the network of processes: the emergy algebra (EMA).

4.1 the four rules of emergy algebra

The four basic rules of the emergy algebra are synthesized there (from [7] page 23):

1st rule : All source Emergy to a process is assigned to the Process output

2nd rule : By-products from a Process have the total Emergy assigned to each pathway [1].

3rd rule : When a pathway splits, the Emergy is assigned to each "leg" of the split based on their percent of the total Exergy flow on the pathway.

4th rule : Emergy cannot be counted twice within a system. [2] In particular:

- a) by-products, when reunited cannot be summed
- b) Emergy in feedbacks should not be double counted

4.2 practical application of the emergy allocation rules

Applying those rules with rigor in an energy networks isn't so easy. Double counting or missing an emergy contribution is easy. A rigorous methodology is needed.

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[1] this concept is really interesting because it leads to an accounting of how the system is factorized as a co-productive system

[2] cautious application of this closure principle respect the energy conservation rule while this is often misunderstood

4.2.1 the matrix method

A first known method is to use a matrix representation of the set of constraints imposed by the rules at each node of the network. The whole methodology and samples are provided by Dennis Collins and Howard Odum in [3]. Once the matrix of the constraints is expressed, the matrix is inverted and emergies and transformities are provided. This method has been analysed by Serge Kere and me at the LEIA: here is what we think about it:

advantage	drawback
inverting a matrix is easy	writing the system is fastidious and risky
	introduce numerical imprecisions
	doesn't provide a formal solution

So we thought that such a matrix methodology only present the advantage of not requiring a graph data structure as we have in Emergy Simulator. Indeed, any numerical calculus software can invert a matrix. The problems of that methodology is that it looses precision because of multiplications and divisions and also it require the user to properly build its system. A quite difficult task when the system gets complex.

4.2.2 the track summing algorithm

A second method is mentioned page 99 of Environmental Accounting [10]. However, it's not explained sufficiently and it seems that many people claiming to work with emergy didn't understand it. It took me sometimes to rewrite this algorithm more precisely in the following section. What we think of this algorithm:

advantage	drawback
provide formal solutions	require a graph handler (like EmSim)
easy to understand and debug	
easier to automate from A to Z	

So on the contrary, the track summing algorithm drives the same results (with more accuracy) and can be completely automated in a graph handler like Emergy Simulator.

4.3 explanation of the track summing algorithm

4.3.1 required entries

The user should provide as an entry:

the graph (actually a multigraph) structure that is:

$$G = (X, A, f)$$

where X is the nodes ensemble, A is the pathways ensemble and $f : A \rightarrow \mathcal{P}_2(X)$ is an application from the pathways ensemble into the ordonned pairs of the nodes ensemble (this because of the multigraph structure).

the energy flows for every pathways.[3]

the independent emergy sources. The roots of the graph should only consist into independent sources. And either the transformity, or either the Emergy of the pathway should be known.

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[3] those energy weights can actually result from a dynamic simulation based on the bond graph paradigm.

4.3.2 allocation rules for the algorithm

The emergy flowing in a pathway a_i knowing the emergy of the origin node $x_q \mid origin(x_q) = a_i)$ of the pathway is calculated this way:

Simple case: Only one pathway outflow from the origin node. Then:

$$Em(a_i) = Em(x_q)$$

Co-production branching case: (see 8.1) Then: $Em(a_i) = Em(x_q)$.

Split branching case: (see 8.1) Then: $Em(a_i) = Em(x_q) \times r$. where r is the energy fraction through the a_i pathway:

$$r = \frac{En(a_i)}{En(x_q)}$$

4.3.3 the algorithm

superposition principle : First, we apply a superposition principle, assuming that each independent source contributes independently to the emergy of each node. If S is the ensemble of all the N sources, and $x_i, i \in \{1, \ldots, M\}$ are the nodes of the ensemble X, we have the algorithm:

$$\forall x_i \in X, \qquad Em(x_i) = \sum_{k=1}^{N} Em_{k,i}$$

Obtention of $Em_{k,i}$: For each independent source S_k, $Em_{k,i}$ is calculated by considering every **simple path** p_j (not crossing the same node twice) from the source k S_k to the node x_i:

$$Em_{k,i} = \sum_{j=1}^{m} Em_{k,i,j}^{indep}$$

where m is the number of simple paths and where $Em_{k,i,j}^{indep}$ are the independent emergies from S_k propagated to x_i through the path p_j. The following section explains how to calculate $Em_{k,i,j}^{indep}$:

single path emergy propagation : obtaining $Em_{k,i,j}$: along each path p_j, we propagate the Emergy brought by the source S_k from node to node while respecting the allocation rules 4.3.2. Also notice that for such a path, the emergy to a node x_m knowing the inflowing emergy from S_k is simply equal to emergy of S_k brought by the inflowing pathway $a \mid target(a) = x_m$.

pathway historic book keeping : At the same time, an historic of the encountered nodes and the emergy from S_k remaining at each node is book kept.

Obtention of $Em_{k,i,j}^{indep}$, avoiding double counting : When reaching the node x_i, we should filter out some $Em_{k,i,j}$ in order obtain the independent emergy contributions $Em_{k,i,j}^{indep}$. Indeed, when faced to a co-productive node, we propagated the emergy normally for each simple path p_j. But we should look further at the logical implication:

The first time the emergy from S_k cross a co-productive node — let's call it x_p — on the way to the target node x_i, this means that to support the x_i resource, then x_p is required and the current emergy at x_i from S_k is the required energy from S_k to support x_p. Once this energy — equivalent to emergy at such an elementary level — is provided the resource x_p exists (assuming that this algorithm will also be done for the other independent sources) and thus all co-products resulting form x_p do exist. So no more emergy from S_k is required to support them!

So then, each time we cross the co-productive x_p node when propagating the emergy to x_i through the other paths p_j, **we should assume that the required energy from S_k to support x_p is already accounted!**

Filtering out double counted energy : Then the question is: when several simple paths from S_k to x_i cross the x_p node, which one carry the right emergy required to support the $x_i resource$? Each of those path account for the energy from S_k to support x_p. But after x_p, depending on the co-product path, more or less emergy will support x_i.

- If we only account for a path not bringing the maximum of those emergies $Em_{k,j}$, then it will fail energy to support x_i (indeed an other path requiring more energy should be supported).
- If we sum several of those co-productive paths, then it's clear that some energy is double counted.
- On the contrary, if we only account for the maximum energy required by any of those co-productive path, then all co-products resulting from the x_p node exist and none double count is done. So that's the solution!

So the ensemble of the $Em_{k,i,j}^{indep}$ is built form the computed ensemble of $Em_{k,i,j}$ by filtering out double counted emergy as explained in 4.3.3. When two paths brought emergy from S_k to x_i while crossing the same co-productive node, then only the maximum emergy of the two enter in the ensemble $Em_{k,i,j}^{indep}$.

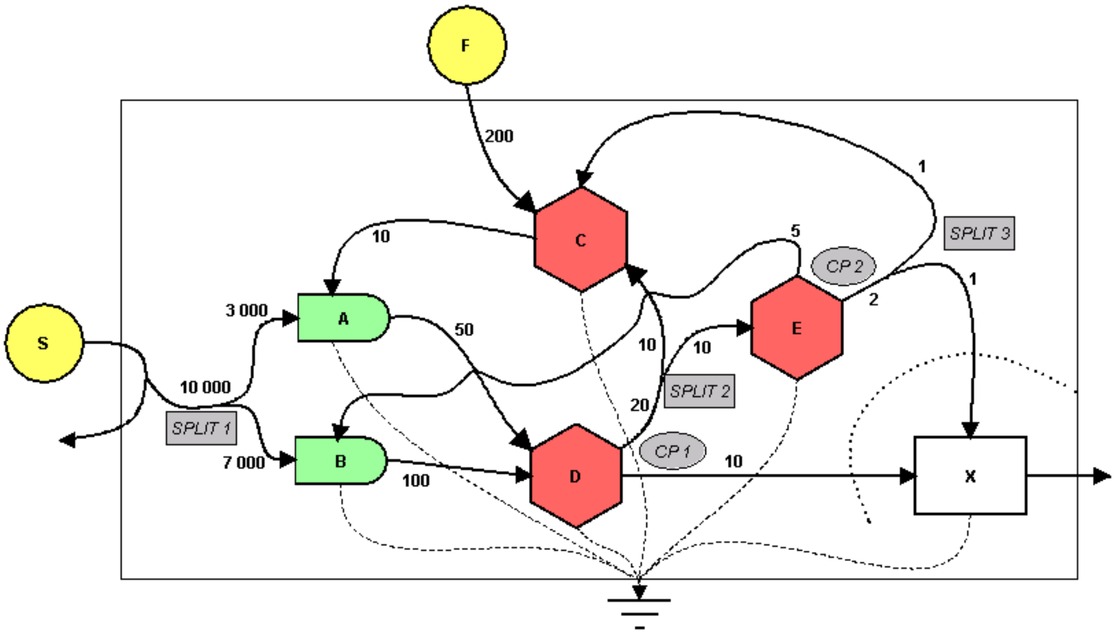
I've been very happy to re-discover such a result explaining while H.T. Odum told to only account for the major contribution when two resources outflowing from the same co-productive process are required. Since no detailed explanation was available so far I was believing this was an huge and hazardous approximation. So the approximation here is only to consider purely co-productive a process that is probably more complex (see the example 5 for instance). So that's great news that if the process is really purely co-productive, then the methodology is mathematically exact.

Chapter 5

emergy track summing example

Assuming we can get the following energy network of a complex network, then we can perform the track summing algorithm for each node, see [10] page 90, this example is provided by Brown and Herendeen. The considered system is at steady state and only a few interesting nodes have been computed whereas the final emegy graph and transformity graph shown at the end are complete.[1]

initial energy data:



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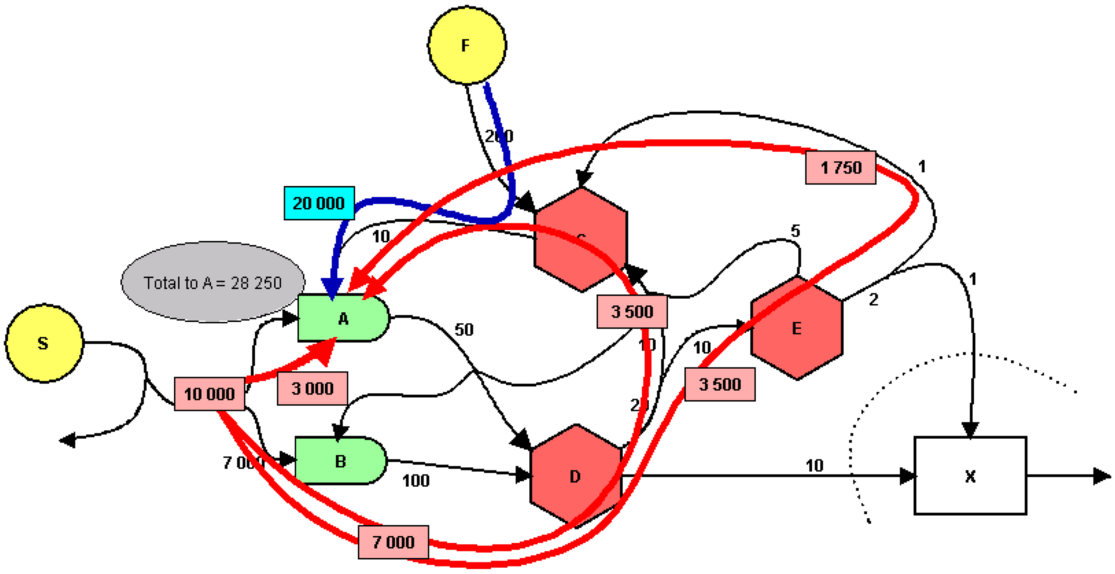
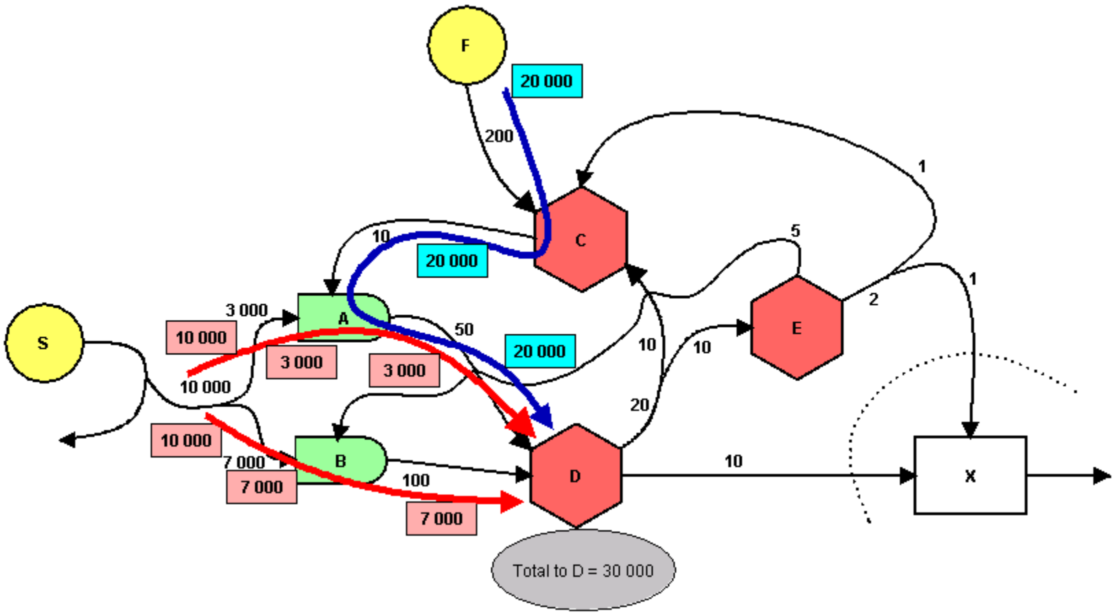
[1] those graphics have been made with Emergy Simulator version 0.2 by Raphael Valyi while the preceding track summing algorithm has been put into Latex by Serge Kere after common reflexion.

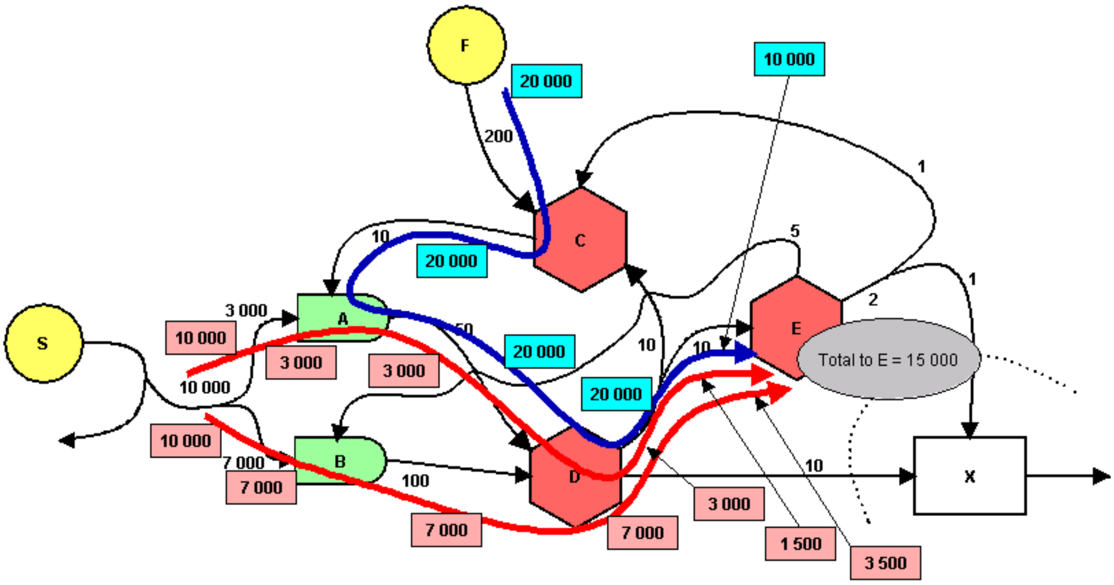
emergy to support a:



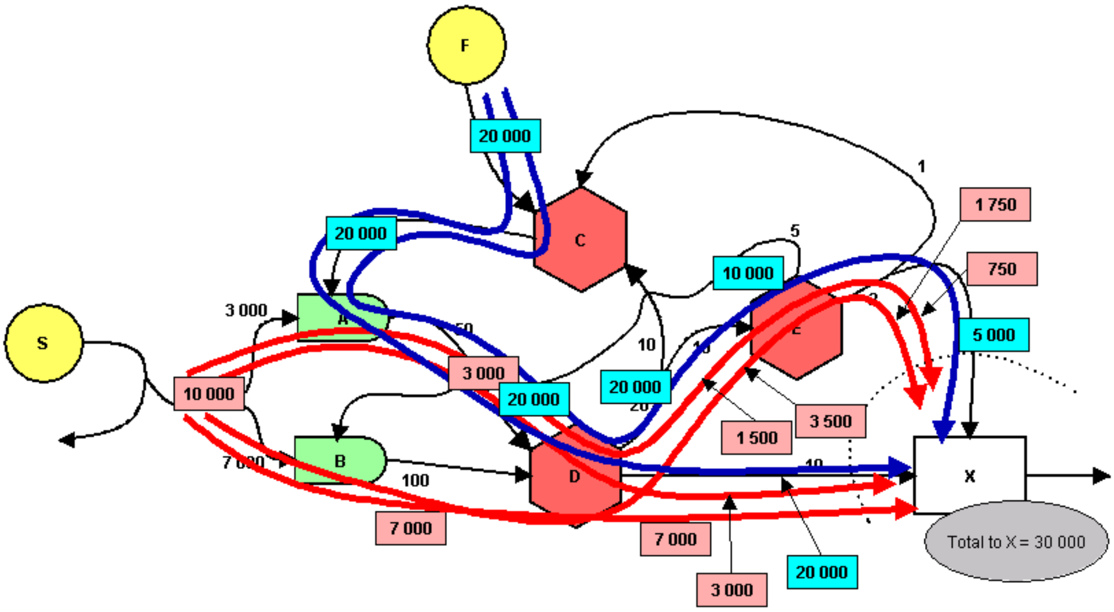
emergy to support d:



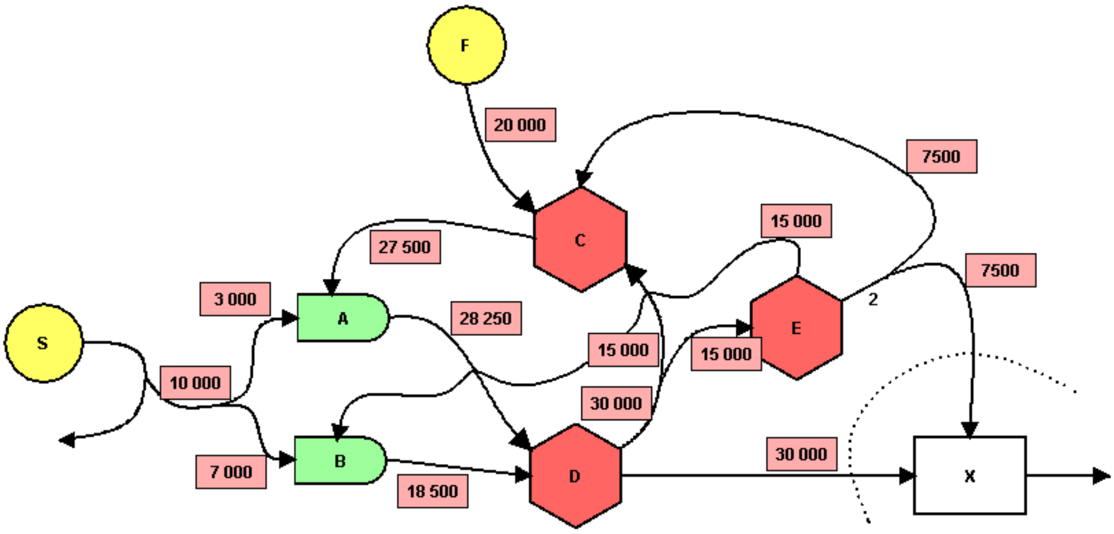
emergy to support e:



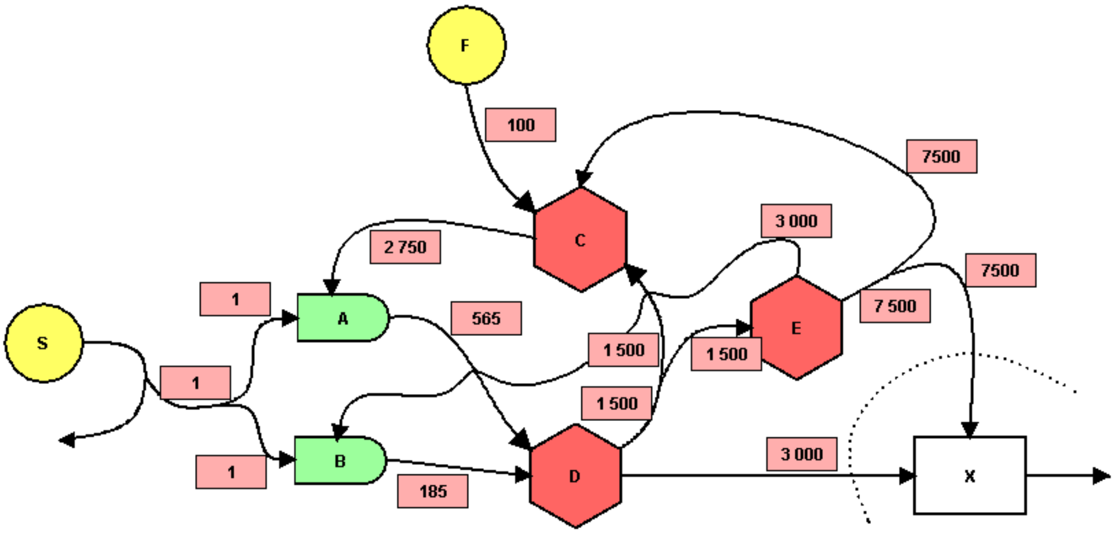
emergy to support x; here we show that non-independent emergy contributions are not summed, only the major contribution is accounted, thus no emergy neither energy is created of course:



Finally, the emergy flowing across the pathways is equal to the emergy that has been computed at their origin node:



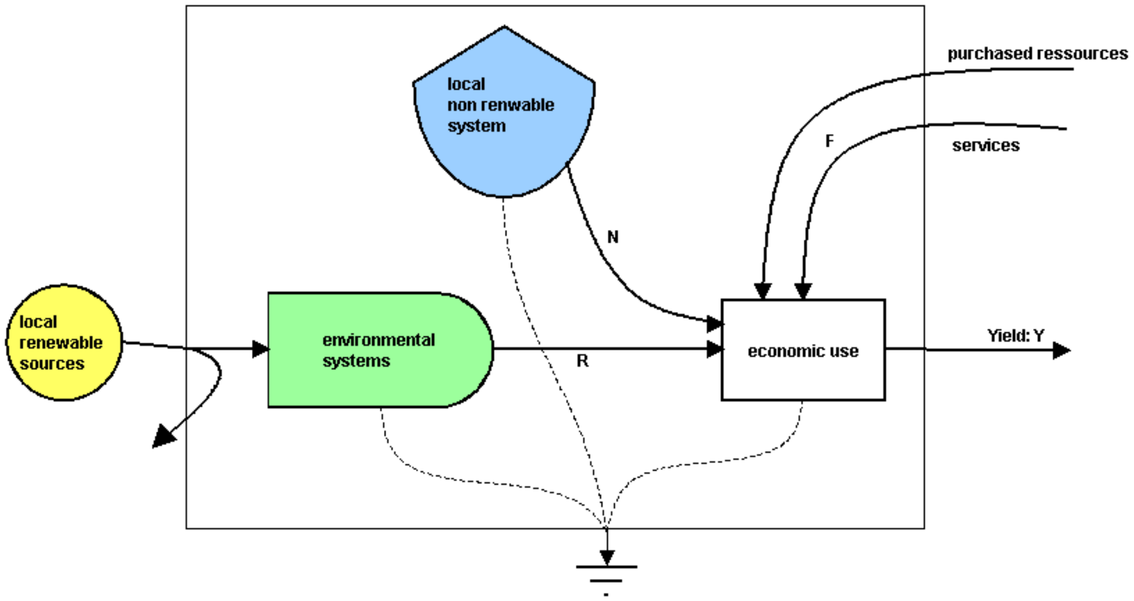
And dividing those emergies by the edge energy flows, we get the edges transformities:



Chapter 6

emergy based indicators for environmental decision making

When the interface between human and ecosystems can be aggregated this way:



then we can analysis the efficiency of the system thanks to the following indicators:

- Emergy Yield by the process: $Y = R + N + F$
- Renewability percentage $= \frac{R}{R+N+F}$
- Non renewable to renewable ratio $= \frac{N+F}{R}$
- Emergy yield ratio $= \frac{Y}{F}$
- Emergy investment ratio $= \frac{F}{R+N}$
- Environmental loading ratio $= \frac{F+N}{R}$

We could have included a special user interface guiding the user to compute those indicators with Emergy Simulator, however, this has not been decided as a priority by Dr. Ortega and moreover the reliability of those indicator is far from perfect as explained in the following.

Using those indicators to judge a development alternative is indeed not always convincing. Clearly, the problems we evoked re-appear and make the decision making not the easy as some claim...

Even more problems appear when we are compelled to tell is a resource is a useful product, a pollutant, a positive feedback, at what time scale and so one...

Application is particularly tricky for yield emergy, emergy investment ratio, environmental loading ratio. The best critics i found are explained in: "Has Emergy Lost its Memory?", see [5]; "Evaluation of EMERGY as a Sustainability Indicator", see [1]; "Emergy Yield ratio, problems and misapplications", see [6].

The problems of those emergy indicators bring us to the next chapter dealing with the em-power principle. Indeed, we could avoid to classify resources as useful or not and privilege the network structure, that's the idea of the maximum empower.

Chapter 7

is the maximum Em-Power principle a more rigorous indicator?

It's very probable that Corrado Giannantoni brought more rigorous analysis tools thanks to his formalism. Indeed he introduced an analytic formulation for the emergy flowing at split or co-productive branchings using equivalent emergy source terms.

Then the maximum em-power is mathematically expressed as the maximization of the sum of the emergy sources terms present within the system (which normally should be as large as possible). Due to natural selection over large time scales, only systems that maximize their useful feedbacks will prevail. The mathematical formulation of this principle express that prevailing systems are maximizing emergy source terms at each scale, a way of doing this is to be as co-productive as possible (a general well know concept among ecologists).

If I understood well the Corrado Giannantoni's new book (see [7]), then it's possible to perform a track summing algorithm on a static or even dynamic energy network, then it's possible to retrieve the analytic formulas for the emergy at each node (co-injection, co-production and renormalization factors). **This leads to the general emergy balance equation and to the em-power estimation. Thus it will be possible to compare several alternatives in a given system to see which one maximizes the empower and is thus likely to be more sustainable...**

I see a method to compute the **em-power** and **circulating emergy** (at least in steady state) of a network that is deterministic and that we could implement on Emergy Simulator:

1. By using the track summing algorithm in Emergy Simulator, we compute the emergies flowing in all pathways of the network.
2. Then, by using the Giannantoni equivalent models for emergy sources, splits and co-productions given in [7] pages 24 to 26, we could compute the so-called **co-injection, co-production and renormalization factors** when equilibrating the following **emergy balance** described page 27:

$$\sum_{j=1}^{m} \alpha_j^* \cdot \alpha_j \cdot Em(u_j) + \sum_{k=1}^{n} \gamma_k^* \cdot \gamma_k \cdot \Phi_k^*(u_1, u_2, .., u_m) = \sum_{l=1}^{p} \beta_l^* \cdot \beta_l \cdot Em(y_l)$$

3. Then, we could express the **circulating emergy** (see page 31) in the network by:

$$E\dot{m}_{circ} = \sum_{l=1}^{p} \beta_l^* \cdot \beta_l \cdot E\dot{m}(y_l) - \sum_{l=1}^{p} E\dot{m}(y_l)$$

4. In steady state conditions at least, we could also retrieve the **empower** of the network (see page 39), expressed as:

$$\sum_{k=1}^{n} \gamma_k^* \cdot \gamma_k \cdot \Phi_k^*(u_1, u_2, .., u_m) = E\dot{m}_{circ} + \sum_{l=1}^{p} Em(y_l) - \sum_{j=1}^{m} \alpha_j^* \cdot \alpha_j \cdot E\dot{m}(u_j)$$

In its book, Corrado Giannantoni explain that systems tend generally to mawimize their em-power by auto-organizing themselves. Systems that don't are generally supplanted by better organized systems in the competition occurring in the natural selection process.

However, when Serge Kere and I asked for practical examples of those computations, Corrado Giannantoni didn't couldn't provide such examples and we have been disappointed.

May be those new indicators could be useful because they attempt to characterize the system directly from its energy network structure, however, the gap for applications seems so wide that we abandoned this subject (too risky for our work placement evaluation). Nevertheless, it would be interesting to look further in that direction in the future...

Chapter 8

my synthesis about often misunderstood emergy concepts

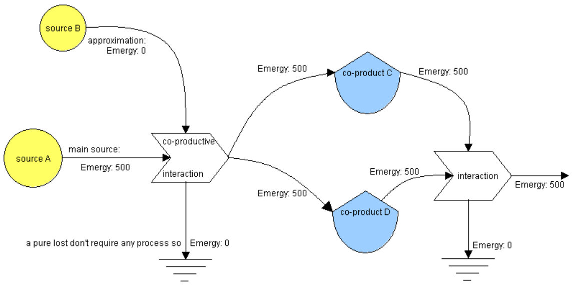
8.1 splits versus co-productions branchings

8.1.1 split branching

A split is **when an homogeneous flow is divided extensively into several flows**, see page 91 of Environmental Accounting [10]. Each flow should thus keep exactly the same intensive properties. For instance a portion of incoming sun flow is used by photosynthesis and the other portion will do some other work or will be reflected (albedo).

8.1.2 co-production branching

Flows are co-products when several flows result from a given energy transformation process without any degree of freedom in allocating the proportions between the various flows, as reminded in [4]. [1] They could have different intensive properties. For instance, this is the case when a chemical product A will transform into two others products C and D as illustrated in the following figure:



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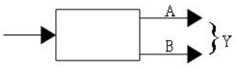
[1] Notice that in Environmental Accounting [10] page 91, Odum still had in mind bond graphs theory since he cited Paynter (the bond graph inventor) and wrote that bond graph convention characterize by the number 2 (if split is 1 or 1 if the split is 0) a co-product branching.

Some people get confused by such an accounting since it seems to violate the energy conservation rule; emergy seems to be created. First that's true emergy wasn't made to be a conservative variable and the specialists still claim it. See the Corrado Giannantoni's comment in [7] page 34 for instance *Emergy Algebra is generally non-conservative because the four rules previously illustrated try to be a faithful representation (at a logical accounting level) of the increase of Quality.*

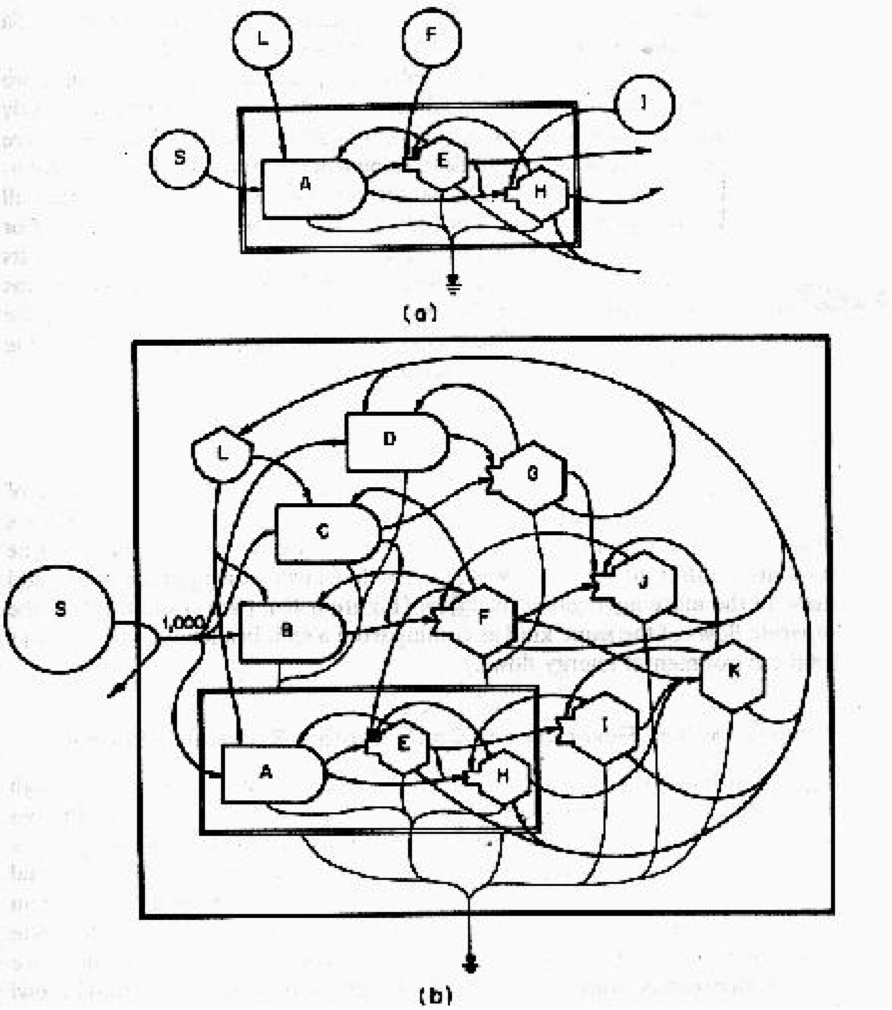
Splits	Co-products
	
(1S) $En(Y) = En(A) + En(B)$ (2S) $0 \leq En(A) \leq En(Y)$ (3S) $EM(Y) = EM(A) + EM(B)$ (4S) $0 \leq EM(A) \leq EM(Y)$ (5S) $Tr(A) = Tr(B)$	(1C) $En(Y) = En(A) + En(B)$ (2C) $En(A)/En(Y) = cost$, with $0 \leq cost \leq 1$ (3C) $EM(Y) = EM(A) = EM(B)$ (4C) $EM(Y) = EM(A) + EM(B)$ (5C) $Tr(A) \neq Tr(B)$

8.1.3 other branchings

Real flows often can't be categorized into split or co-production branching. I personally think this problem arises because of abusive aggregation of different flows. Anyway, more theoretical work should help us to perform real study cases. We should especially look for a methodology to project real experimental flows into a base of split and co-production branching or at least telling how to solve the allocation paradox.

8.2 about the independence of sources

Sometimes we will tend to add inflows that are in fact not independent (S, L and F on the figure). Of course that's wrong. Finally the better we know the whole system, the best the result is accurate:



8.3 what kind of value emergy stands for?

There are to types of emergy for a given product: this one resulting from the process which is being considered and eventually an other optimum one resulting of a huge space and time scale trial and error selection of the more efficient process. Odum says in [9] p.253: *The most efficient energy transformation that is possible with maximum power is the one that is both competitive and the most transmissive of energy.*

Thus in nature, it could be true that the emergy to a product is directly linked to the controlling power or even the so called real value of this product. In [9] p.252, Odum explains about this: *If items and flows have value because of the effects they can exert on a system, and if their ability to act are in proportion of the energy used to develop them (after selective elimination of those that do not), the value is proportional to the* *embodied energy* [2] *in systems emerging from selection process.* And also: *embodied energy may measure value because it measures the potential for contributing effects to maximize power and ensure survival.*

However, **for an arbitrary human built process, there is absolutely no reason that emergy should be representative of any quality of the product**. Indeed a process can be really wasteful and the high emergy required would thus over estimate the value of the product.

At the end, this consideration of emergy-quality may be right but only in the evolutionist perspective and it doesn't consider that human may do better than nature for some processes. Odum says in [9] p.253: *It is not difficult to observe and measure energy transformation ratios, but whether the observed ones are close to the inherent thermodynamic maximum possible is not easily known. We sometimes assume that the ratios observed in ancient systems with millions of years of operation like many in the biosphere are good numbers [...] not likely to be exceeded.*

So the question is when an emergy value should be admitted or not as a measure of value? To answer we should also consider that any process is a selective process over a large time scale, then the question could be transformed in: **is the considered process a small scale accident or is it a large scale thermodynamic optimum?**

Moreover, emergy studies would probably gain in clarity if one always specify if the considered emergy of a product has been calculated from the considered system or if it has been approximated from an optimum value.

8.4 how does emergy account for pollution?

In fact a toxic product generally affect the optimized dynamic equilibrium (conservative in term of structure) of the ecosystem decreasing the efficiency of the global system. So if the time and space scale are large enough, the emission of pollutant will have negative feedbacks on the ecosystem and the renewability of the considered process will decrease. A case study is given in [2] by Pillet. We speack about "Emternalities" when dealing with those pollutants.

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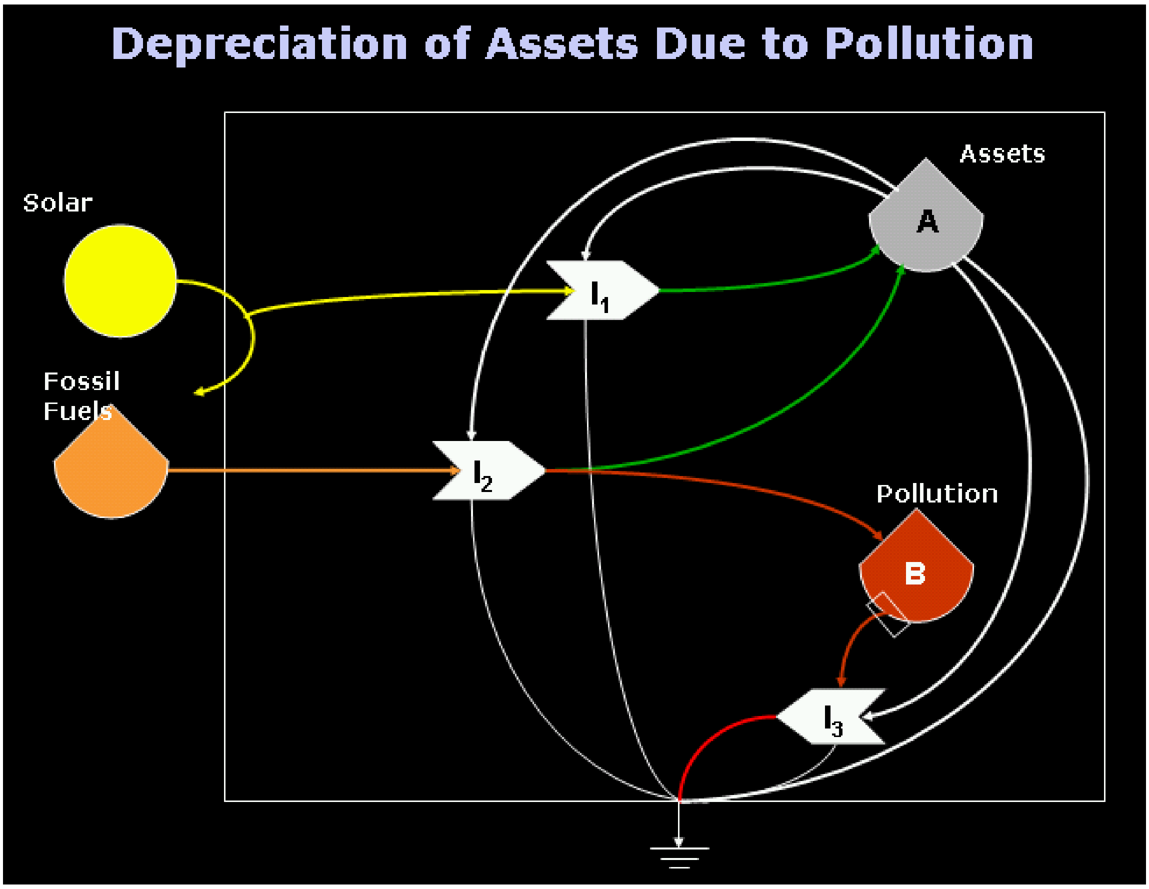
[2] when Odum was writing this in 1983, embodied energy was in fact emergy. But since embodied energy then has been used outside from the emergy algebra context (input/output energy analysis for instance, he decided to change the name to emergy.



Anyway, what **it's really important to insist that emergy accounting isn't less consistent than any other methodology when dealing with pollution.** It's generally accepted that emergy do well account for the energy production price but that exergy analysis for instance better account for externalities. After several debates in the laboratory, I insist that this critic only result from a misunderstanding of modern emergy accounting (based on the exergy definition).

Indeed some argue that the exergetic potential of a product is the better way to account for pollution. I think this is simply false: through the setup of a laboratory for irradiated metal with the french company Framatome, and also through what I studied with the Environment option at the Ecole Centrale, I learned this: the exergetic potential of a a product do well account for the energy you are wasting in a given process (that's why companies generally interest themselves for such analysis).

That's to say if the product you reject as a high exergetic potential, then is very probable you could imagine an industrial process taking advantage from the remaining energy. It also imply it's probable that a natural living process will exploit in a way this energy, this disturbing the whole ecosystem.

But it the exergetic potential is only a potential, it doesn't consider how the real carrying ecosystem is going to use the pollutant. But even low concentration of radioactive product do have such a negative impact sometimes. For instance fishes in the sea will concentrate again the radioactive particles leading to a dangerous concentration for all the food chain species.

Considering this, exergy analysis will correct its prognostic by accounting for the tabulated toxicity of the product which in turn account for the the negative effect of the real carrying ecosystem. **also notice that such a tabulated toxicity as really no more chance to be locally more valid than the negative effect resulting from a well done emergy diagram**.

So at the end, pollution exergy analysis is loosing it's homogeneity because it also relies on the toxicity model. Toxicity evaluation isn't really different than the negative impact evaluation in an emergy study, and moreover emergy already include exergetic potential [7]. **This reflexion leads me to think that the emergy analysis is by far superior because it try to organize the knowledge of the pollution process in a whole coherent and homogeneous framework bringing a single consistent result while not loosing any concept nor precision**

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