Life Faculty
University of Copenhagen

Ecosystem Services

in emergy terms:

Danish Energy Crops

Acknowledgements

This Thesis is written by Manuel Montesino, as the ending point of my studies in Agronomical Engineering thanks to the University of Copenhagen. This work is intended to all those interested in environmental valuation with previous basic knowledge in ecology. This study offers an analytical and innovative perspective in the field of ecosystems valuation. I would like to thank my supervisor, professor John R. Porter, for giving me the opportunity to work in so novel idea and for his constant words of support. I would like also to highlight the contribution of Laura Alija Ruiz and my family for the given words of encouragement along this experience.

ECOSYSTEM SERVICES IN EMERGY TERMS: DANISH ENERGY CROPS

SUMMARY

Currently, benefits generated by natural environments, such as carbon sequestration or water retention and others, are measured in economic terms based on "willingness to pay" of society (using the TEV or Total Economic Valuation). Thanks to these measurements, decisions can be made about items related to natural ecosystems in the field of politics, construction projects and quantification of financial aids for the agricultural sector.

However, a group of scientists involved in Environmental Economy, thinks that this method is not suitable, as society do not really know the true value of the functions of the ecosystems. Even more, they add that solution has to do with the energy measurement of those benefits in order to give them their real value (objective value). In contrast, another group of scientists consider that Ecosystem Services (ES) valuation based on society's opinion is completely necessary, justifying that these values are lated used as a politic tool.

Therefore, the Thesis borns on order to answer this controversy, beginning with the energy calculations of the benefits produced by agricultural environments dedicated to energy crops. Besides, it also aims to clear if the current subjective method of valuation, the TEV, is the best choice for the job of political tool or if there is instead, another better way of doing this.

To do that, It has been used an innovative method; The Emergy Method (spelled with "m"). This method consist of determining the necessary energy investment for developing services such as carbon sequestration or water retention, among others. In other words, it allows to obtain the environmental effort printed on the implementation of beneficial ecological functions for human being.

With results already obtained, it can be seen; first, the energy investment necessary for biomass production; second, the current method, based on Total Economic Valuation does not express the true value of the ecosystem functions as are undervalued in 331 dollars per hectare and year (in energy crops); third, the best way for valuing ES implies a combination of methods, the Emergy and the TEV.

Finally, through the obtention of the energy investment required by the environment for the biomass production, first steps for developing an application that allows to define the most proper areas for a biomass burner industry are given. These areas bounds the surface in which the obtention of a joule of electricity using energy crops requires less environmental effort that the same joule based on fossil fuels, taking on account the terrain, the geometry of the roads used for supplying the industry of biomass and the efficiency of the combustion process.

Table of content

Introduction

The introduction includes the contextualization of this work in order to expose the main reasons about why this project should be done, the objectives concretion or the raised questions to solve, regarding the explained context, and the minimum theoretical basis for understanding the work done.

Historical review

According to Man Yu Chang, between the years 50 and 70, is given a wide growth of industrial activities in all over the world as a consequence of the use of new technologies in this sector and the application of new chemical products. This growth begins to have negative implications on natural environments, where can be seen the results in local scale at the end of the 70's. This consequences forced researchers from different disciplines to look for solutions for protecting the threatened ecosystems. This resulted in the appearance of different methodologies for valuing those ecosystems.

From the economic science, a new branch was established destined to the economic valuation of natural environments and more questions referred to the ecosystems called environmental economy. It had his own entity at the end of the seventies (Man Yu Chang, 2000). With the purpose of natural spaces protection, these were valued economically through the application of the Total Economic Valuation (TEV) method. Otherwise, already form the beginning of the 50's it was planted the seed for what is now known as Emergy valuation method (Jorge L. Hau and Bhavik R. Bakshi, 2004; Mark T. Brown and Sergio Ulgiati, 2004). However this methodology is based on the energy fluxes analysis and required more time to find the solutions to some obstacles that arose along the way. In the 70 decade, H. T. Odum (the main creator of the method) touched one of the most important concepts of the valuation system, the differentiation of the energy qualities (Jorge L. Hau and Bhavik R. Bakshi, 2004; Mark T. Brown and Sergio Ulgiati, 2004). It was in 1983 when David Scienceman finally talked about the concept of emergy (that gives the name the valuation system) as a constriction of embodied energy. From then on the methodology has suffered constant transformations.

Since its appearance , the suitability of both methodologies for valuing the environment has been widely criticized. However of the two methodologies, the economic one is the most extended and the only one completely applied to the ecosystem services (ES) valuations generated form agricultural activities. The Emergy methodology has started to walk some steps forward in this sense:

1.- By publishing descriptive articles which highlight the importance of valuing the ES using Emergy methodology (such as that written by H.T. Odum and E. Odum titled "The Energetic Basis for Valuation of Ecosystem Services").

2.- With the appearance of practical applications of the Emergy methodology in the agricultural sector ("Emergy Evaluation of Denmark and Danish Agriculture" written by Andrew C. HAden, 2003).

3.- The erosion service already valued using emergy (“Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis” written by Matthew J. Cohen, Mark T. Brown and Keith D. Shepherd).

Objectives

Questions to solve

From the previously explained situation, it is extracted that is necessary to complete the valuation of the ecosystem services using the Emergy analysis. Therefore, the target is establishing the methodology needed to reach this purpose and obtaining the first orientate result of the ES in emergy terms using information not specifically obtained for the calculations required.

This will allow to make from the ES the perfect starting point for the comparison of both methodologies, being able to determinate the suitability of each valuation system and putting an end to the controversy referred to this question. Moreover, if the study is focused on the ES promoted by energy crops so results can provide more additional information about the renewability of the use of biomass as a combustible source and also some industrial applications.

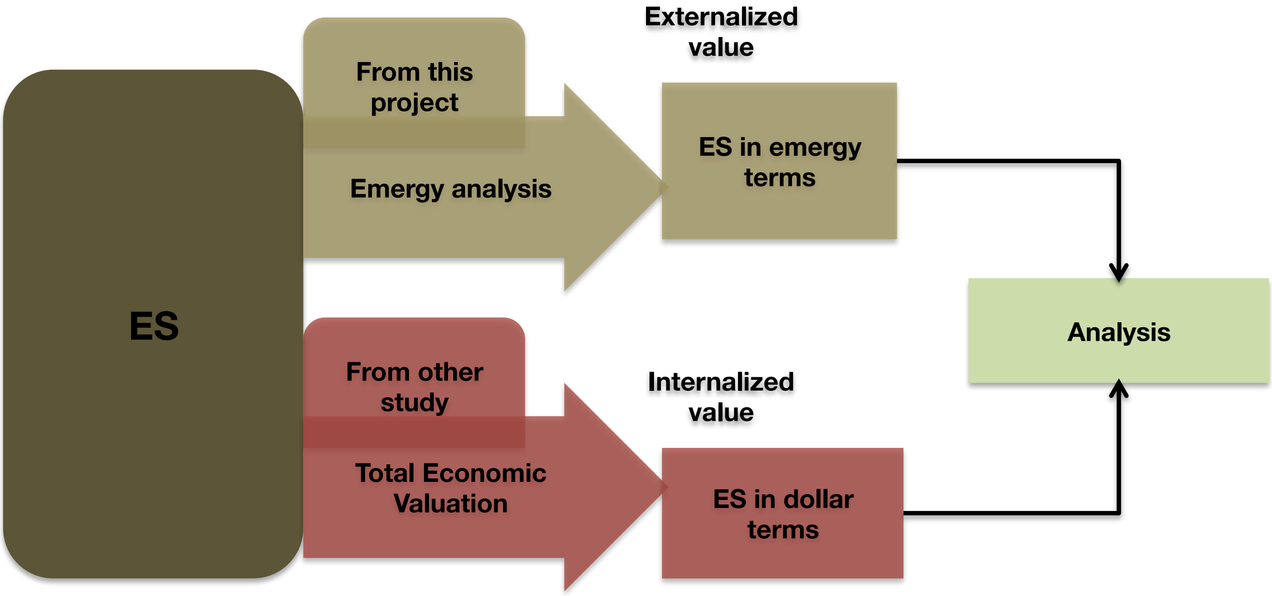
These objectives can be formulated as a question as:

- Which are the emergy and transformity values for the ES generated by energy crops?
- Is the energy from biomass more renewable than the energy from fossil fuels?
- In which way the emergy valuation can contribute to obtain energy from crops with higher renewability?
- What can be extracted from the comparative analysis of the results from both methodologies applied to energy crops?
- Is there a way to use both methodologies to obtain a combination that uses the the better aspects form both taking as a example the ES from energy crops?

First steps to walk

In order to solve these questions, it is needed to raise a working plan that goes though establishing a methodology, finding required information for applying the methodology, obtaining coherent results and contrasting them with other results from energy crops obtained using the Total Economic Valuation.

Figure 1. Simplified scheme of the project procedure



As it can be seen at figure number one, ecosystem services from energy crops are valued using two different pathways. The first one corresponds with the emergy methodology of valuation, specifically adapted to value services an functions derived from energy crops ecosystems. The second one belongs to the economic valuation methodology, already applied in some studies to energy crops such as John Porter´s report . Finally, two different results will be obtained and compare in order to find out the answers looked for with this thesis about both methodology and some concrete aspects about energy crops and their ecosystem services.

Composition

This project is divided in 4+1 sections. The first four chapters are the main ones; Introduction, Methodology, Discussion and Conclusions followed by one appendix.

- The introductions allows to the reader to contextualize the project, introduces him into the main concepts of ES valuation and informs about the main targets pursued with the realization of this project.

- The second section raises those benefits generated by each ecosystem service in order to identify the ecosystem functions on which are based and introduces the basic theory of the interconnection of ecologic process that allows finally to identify the main original energy sources that generate them. With all this, formulas are developed to calculate emergy values of those ES.

- Once results are obtained, it is played with them, being compared with the monetary values from other similar studies. That, allows to give an answer to the questions made earlier that in this section are written dilated.

- Finally the conclusions offer short, simple and concrete answers where all concepts explained before in the discussion section are condensed.

In last place, appendix corresponds to the section in which calculations are detailed and sources of information and the logic for simplifying them, are also explained.

Theoretical Approach

Emergy concepts

Emergy

Emergy is defined as “the available energy of one kind of previously used-up directly and indirectly to make a service or a product. Its units are emjoules”(Odum, 1986,1988; Scienceman,1987). For this reason, emergy is also known as the “memory of energy” (Scienceman, 1987)The emjoules are always defined by the source of emergy of reference (Odum, 1996; Brown and Ulgiati, 1999). In most cases the source of reference is sun so the units of measurement are expressed as solar emjoules (sej). In that way, not only the quantity of emergy is written, but also the quality the emergy is reflected.

In our case emergy can be defined as the work that environment has to make to obtain a certain product, i.e. reflects the effort of nature in its generation.

Transformity

In nature, like in other systems, occur transformation processes in which certain amount of energy available in their precursors result in a product or service of lower energy content (Odum, 1996). In this processes, energy of one kind is converted on another (Odum, 1996). A clear example of this, are the agro-ecosystems, where the diluted and available energy of the sun has resulted in plant tissues formation, biochemical reactions, etc. The energy content of plants (output) is lower than the incident sun radiation (input). The quotient between the emergy needed for a process and the output energy is called Transformity (Brown and Ulgiati, 1999).

The units of transformity are the emergy/energy (sej/J) although in other occasions it also can be expressed as the emergy per mass of product formed. In our study most of the transformities will be measured in emergy/mass as it can be used more easily to calculate emergy in other studies because it simplifies the data required.

By definition “the solar transformity of the solar radiation absorbed by the earth is 1.0” (Odum et al. 2000).Really there is range of transformities for almost all products in which upper limit can result from very inefficient processes and the lower limit corresponds with that below which product can not be made (Brown and Ulgiati, 1999).

Energy hierarchy

Transformity can be also understood as a measure of energy quality (the grater the work of environment to create a product or a service (with certain energy content) the greater the quality and transformity). The different energy transformities along the production chain allows ordering the energy by qualities (Odum, 1996).

Empower

Empower is the flow of emergy. It units are emergy per unit of time (Odum, 1996).

Maximum empower principle

“Self-organizing systems develop autocatalytic storages to maximize useful power transformations (Maximizing power use also maximizes the rate of the dissipation of available energy and the rate of entropy production) (Odum, 1996). In an environment with limited resources, the organism or the ecosystem that empower will be more maximized will survive (Hau and Bakshi, 2004).

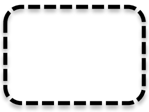
Emergy money ratio

The emergy money ratio is a quotient between solar emjoules and dollars (Odum and Brown, 2000). It can be calculated by dividing the total emergy use of a country and its gross economic product (Odum, 1998; Odum and Brown, 2000).

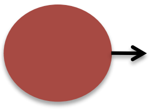
Emergy system diagram

The emergy diagram are representations of the energy pathways inside of the boundaries of the study window that determinate the flows, relations and functions for each process. Besides, it allows to analyze the inflows and outflows of the window, which are fundamentals for calculating emergy processes. In some locations, from these diagrams can be defined the equations used in simulations (Odum, 1996).

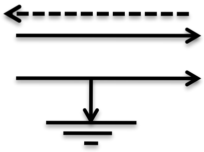
Figure 2. Main energy system symbols



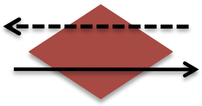
System Frame: Represents the boundaries of the window of study.



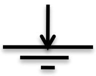
Source: all the energy inputs that crosses the system boundaries is considered a source independently of the kind of energy that inflows (information, human services, pure energies and included those which are destructive).



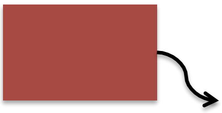
Pathway lines: Any flow is represented by a line including information, material, energy.



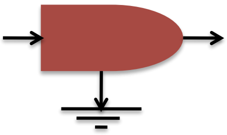
Exchange transaction: it represents the exchange of quantities of one flow by those of another.



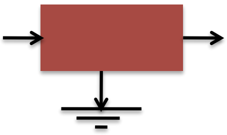
Heat sink: is the symbol that represents the second energy law, i.e. the degradation of energy in a process into a used state and not capable of further work.



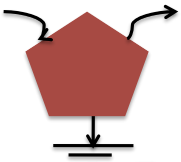
Outflow: It represents the outflow of any thing with available potential , materials or usable information.



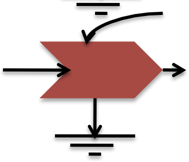
Producer: Unit that collects and transforms low quality energy under control interactions of high quality flow.



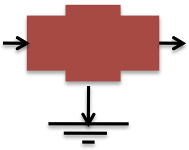
Miscellaneous box: Is used for any subsystem or structure.



Tank: represent the storage of energy within the system, storing a concrete quantity while valance of inflows and outflows stay invariable.



Interactions: represents a process in ecosystems where different required flows of energy converge.



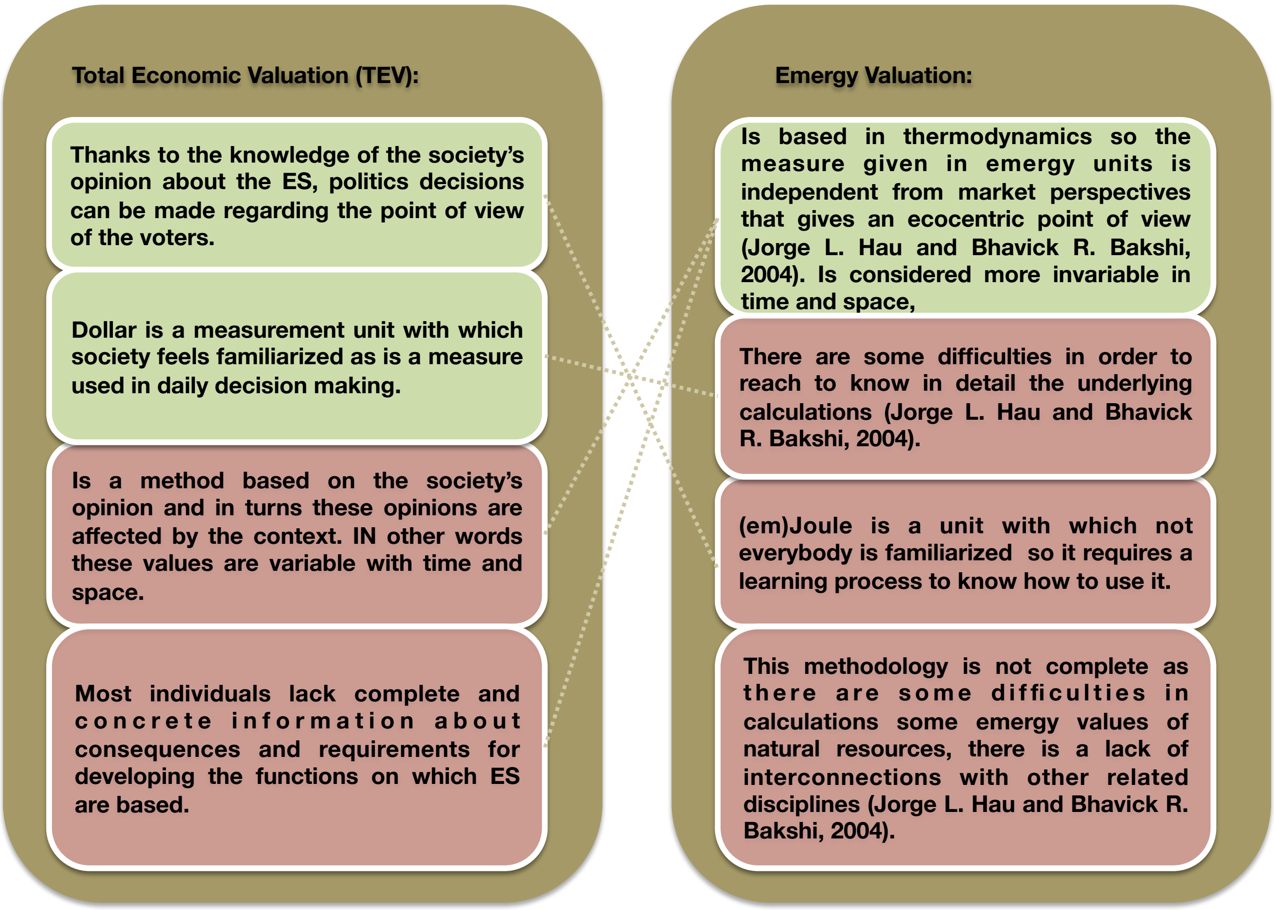
Switch: it is a symbol that indicates one or more switching actions.

The symbols commonly used are described in detail by Odum (Odum, 1983, 1994,1996). The had been slightly modified to suit the available tools for the implementation of the project. Emergy diagrams here represented are simplified representations of the emergy fluxes that could obviate some of the rules established by Odum.

Emergy vs. TEV

The existent controversy between the application of both valuation methods is not meaningless, taking on account that they are contrasting perspectives with wide applications. The Total Economic Valuation method can be summed up as the subjective valuation method (depending on the "receiver value" perspective), based on "willingness to pay" and market laws, with which result is measured in monetary terms. Otherwise, the Emergy Valuation method gives an objective value (depending on the ecocentric perspective), based on thermodynamics, with a result in emergy units.

This is derived in:



Total Economic Valuation (TEV):

Thanks to the knowledge of the society's opinion about the ES, politics decisions can be made regarding the point of view of the voters.

Dollar is a measurement unit with which society feels familiarized as is a measure used in daily decision making.

Is a method based on the society's opinion and in turns these opinions are affected by the context. IN other words these values are variable with time and space.

Most individuals lack complete and concrete information about consequences and requirements for developing the functions on which ES are based.

Emergy Valuation:

Is based in thermodynamics so the measure given in emergy units is independent from market perspectives that gives an ecocentric point of view (Jorge L. Hau and Bhavick R. Bakshi, 2004). Is considered more invariable in time and space,

There are some difficulties in order to reach to know in detail the underlying calculations (Jorge L. Hau and Bhavick R. Bakshi, 2004).

(em)Joule is a unit with which not everybody is familiarized so it requires a learning process to know how to use it.

This methodology is not complete as there are some difficulties in calculations some emergy values of natural resources, there is a lack of interconnections with other related disciplines (Jorge L. Hau and Bhavick R. Bakshi, 2004).

Figure 3.Positive and negative aspects in using both methodologies

All are weighty reasons, either to the proper reflection of the environmental value either in its application on project development or in decision making. However, as it can be appreciated at figure number 2, the most shortcomings of a method is the strength of the other one and vice versa. There is only one in Emergy Valuation that is not related to others in TEV, as it is a shortcoming of the method itself. However this weakness can be solved by inverting more time in developing the methodology.

Methodology

The methodology is mainly based on analysis of scientific articles. Into them, two kind of information are defined; a theoretical approach useful to create formulas in order to obtain emergy and energy values, and data recorded which can be used later to fill in the formulas.

Therefore, each chapter analyses a concrete ecosystem service. Each chapter contains four subsections; benefits, which specifies the concrete benefit produced by the service and the crop influences; emergy and energy parameters, which describes the variables in which emergy and energy are measured in general terms; emergy diagram, which shows the resources of energy and their relationship with the service (flow of emergy); and finally the evaluating method, which specifies the formulas.

In emergy calculations, the emergy per year and per hectare are calculated because of; most of the energy crops area in Denmark are in scientific test so besides being a very small area it is also a very volatile value; Obtaining the total emergy value it only useful for current situation but calculating the solar emjoules per hectare and year is useful for longer time, it has a more atemporality character.

Biomass production

Benefit

The main target cultivation energy crops is biomass production. It represents the fundamental inflow of energy and matter to markets and society.

Energy and emergy parameters

- Energy measurements is provided by the energy content of the biomass.
- Emergy is the result of the energy resources in Danish energy agriculture, multiplied by each respective transformity.

Emergy diagram

According to Andrew C. Haden´s work, the sources if energy in agriculture can be classified in four groups:

- Renewable sources; contains the sources provided by the ecosystem such as sun, wind, rain and geological inputs.
- Purchased inputs; manmade materials such us fertilizers and pesticides. Fuel is also included.
- Labour: work done by farmers.

The sum of this contributions is the energy available for a crop for growing up and producing, so by definition, it constitutes the emergy of the process. At the end of the production season, biomass is harvested and traded by money. This money gets out from the boundaries of the study window when it is exchanged by purchased an labour windows.

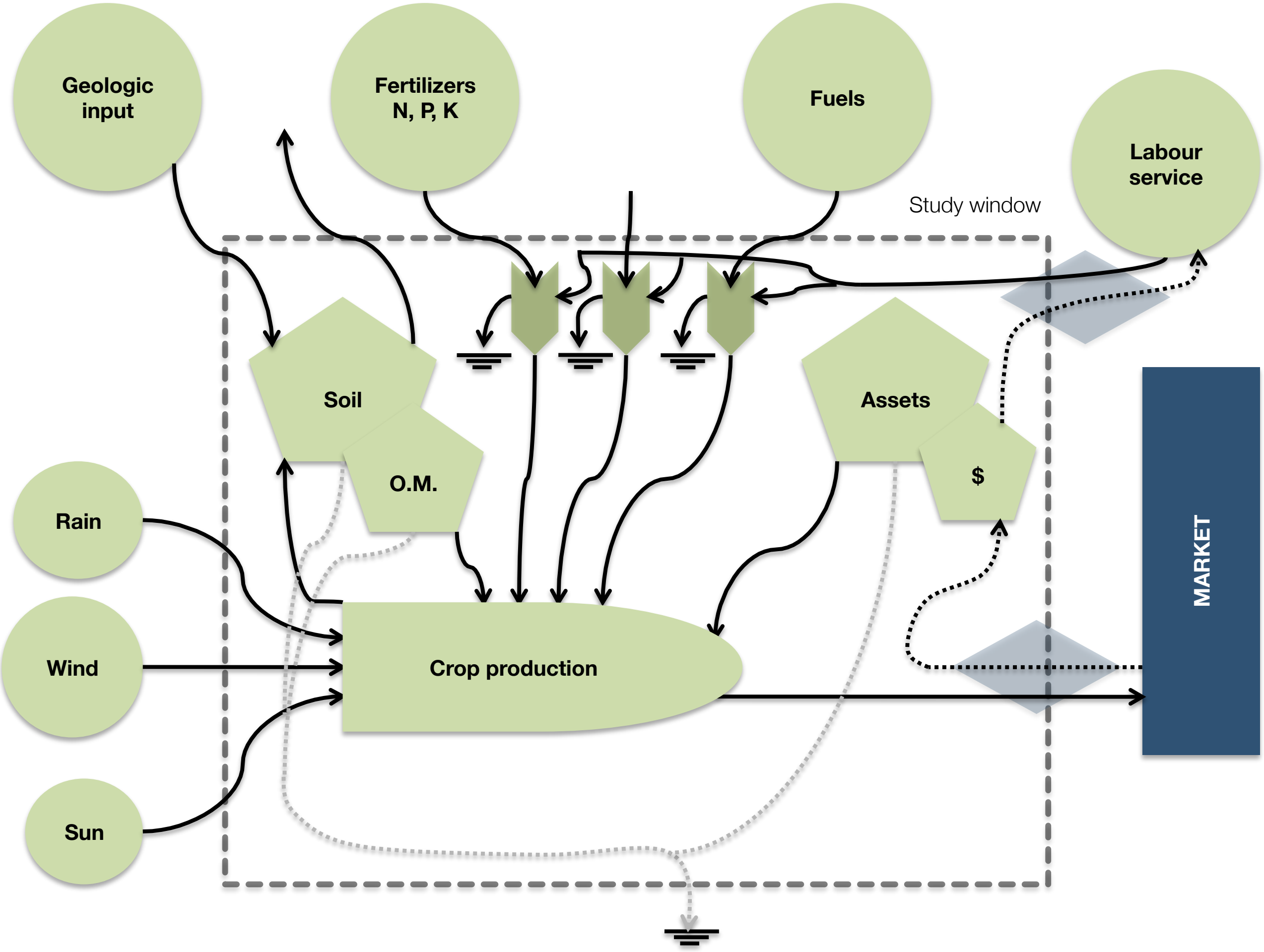


Fig.4. Simplified emergy diagram in Danish agri-

Emergy and Energy equations

In order to calculate the energy inverted by unit of area to lead the process of biomass production:

- Main emergy inputs in Danish agriculture (indexed by Andrew C. Haden) had to obtained separately.
- Result form the step above, should be added to obtain total emergy input.
- Meanwhile, an average quantity of energy of biomass is needed for the year 2009. In order to do that, predictions estimated by Borjesson in 1996 are used.

- Once both values are solved, emergy is divided by the energy to get the transformity value.

This figure can be finally compared with transformity values form other energy resources, such as fossil fuel. The procedure explained above is showed in figure number two, in which time advances from the left to the right.

Emergy for biomass production

The calculations of the emergy inverted by specified agricultural resources (numbered paragraphs above) are based on the equations described by Andrew C. Haden in his work *“ Emergy evaluations of Denmark and Danish Agriculture”* published in 2003.The getting in inflow energies are first calculated and later are transformed into solar emjoules by multiplying them by their respective transformities (calculated most of them originally by Odum in 1996).

Renewable emergy formulas

Solar emergy:

$$\text{Solar emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Solar energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\times\ \text{Solar transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Solar energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=\text{Land area dedicated for biomass production}\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot\ \text{Average insolation}\left(\frac{\text{J}}{\text{yr}\cdot\text{m}^2}\right)\cdot\ (1\text{- Albedo})$$

Wind emergy:

$$\text{Wind emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Wind energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Wind transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Wind energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=\ \text{Reference height (m)}\cdot\ \text{Land area (ha)}\cdot\ \text{Air density}\left(\frac{\text{kg}}{\text{m}^2}\right)\cdot\left[\frac{0.4\cdot\ \text{Wind speed}\left(\frac{\text{m}}{\text{sec.}}\right)}{0.6}\right]^2\cdot\ {}^1\!/_2$$

Rain emergy:

$$\text{Rain emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Rain Chemical Potential Energy (CPE)}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Rain transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{CPE}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=\text{Precipitation}\left(\frac{\text{m}}{\text{yr}}\right)\cdot\ \text{Land area (m}^2\text{)}\cdot\text{Water densisty}\left(\frac{\text{g}}{\text{m}^3}\right)\cdot\ \text{(1-Run off coefficient)}\cdot\ \text{Gibbs Free Energy}\left(\frac{\text{J}}{\text{g}}\right)$$

Geochemical emergy:

$$\text{Geochemical emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Geochemical energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Geochemical Transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Geochemical energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=\text{Heat flow}\left(\frac{\text{J}}{\text{yr}\cdot\text{m}^2}\right)\cdot\ \text{Land area}\left(\frac{\text{m}^2}{\text{ha}}\right)$$

After those calculations renewable emergy is written as:

$$\text{Renewable Emergy Resources}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Solar emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Wind emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Rain emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Geochemical emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

One year referred to renewable energy inputs differ from the year when is talked about purchased inputs or biomass production, as in the first case one year is referred to a whole year and in the second one to a crop season. This crop season varies in number of months depending on the kind of emergy crop and its management. Then all measures had to be transformed to work with the same time basis. For annual crops, renewable inputs should be divided by the number total number of months in a year (12 months) and then multiplied by the number of them that biomass keeps on growing.

In the emergy crops, annual and multi annual crops are valued. Annual crops are defined as as those ones which remains at the plot less than a year. After this time biomass is harvested. In our case the crops that match with this description are wheat, rape and potatoes. Multi annual crops instead are the crops which is needed more than year to be harvested. In this group are included, Lucerne, different kind of grasses, Sugar beat and Willow. In this las group there are also different kinds of harvesting in this group, there also different times of harvesting. While Salix stay untouched at the plot for four-five years, grass biomass is harvested annually, although plants remain on at the plot.

Multi annual crops are not necessary to be corrected, as in the article in which data are recorded, productions are presented with the calculations already done.

Purchased inputs

Pesticides:

$$\text{Pesticides emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \text{Average pesticides used}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Pesticides transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

Fertilizers:

In case of fertilizers, calculations are divided according to the main elements that constitute them,i.e. Nitrogen, Phosphorus and Potassium are calculated separately:

$$\text{Nitrogen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \text{Amount of nitrogen}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Nitrogen transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

$$\text{Phosphorus emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \text{Amount of phosphorus}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Phosphorus transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

$$\text{Potassium emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \text{Amount of potassium}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Potassium transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

$$\text{Fertilizers emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) =$$

$$\text{Nitrogen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) + \text{Phosphorus emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) + \text{Potassium emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Mechanical Equipment:

$$\text{Mechanical equpment emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \frac{\text{Embodied energy}\left(\frac{\text{MJ}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Mechanical equipment transformity}\left(\frac{\text{seJ}}{\text{kg}}\right)}{\text{Mechanical embodied transformation}\left(\frac{\text{MJ}}{\text{kg}}\right)}$$

Fuel Emergy:

$$\text{Fuel emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Average hours of machinery use}\left(\frac{\text{h}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Average motor fuel consumption}\left(\frac{\text{l}}{\text{h}}\right)\cdot\ \text{Diesel energy content}\left(\frac{\text{J}}{\text{l}}\right)\cdot\ \text{Motor fuel transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

Services; Labour

$$\text{Labor emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Total employees in Agriculture}(\text{ind})\cdot\ \text{Average caming}\left(\frac{\text{DKK}}{\text{month}}\right)\cdot$$

$$\cdot\ \text{Exchange}\left(\frac{\text{USD}}{\text{DKK}}\right)\cdot\ \text{Months a year}\left(\frac{\text{month}}{\text{yr}}\right)\cdot\text{Money transformity}\left(\frac{\text{seJ}}{\text{USD}}\right)\cdot\left(\frac{1}{\text{Total agricultural area (ha)}}\right)$$

Pest control

Benefit

Energy crops provide refuge for phytophagous predators, which maintain an equilibrium balance of insect population through depredation. This decreases damage and improve yield. In long term an ecological equilibrium that prevents herbivore insects from reaching pest status (Zhang et al., 2007).

Another benefit of this natural function is avoiding or reducing the use of chemical products in pest management, which causes several problems as resistance development, human health damages, bringing down predation rates by killing predators and other unforeseen negative consequences.

Energy and Emergy parameters

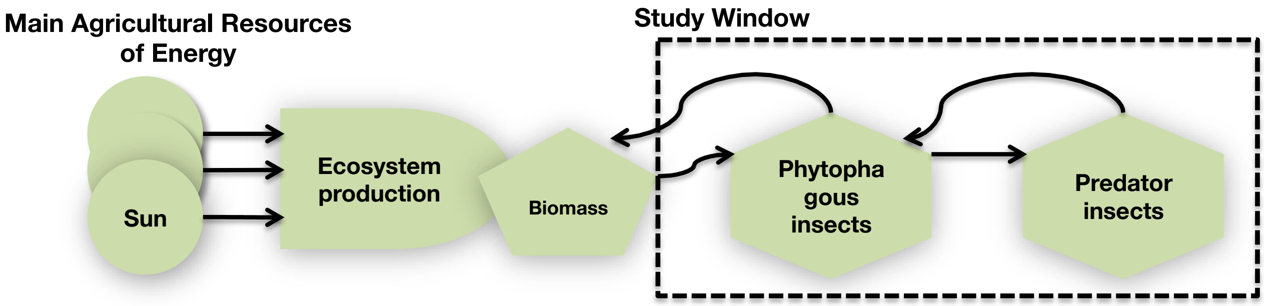
For pest control activity, is needed the existence of prey and predator species, in other words, it is necessary the existence of the trophic chain fragment that contains both species. Energy, in biological chains, flows in the ecosystem through the trophic chain. Along this pathways, energy is transformed into different forms of energy. The energy content of each level of this chain is less than the previous one. However, the emergy remains constant and is equal for all steps (Odum, 1996). However transformity increases along this pathway and so is the energy hierarchy(Odum, 1996). Then is deduced that the emergy for the existence of a trophic chain is given by the fraction of the first energy transformer (plants) that us derived to the maintenance of the herbivorous species. I.e., the emergy can be quantified as the fraction of plant emergy consumed in a given area by phytophagous insects.

Predation is the ecosystem function that originates the ecosystem service.Therefore, the measurement of wealth should be done by valuing the effort that a predator has to make for hunting.

Emergy diagram

Emergy diagram is represented by the trophic chain in an agro-ecosystem, constituted by a crop, phytophagous and predator species. The main source of energy and matter for predators species is represented by herbivore insects, i.e. by the predecessor organisms in the food chain. Predators feeding exercises a regulatory pressure on phytophagous population, which is represented by arrows running form the back to the front levels of food chain. In turn, the source of energy for those phytophagous insects is the proportion of biomass eaten by them. The source for crops are those explained the chapter before (here represented in simplified form and converted to "Main Agricultural Sources of energy" in the scheme).

Fig.5. Emergy diagram of the three leveled food chain in energy



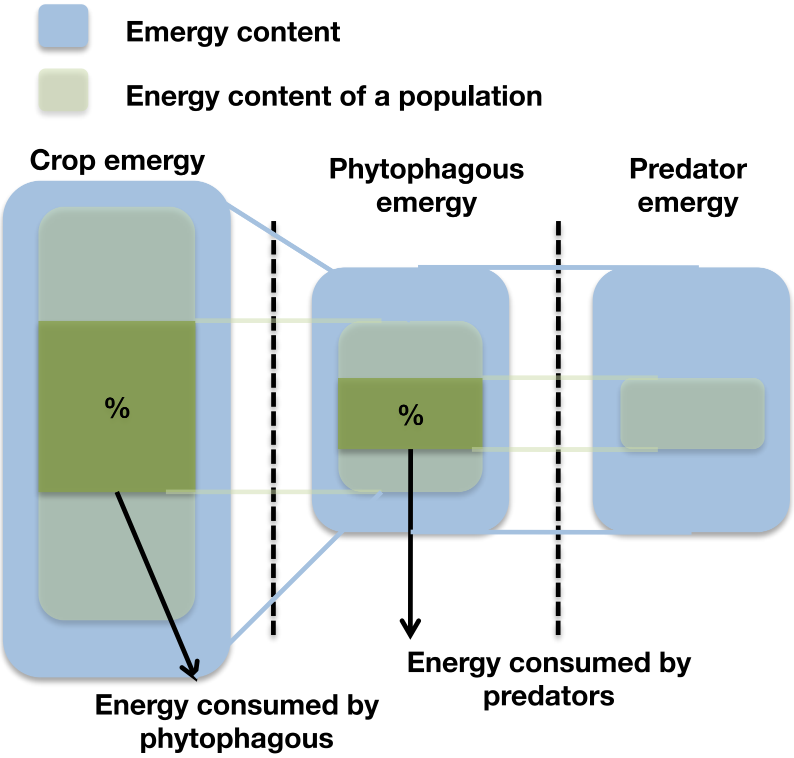
In this study, a concrete part of food chain is being studied, so the emergy that gets into the study window is given by the proportion of biomass emergy derived into the chain.

Emergy and energy equations

Predator emergy formulas

As it is said in previous sections, the emergy of pest control is considered the emergy for the maintenance of prey and predator species in energy crops.

Fig.6. Emergy and energy flow for the concrete study area



As it is represented at the figure number four, the energy content of each trophic chain level (represented by red rectangles) is reduced from one to the next one. However emergy (blue rectangles) is considered equal inside the study window (for phytophagous and predator insects) but lower than outside the study window. That is because emergy that inflows at the boundaries of the study area is equal to the biomass eaten by those insects, multiplied by biomass transformity and that emergy is also needed to maintain a higher level in equilibrium conditions. So emergy in pest control can be expressed as:

$$\text{Pest control emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Energy of biomass ingested by phitophagous}\left(\frac{\text{J}}{\text{ind.}\cdot\text{yr}}\right)\times\text{ Transformity of biomass}\left(\frac{\text{seJ}}{\text{J}}\right)\times\text{ N}^{\text{o}}\text{ of individuals}\left(\frac{\text{ind.}}{\text{m}^2}\right)\times\text{ Area}\left(\frac{\text{m}^2}{\text{ha}}\right)$$

Cereals is the crop in which this characteristics are going to be quantified as is the energy crops in which data were available. For further calculation details, see Appendix A.2.

Hunting energy formulas

Energy dedicated in hunting is difficult to quantify without making approximations and suppositions:

- First supposition made is that the effort inverted in hunting is never going to be higher than the energy content of the hunted insect (this means that predator not bothered to look for food when its reward is less than the effort in looking for it).
- In our study, a hairpin is going to be created supposing that the energy can fluctuate from zero to a maximum value that is equal to the quantity of energy explained in the previous point (energy content of hunted insect). With this rule, it is only known the limit values of the hunting travel but it is not known the exact values and the frequency with which this value is reached. In order to take a concrete value and owing to the lack of studies addressing this item, the arithmetic mean is taken as a representative value of hinting energy,

The second approximation comes form the idea that hunting energy changes according to phytophagous density. When its density grows up, energy inverted is less as the predator does not need to travel so far to fin food. On the contrary, when population density decreases, hunting energy is higher. If hunting energy would be measured and its frequency would be represented, the mode moves according to the phytophagous density. Due to the lack of data, it is supposed a normal distribution with a mode equal to mean and situated at the central point and between zero and maximum energy considered.

Then, hunting energy is described by:

$$\text{Maximum value (J/yr/ha)} =$$

$$\text{Dry weight phytiphagous insect}\left(\frac{\mu\text{g}}{\text{ind}}\right)\times\text{Energy content}\left(\frac{\text{J}}{\mu\text{g}}\right)\times\text{ Phytophagous density}\left(\frac{\text{ind}}{\text{ha}\cdot\text{yr}}\right)$$

After calculating emergy and energy values, transformity is expressed as their respective division.

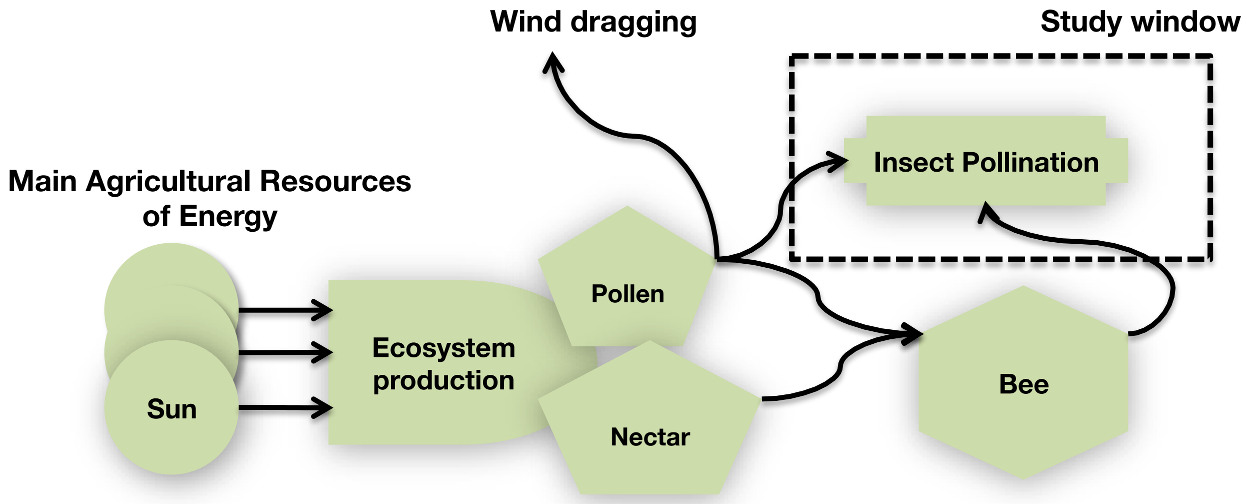
Pollination

Benefit

Pollinations is the service provided by nature that helps crops from fecundating the stile of their flowers and therefore from starting to move nutrients form the plant to the embryo, branding the beginning of food production. This is translated into higher yield and quality of food production (Delaplane et al., 2000).

Emergy and energy parameters

There are several flying insect species that contribute to pollination in crops. However, in our case the measurement of the services that one carried out by bees as they represent the 73/ of recorded visitors in plants that require pollinators in all over the world (Free, 1993; Kremen, 2008). That is why this specie is considered most important pollinator (Delaplane et al., 2000; Roubuck, 1995; Nabban and Buchman, 1997).



The function of pollinating consist on pollen transporting by flying bees. Therefore, the emergy is given by the emergy of the two essential components of pollination; the bee and pollen. In other words, the emergy of pollination is the sum of the bee emergy and pollen emergy. The energy of the ecosystem function, which is necessary to calculate transformity, is concreted in the flight energy.

Emergy diagram

As it can be seen at the Emergy diagram, the study window contains pollination process and it has two different inputs;

- The pollen produced by plants.
- Bees, necessary for insect pollination trough the flight form flower to flower.

The emergy for developing bees and pollen is the emergy necessary for insect pollination. Pollen emergy is equal to the emergy needed for making the crop growing up till flowering (the representation of sources of energy in crop growth has been simplified to focus attention on pollination representation). Emergy of a bee is that one which satisfies their energy requirements in form of pollen and nectar.

Fig.7. Emergy and energy flow in pollination service

The flight from one flower to another is the energy of the service provided by insects in pollination and represents the switching on process for ovules fertilization and therefore for seeds and food production (output of the study window).

Emergy and energy equations

Bee emergy

The emergy requirements of bees are satisfied through the consumption of honey, elaborated with nectar and pollen. In order to obtain the emergy requirements for bees as pollinators a whole hive food input is analyzed for a year. So the energy analysis includes not only the energy to reach adult state, but also to keep on alive.

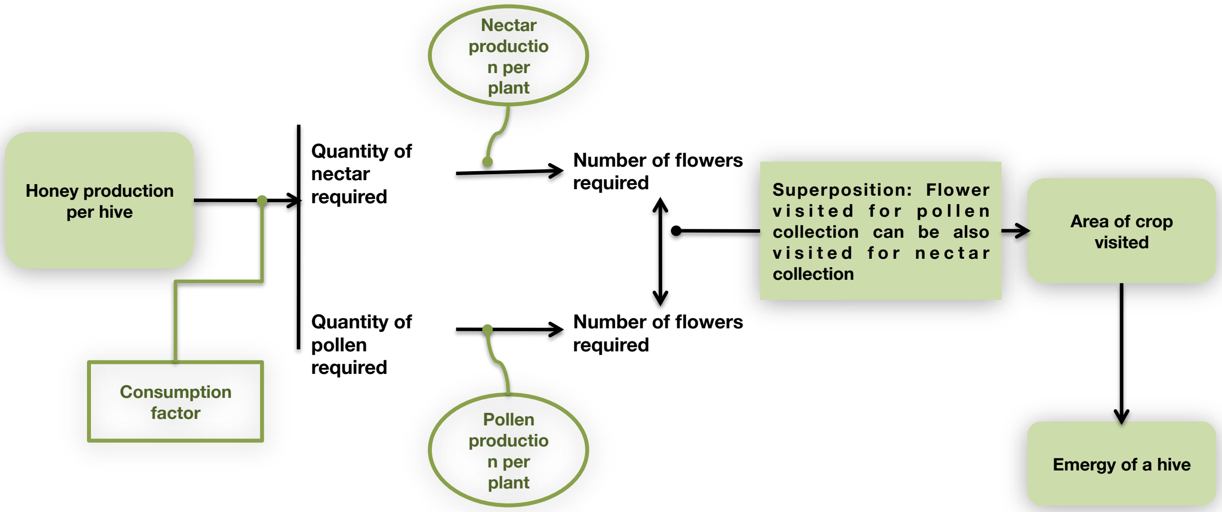


Fig.8. Procedure in bee emergy calculations

A methodology for bee emergy calculations is that one illustrated in figure number six. From honey production, bees just consume a part of it. Therefore, It can be calculated the pollen and nectar requirements to elaborate that amount of honey. From that figure, it can be estimated the amount of flowers visited by bees. However, a flower visited for pollen collecting can be also be visited for nectar collection, in other words, flowers visited can not be expressed as the sum of flower visited for nectar and pollen collection as it is needed to take into account the superposition. This superposition is considered one in order to make this procedure analog to multiplying nectar and pollen necessities by their respective transformities and because of knowing the minimum emergy quantity.Once flowers are already calculated, the can be associated with an area and then with a emergy quantity. As it is written at the beginning that is the emergy for a whole colony in one year. A hive is expected to cover in pollination a determinate area round the hive so finally solar emjoules per year and hectare can be calculated.

So:

$$\text{Pollen requirements}\left(\frac{\text{grain}}{\text{yr}\cdot\text{hive}}\right)=\text{Anual pollen necessities}\left(\frac{\text{grain}}{\text{yr}\cdot\text{hive}}\right)\cdot\left(\frac{\text{Honey consumed}}{\text{Total honey production}}\right)$$

$$\text{Nectar requirements}\left(\frac{\text{g of sugar}}{\text{yr}\cdot\text{hive}}\right)=$$
$$\text{Anual nectar necessities}\left(\frac{\text{g of nectar}}{\text{yr}\cdot\text{hive}}\right)\cdot\text{Sugar content}\left(\frac{\text{g of sugar}}{\text{g of nectar}}\right)\cdot\left(\frac{\text{Honey consumed}}{\text{Total honey production}}\right)$$

$$\text{Pollen bee consumption emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\frac{\text{Pollen requirements}\left(\frac{\text{grain}}{\text{yr}\cdot\text{hive}}\right)\cdot\text{Emergy of a crop}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{\text{Pollen production}\left(\frac{\text{grain}}{\text{ha}}\right)\cdot\text{Pollination area}\left(\frac{\text{ha}}{\text{hive}}\right)}$$

$$\text{Nectar bee consumption emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\frac{\text{Nectar requirements}\left(\frac{\text{g of sugar}}{\text{yr}\cdot\text{hive}}\right)\cdot\text{Emergy of a crop}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{\text{Nectar production}\left(\frac{\text{g of sugar}}{\text{ha}\cdot\text{yr}}\right)\cdot\text{Pollination area}\left(\frac{\text{ha}}{\text{hive}}\right)}$$

Pollen emergy

First of all, pollen involved in pollination is tried to be estimated. It is known that pollen transported by bees cliff to their bodies and are afterwards deposited. This quantity of pollen can be estimated form the number of seeds but taking into account two efficiency losses;

- First reduction: Not all the pollen transported reaches to build polliniferous tubes and getting to the ovule.
- Second reduction: Aborting. During the growth of the embryo, death takes place caused by different reasons.

In this project, these two losses are represented as one single coefficient with the noun “pollination efficiency coefficient” (PEC). To estimate the number of grains transported by is necessary to divide total seed produced through insect pollination by PEC coefficient.

In case of most energy crops, if not all, insect pollination is mixed with wind pollination. In several studies, seeds produced by plants are recorded, so this figure has to be multiplied by by a coefficient which expresses the impact degree of insect pollination against wind one as a percentage. That means that finally, the amount of grains involved in this environmental function can be calculated from the total seed production using:

$$\text{N}^{\text{o}}\ \text{of pollen grains involved in insect pollination}\left(\frac{\text{grain}}{\text{yr}\cdot\text{ha}}\right) = \frac{\left(\text{Total seed number}\left(\frac{\text{grain}}{\text{yr}\cdot\text{ha}}\right)\cdot\%\text{degree of insect pollination impact}\right)}{\text{PEC}}$$

$$\text{Insect pollination pollen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \frac{\text{N}^{\text{o}}\ \text{of pollen grains in insect pollination}\left(\frac{\text{grain}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Emergy of a crop}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{\text{Total pollen production}\left(\frac{\text{grain}}{\text{yr}\cdot\text{ha}}\right)}$$

Total Insect pollination emergy is:

$$\text{Insect pollination emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = \text{Insect pollination pollen emergy} + \text{Nectar bee consumption emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) + \text{Pollen bee consumption emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Pollination energy

Pollination energy is defined by the energy of flight. This energy has been already measured by authors as Southwick and Pimentel in energy by distance unit. So establishing the distance traveled for pollination (also calculated by Southwick and Pimentel), the energy of the service is given by the multiplication of both terms. However result has to be divided by the pollination area (previously calculated) to obtain the energy per unit of area.

$$\text{Insect pollination energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right) = \frac{\text{Pollination distance}\left(\frac{\text{km}}{\text{yr}}\right)\cdot\text{energy consumption in flight}\left(\frac{\text{J}}{\text{km}}\right)}{\text{Pollinationa area (ha)}}$$

Now transformity will be the result of dividing Insect pollination emergy per insect pollination energy.

Erosion control

Benefit

The crop existence allows avoiding erosion in several ways:

- Direct strike on soil from rainwater drops, which causes the disaggregation of soil particles (Morgan, 2005;Terrence et al., 2002; Brondford and Huang, 1996; Stone et al., 1996; Pimentel and Kounang, 1998), is avoided. This disaggregation makes soil particles easier to transport (higher transportability) increasing the erosion rate.
- Roots offer extra mechanical strength, comprising the root system (Morgan, 2005).
- Crop protects soil from wind, reducing the force of wind and increasing the soil resistance (Morgan, 2005; Terrence et al., 2002).
- Water infiltration is improved by vegetation roots. This decreases the amount of water that runs-off. Roots also acts as mechanical soil holder. The plant stem reduces the speed of water flux, decreasing with that the erosive power of running water (Morgan, 2005; Terrence et al., 2002).
- In an indirect way, organic matter decayed can also improve soil structure, The adhesion of soil particles is stronger, making particles heavier and then with lower erosivity (Terrence et al., 2002).

All of this is translated into lower topsoil loss. The losses of the upper soil layer is important in productivity losses due the drag of nutrients (Weesies et al., 1994); Lal, 1995; Mulengera and Payton, 1999; Terrence et al., 2002; Morgan, 2005), in water contamination that can result into environmental problems (Morgan, 2005) such us pesticides that firstly were absorbed by sediment particles and are transported now from the plot to water currents (Terrence et al., 2002).

Emergy an energy parameters

Erosion analysis is centered on organic matter losses. Organic matter is one of the most import components of soil as its loss is translated into soil structure degradation, nutrient depletion and therefore productivity declination (Morgan, 2005). A high concentration of this soil component in lakes rivers, etc. has an important impact on natural environment as for example it is the reason of the phenomenon eutrophication. That is why erosion benefit can be measures according to the emergy and energy of organic matter evacuated.

Soil erosion emergy

In soil erosion phenomenon, two agents can be distinguished;

- The erosive agents; water and wind are the natural erosive agents that provide energy for organic matter drag outside the plot.
- The transported agent: as it is said, organic matter is the most valuable soil component for determining benefits and damages.

The emergy of soil erosion is given by the energy necessary for this phenomenon, i.e. the energy contributions from wind, rain and soil organic matter formation. Crop benefits are introduced as soil organic matter formation and the erosion rate.

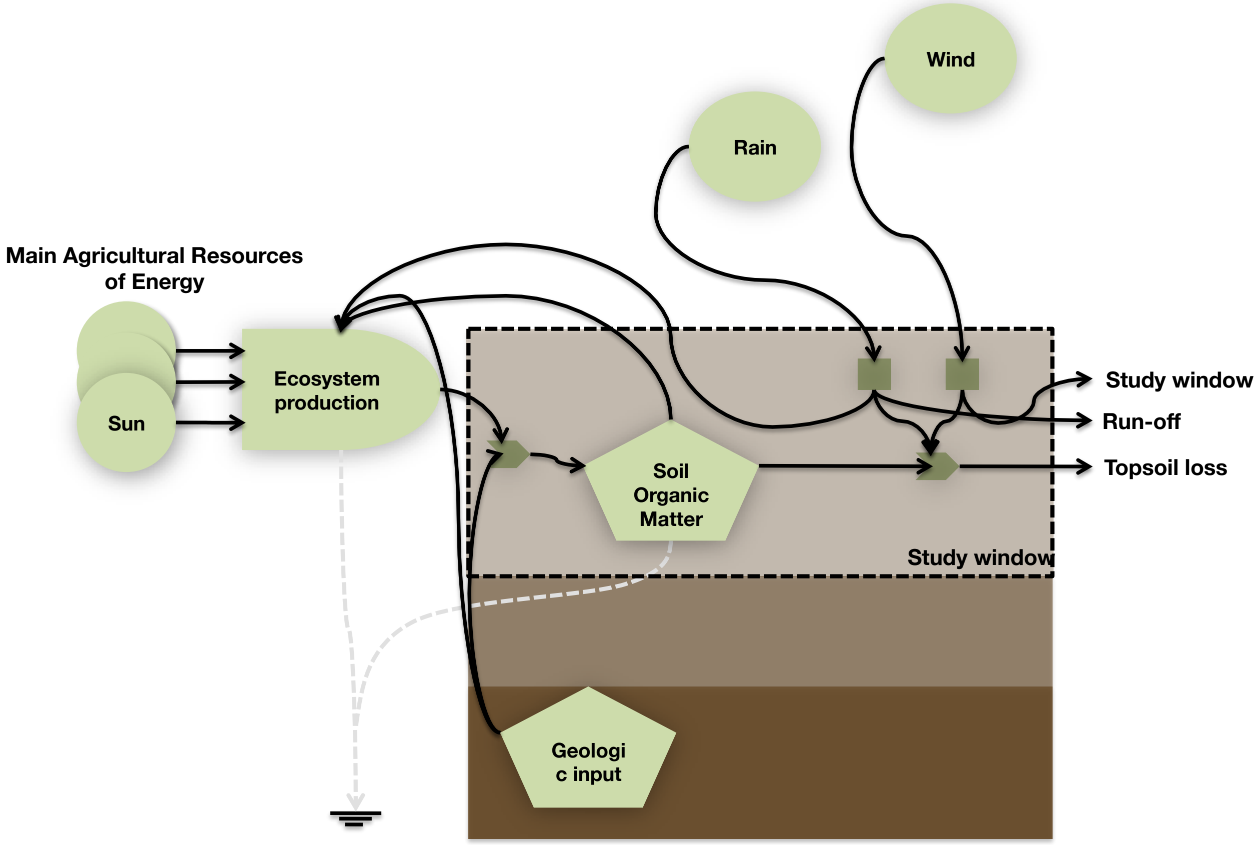
Soil erosion energy

The soil erosion is given by the loss of organic matter, so soil erosion energy is calculated as the energy quantity of dragged soil organic matter.

Emergy diagram

Soil erosion effects depends on the soil erosion agents intensity (erosivity of wind and rain) and the soil resistance (erodibility) (Morgan, 2005) Erodibility, in turns, depends on soil composition that is a mixture of mineral elements from sedimentation, weathering of the parent rock, etc. (here presented by geologic inputs) together with organic compounds derived from biological activity from plants and soil organisms (whose activity is based on plant organic matter contribution (heterotrophs) or sun and mineral contribution (autotrophs). The window of study is located at the upper layer of soil, so both are taken into account by quantifying the energy provided by the crop as death organic matter and the mineral contributions.

Fig.9. Soil erosion emergy diagram



The erosivity of wind and rain is also taken into account by calculating the energy of wind and rain contribution as energy input as it has been calculated in other ecosystem services.

Emergy and energy equations

Rain, Wind, Geologic and Organic matter emergy formulas

Rain and wind formulas are already raised some paragraphs above. The only difference between previous situations and this one is the fact that now for emergy calculations is taken into account the filtered and unfiltered rainwater as both parts can cause soil erosion (through raindrops in case of filtered water and run off for unfiltered water). In wind case, the erosive energy can be considered all the energy of wind as the absorbed part is the energy lost by friction which causes soil particles disintegration and non absorbed energy serves for particles transportation. So:

Rain emergy

$$\text{Rain emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Chemical Potential Energy of rain (CPE)}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Rain transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Chemical Potential Energy of rain}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Precipitation}\left(\frac{\text{m}}{\text{yr}}\right)\cdot\ \text{Land area}\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot\ \text{Rain density}\left(\frac{\text{g}}{\text{m}^3}\right)\cdot\ \text{Free Gibss Energy}\left(\frac{\text{J}}{\text{g}}\right)$$

Wind emergy

$$\text{Wind emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Wind energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\text{Wind transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Wind energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Reference height}(\text{m})\cdot\ \text{Land area}\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot\ \text{Air density}\left(\frac{\text{kg}}{\text{m}^3}\right)\cdot\left(\frac{\text{Wind speed}\left(\frac{\text{m}}{\text{sec}}\right)}{4}\right)^2$$

Geologic emergy input

For Geologic emergy input it is considered that the weathering of the bedrock is equal to the steady state erosion rates according to Chen et al.:

$$\text{Geologic input}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Weathering bedrock rate}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Geologic input transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

Organic mater emergy

The organic matter provided by the crop is estimated to be equal to residues left form harvesting that remains at the plot:

$$\text{Organic matter emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Crop emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Residues proportion}(\%)$$

Energy loss in soil erosion

Energy loss in soil erosion is equal to what other authors call the energy of “Top soil loss” which is calculated from the organic matter energy loss:

$$\text{Energy loss in soil erosion}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Soil organic matter loss}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Organic matter energy}\left(\frac{\text{J}}{\text{g}}\right)$$

$$\text{Soil organic matetr loss}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)=\text{Erosion rate}\cdot\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\ \text{Organic matter percentage in soil}(\%)$$

Nitrogen cycle

Benefit

The benefits of nitrogen cycle in agro-ecosystems are:

- Soil nitrogen enhances plants in order to produce food (John R. Porter, 2009).
- It retention in soil is also important as if it released to environment it can degrade ecosystems and services they provide, having a potential impact on human health and well-being (EPA). Most important impact is that on water quality; agricultural nitrogen is the major contributor to eutrophication (Mosier et al., 2004).

Emergy and energy parameters

In the nitrogen cycle in agricultural environments there are two principal external sources of nitrogen. The first one is the contribution through the use of fertilizers and the second one is the fixation of the atmospheric nitrogen by soil microorganisms. Mineralization it can not be considered here a source of nitrogen as it is an internal transformation of nitrogen in the study window. So the emergy of this mineral retention in agricultural soils is given by the emergy of both process.

After one year valuing the inflow and outflow of nitrogen in soils, it is conclude that there is an storage of this element in it. This storage is the natural function that provides the ecosystem service and benefits. So the energy measurement of the storage is the value of the benefit in energetic units.

Emergy diagram

The nitrogen comes into the agricultural soils through two principal activities; fertilizing (human activity) and fixation (bacteria activity). Once nitrogen us introduced inside, it flows through several pathways suffering chemical transformation in a relationship network built between plants, soil and bacteria. During this changes some nitrogen losses take place using three ways to get out from the system; the first one in gaseous state (volatilization by denitrifying bacteria), the second one given by the drag of soluble forms through deep percolation of water (leaching) and the third one in solid form through crop harvesting.

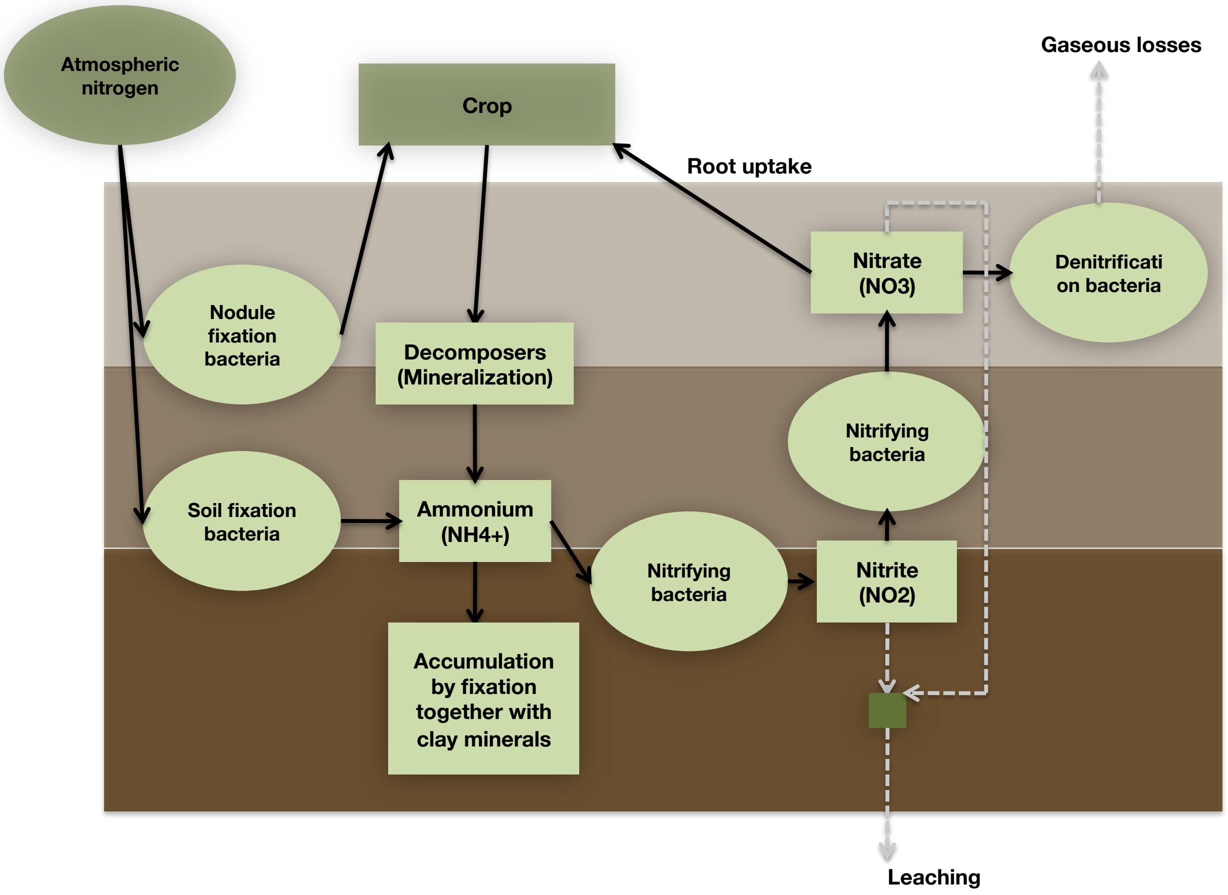
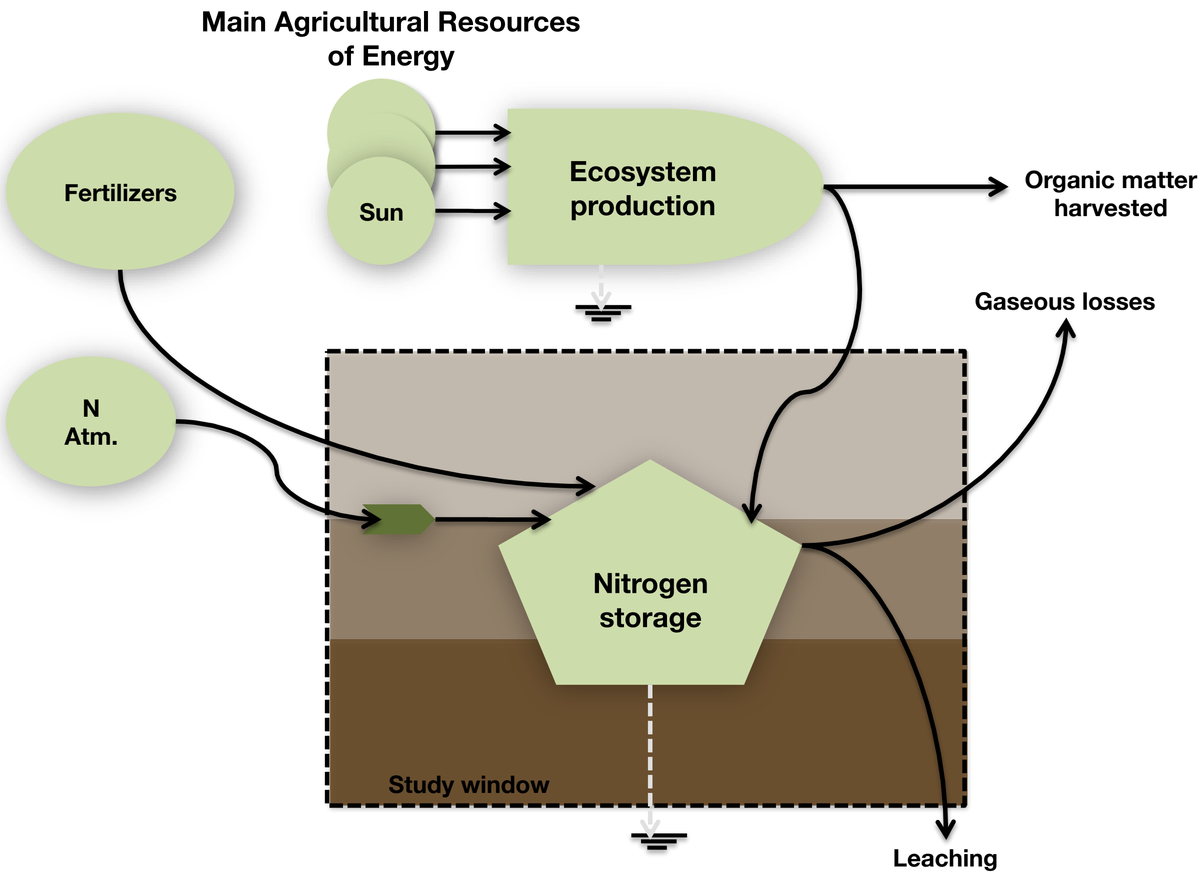


Fig.10. Nitrogen flow in agricultural ecosystems

The nitrogen that remains into the cycle keeps moving from one place to another being part of bacterias, plants or adsorbed by soil particles. In this study, the circulation network of nitrogen inside the soil ecosystem will be considered as a black box with three main entrances (fixation, fertilization, crop residues) and two outputs. The emergy of nitrogen stored in soil is the measure of the benefit, as it provides nitrogen for next crops at the same plot and also serves as a value of the energy saved for the next production. Emergy stored is then proportional not only to productive purpose but also for avoiding environment contaminations.

Fig.11. Simplified nitrogen emergy diagram



Emergy and energy equations

Nitrogen emergy formulas

Nitrogen emergy, as it is seen at the figure number 8, is given by the energy of fixation,fertilization and crop residues incorporation into the soil:

$$\text{Nitrogen fixation emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$
$$\text{Amount of nitrogen fixated}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Fixation transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

$$\text{Fertilizers emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$
$$\text{Amount of nitrogen used as fertilizer}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Nitrogen transformity}\left(\frac{\text{seJ}}{\text{g}}\right)$$

$$\text{Crop residues emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$
$$\text{Biomass production}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot\ \text{Residues percentage(\%)}\cdot\ \text{Biomass transformity}\left(\frac{\text{seJ}}{\text{J}}\right)$$

$$\text{Nitrogen cycle emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$
$$\text{Nitrogen fixation emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Fertilizers emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Crop residues emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Energy of nitrogen storage

In some articles referred to nitrogen emergy valuation, transformity values are not expressed in solar emjoules per unit of energy. Instead of that transformity results form dividing the emergy inflow by units of mass. Besides it results complicated as during its cycle nitrogen takes very different forms and very different states of energy. It is also useless transforming nitrogen to energy measurements as nitrogen figures in agriculture studies are all referred to mass so in order to calculate emergy it is easier by applying an emergy per mass ratio. Nitrogen balance then can be calculated from modified formulas that own to Hansen et al.:

$$N_{\text{net input}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)=$$

$$N_{\text{leaching}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)+N_{\text{gaseous losses}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)+\Delta N_{\text{soil}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\rightarrow$$

$$N_{\text{net input}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)-\left(N_{\text{leaching}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)+N_{\text{gaseous losses}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\right)=$$

$$\Delta N_{\text{soil}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)$$

Nitrogen transformity therefore is calculated as:

$$\text{Nitrogen storage transformity}\left(\frac{\text{seJ}}{\text{g}}\right)=\left(\frac{\text{Nitorgen cycle emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{\Delta N_{\text{soil}}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)}\right)$$

Water cycle

Benefit

Plants take part in hydrological cycle (Myers, 1996). They promote water storage in soil after the end of the growing season. This water recharged provides human wealth because it can be used for next crops with the consequent reduction in water waste and sometimes it contributes to recharging water breading that can be used afterwards for human consumption.

As it is mentioned previously, roots improve water infiltration in soil by creating galleries through their roots or providing organic matter to soil making its structure getting better. Plants presence also creates a microclimate in crop area as they intercept radiation of the sun (which makes reducing soil moisture) and protects the soil surface from the wind (limiting water exchange between soil and the atmosphere).

Emergy and energy parameters

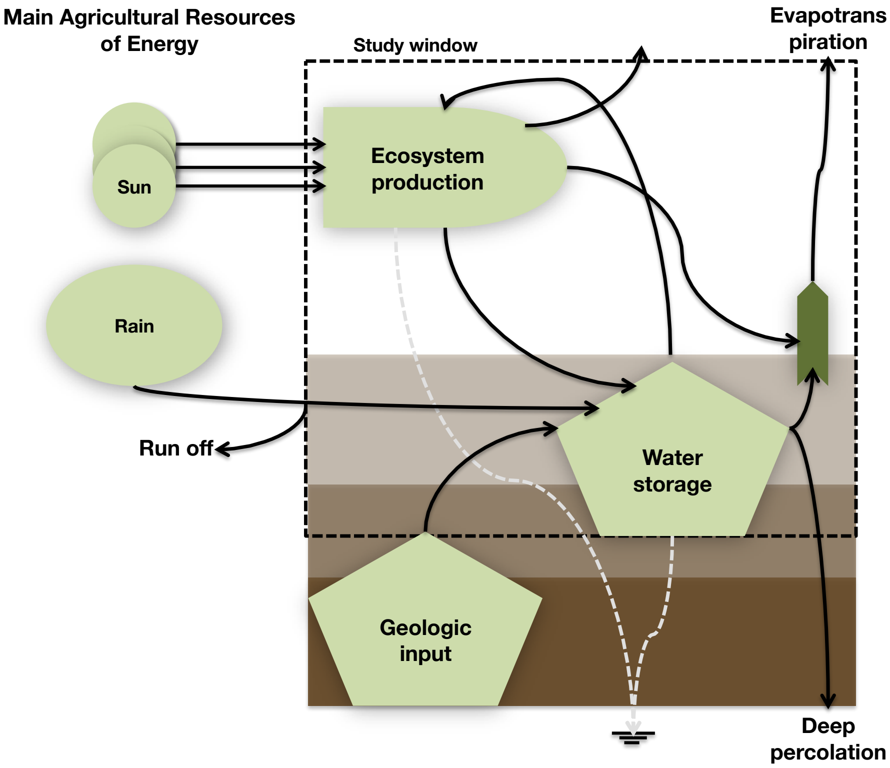
Emergy is the energy needed for a process. In this case there are three parameters conditioning the water storage. The first one and more evident is the emergy of rainwater which infiltrates in soil. Soil could be considered as the recipient in which water is retained so the energy for creating this storing place has also to be taken into account. Crop takes part through physical process, climate and organic compounds. First characteristics are involved in reducing the evaporation rate and increasing the infiltration and the second one improves soil structure, i.e. if energy in crop cultivating would not be inverted, soil water balance would be different so crop emergy should be also be considered.

In order to make transformities easier to use in other studies, transformities will be also an emergy per mass value (dividing the emergy input by the total quantity stored), rather than trying to find an energy value of it.

Emergy diagram

All emergy sources and their relationship are explained above. Once the water is located into the soil, water can get out from the studied system using four pathways. The first one is by deep percolation, i.e., water keeps on going dawn through the soil layers. The second one is through the evaporation (a change in the state of liquid water that turns into gaseous state mainly due to energy from sun and wind. Also those climate factor affect plant transpiration, but are not the only one. The surface and the state of growth are also determining parameters for transpiration. At emergy diagram, both, the evaporation and transpiration are converted in evapotranspiration as both depends on plant presence and the climate factors. The third pathway that water can get out of the study window is by the water plant storage that at the end of the agricultural season is harvested and transported out form the plot. Part of the water absorbed by plants remains at the plot in the form of crop residues. Those process affects water balance but are not involved in emergy calculations.

Fig.12. Simplified emergy diagram of water cycle



Emergy and energy equations

Water cycle emergy

In this case all contributors formulas are already raised in previous points. The only thing remarkable is the fact that rain is not going to be calculated separately to avoid double counting as it is already included in the crop emergy calculations. Total emergy for water storing is:

$$\text{Water cycle emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Crop emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Geologic input emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Soil water energy

As it is written, instead of using energy, mass is going to be used for transformity calculations. That information is a direct data recorded in some studies such as John R. Porter’s work paper.

Transformity value surges from dividing the emergy by mass of stored water.

Carbon sequestration

Benefits

The benefit of this ecosystem services, as its own name says is the carbon dioxide absorbed by plants through photosynthesis process. The carbon of this molecule is used by plants to build up new organic tissues, molecules for energy reserve, etc. so the carbon is retained by plants. After harvesting part of this carbon remains on the soil being part of the organic matter from crop residues. This transference of carbon to soil supposes a secure storage of the atmospheric CO2 (R. Lal, 2008) and it is considered one of the mitigation technologies (IPCC) to offset part of the emissions from biofuels burning (West et al., 2003).

Emergy and energy parameters

When it is talk about carbon sequestration, is referred to soil organic carbon provided by crop residues that remain on topsoil after harvesting. Soil organic carbon is intimately linked to soil organic matter. Indeed, in some studies, soil organic carbon (SOC) is referred interchangeably as soil organic matter (SOM) (R. Lal, 2008) so the emergy pathways for carbon sequestration can be considered also equal to carbon sequestration. According to Matthew J. Cohen, soil organic matter has to different emergy sources;on the one hand geologic inputs and on the other the ecosystem production (that in our case is the crop residues.

As in previous cases carbon is not quantified in energy terms but in mass terms. Here, the reasons which lead to calculate transformity as an emergy per mass ratio are the same than those written on other sections.

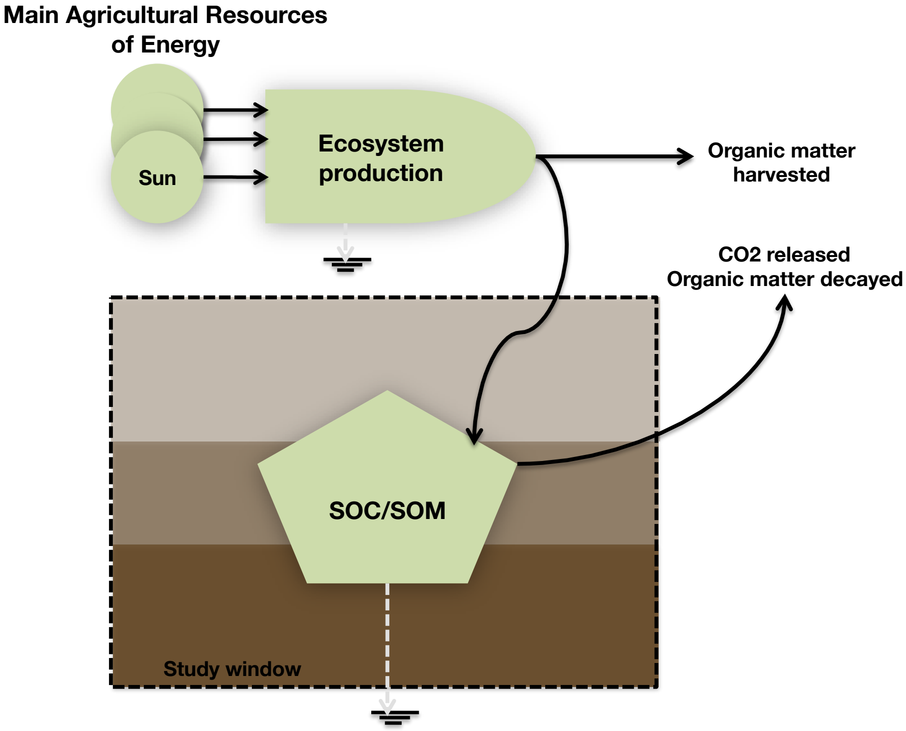
Emergy diagram

Atmospheric carbon can be transmitted to soil through two pathways. The first one goes through organic matter. Vegetative residues represent an important replenishing SOC (R.

Lemus and R. Lal, 2005). Above ground biomass and roots represent a prominent role in C sequestration and their turnover (Tufekcioglu et al., 2003; R. Lemus and R. Lal, 2005). Plant litter, roots and their exudates (Gregorich and H.H. Janzen, 1996) remains on soil after harvesting being decayed by soil organisms and transformed into humus forming the soil organic carbon (SOC) (R. Lal, 2008). This pool occupies a small portion of the soil mass but is highly enriched with C and may contain a substantial portion for the total carbon in soil (Gregorich and H.H. Janzen, 1996). The second one is the geologic input that contribute to total carbon sequestered providing secondary carbonates. This contribution forms the soil inorganic carbon (SIC) part (R. Lal, 2008). The SIC includes elemental carbon, primary carbonates and secondary carbonates. The primary carbonates are elements that come from parental material and secondary by dissolution of carbon dioxide from the atmospheric pool (R. Lal, 2008)

In spite of existing two carbon sources, only the first can be considered direct consequence and then direct benefit, from agricultural activity. Besides, it is the largest source of carbon entering the soil (Gregorich and H.H. Janzen) so the organic apportions would be the only emergy source considered.

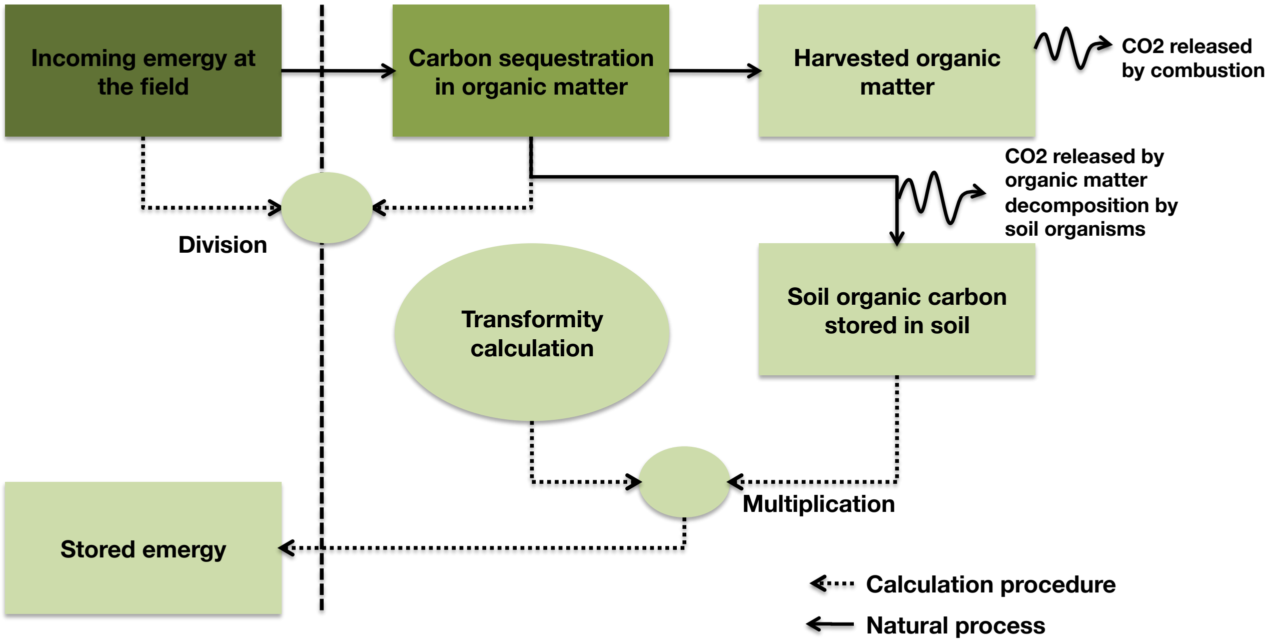
Fig.13. Simplified emergy diagram of soil organic carbon



Emergy and energy equations

As long as the crop is keeping on with the photosynthetic activity, the CO2 is absorbed by plants to produce organic compounds. That means that carbon sequestration happens along the live of crops. After that not all the carbon keeps on being sequestered; harvested biomass is burned for obtaining electricity so CO2 is released again and the organic matter that remains at the plot also losses part of the carbon during its decomposition.

Fig.14. Procedure of soil organic carbon emergy calculation



Emergy formulas

At this point, al formulas have been raised, the incoming energy at the field is what in other chapters receive the name of “Main Agricultural Resources”. Using data recorded in some articles, carbon proportion can be used to now the total amount of carbon sequestered by plants in order to obtain the transformity (in emergy per mass units). Once known the sequestered carbon transformity this is multiplied to the amount of carbon retained in agricultural soil to obtain finally the emergy total emergy in soil in form of organic carbon.

Biodiversity

Benefit

Biodiversity is defined as the existence of varieties of plants, animals and other life forms living independently of humans"(Cook et al., 1991) and represents the health of the ecosystem itself. Besides, this service has a direct connection with other ecosystem services (Cook et al., 1991;Benton et al., 2003). As an example, this proper of the environment (biodiversity) influences aesthetics and recreational services of the natural environments. Any modification in biodiversity value affects both services values. Finally then, it is conclude that, given the interconnections between biodiversity and other services, a modification in biodiversity value affects the value of whole ecosystem (Cook et al., 1991).

Furthermore, nature biodiversity can be seen in biotechnology terms as a source of genome characteristics than can be used as a source of genomic information to create new genetic modified organisms or as a pharmaceutic source of new organic compounds for fighting diseases.

Emergy and energy parameters

According to Odum, biodiversity can be measured as the complexity of the ecosystem, counting the number of interconnections of different species one to each other. This complexity is transformed into bits or nits that are defined as the logarithm in base 2 or "e" respectively of the number if connections between species forming the food chain in the ecosystem. This serves to obtain a numerical value of biodiversity that can divide emergy to obtain a transformity value.

The emergy for biodiversity is that one that enters into the ecosystem as sun, wind, rain, geologic heat and other non-renewable sources in case of agriculture.

According to bibliography, two kinds biodiversities can be distinguished according to the scale of the study:

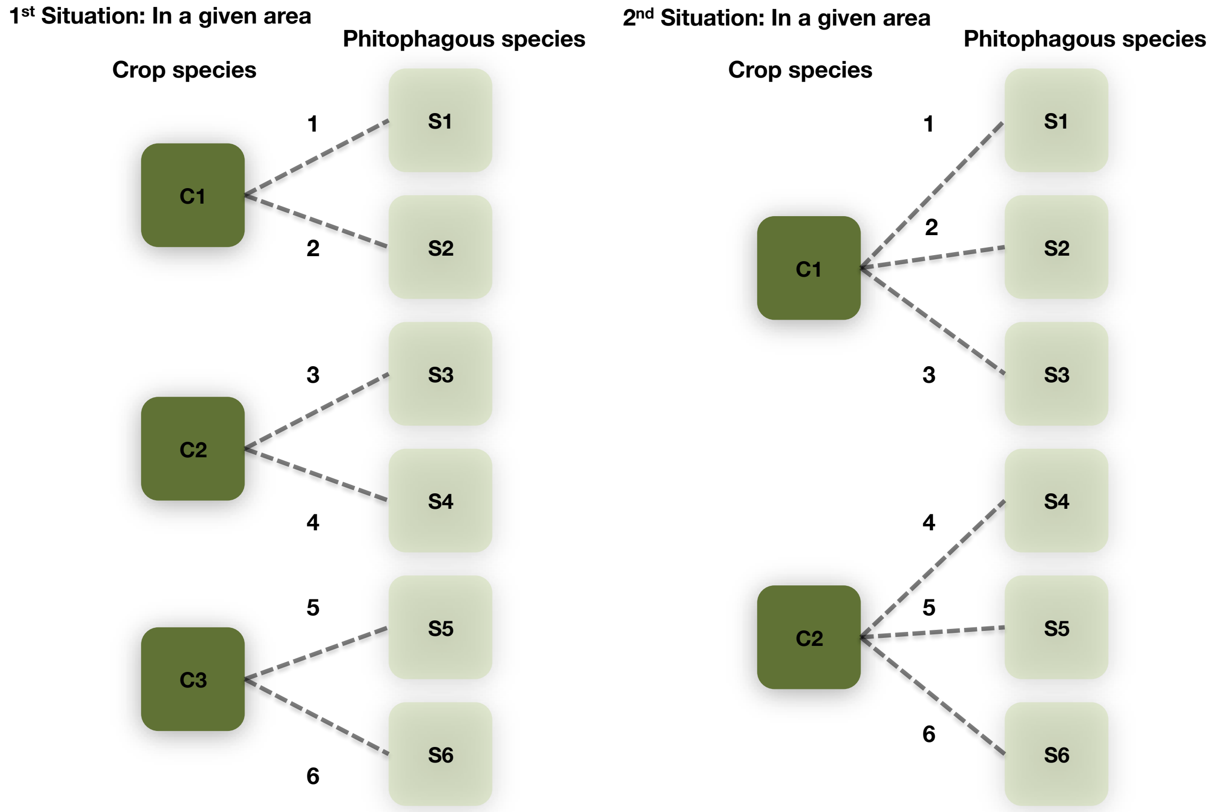
- The plot level; it represents the food chain that parts from a concrete crop.

- The landscape level: This level values the crop diversity a concrete area.

Analyzing food chains for counting species relationship only measures the first kind of biodiversity (plot level), crop biodiversity is not included properly as the chain begins from the crop itself. In order to solve that problem, here is suggested biodiversity valuation on the basis of the emergy chain instead of food chain. Both representations are very similar, however with the las one, relationship between a global emergy source (concentration as one for all sources of energy at the boundaries of the study area) and crops can be taken into account, so landscape biodiversity level would be also included.

To be clearer with the problem and solution suggested, next figure has been created. It represents two different and simplified situations. In both situations there are different crops (c1,c2 and c3) which serve as food for other species located at the next level of the food chain(s1,s2, etc.). If interconnections are numbered, both situations would have the same biodiversity. However,as it can be seen, first situation is richer in species than the second one. If energy chain is built and connections are numbered, it seen how landscape biodiversity value, is now included.

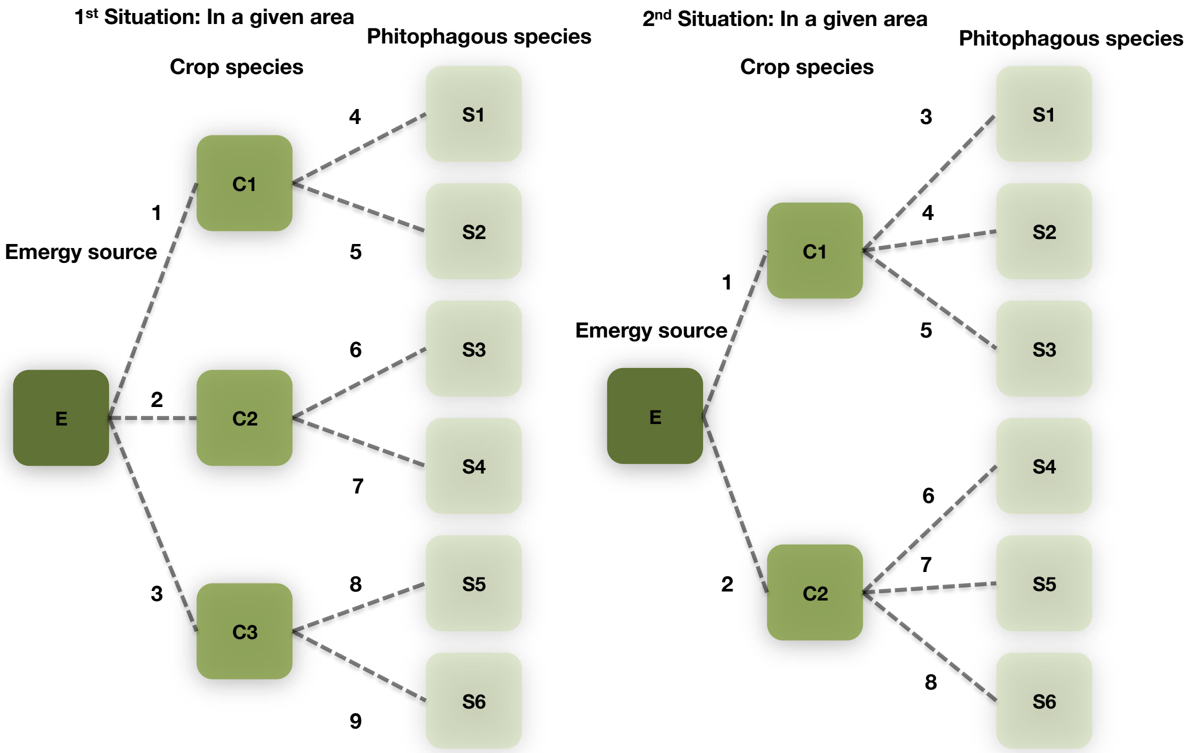
As it can be seen, the only modification between the emergy and food chain is the corresponding part to the relationship between emergy source and crops. After that the emergy chain is the same as food chain, as food is also an energy connection between different levels of the food chain.



Number of connections based on food chain analysis: 6 connections.

Number of connections based on food chain analysis: 6 connections.

Fig.15. Emergy calculation of biodiversity according Odum



Number of connections based on emergy chain analysis: 9 connections.

Number of connections based on emergy chain analysis: 8 connections.

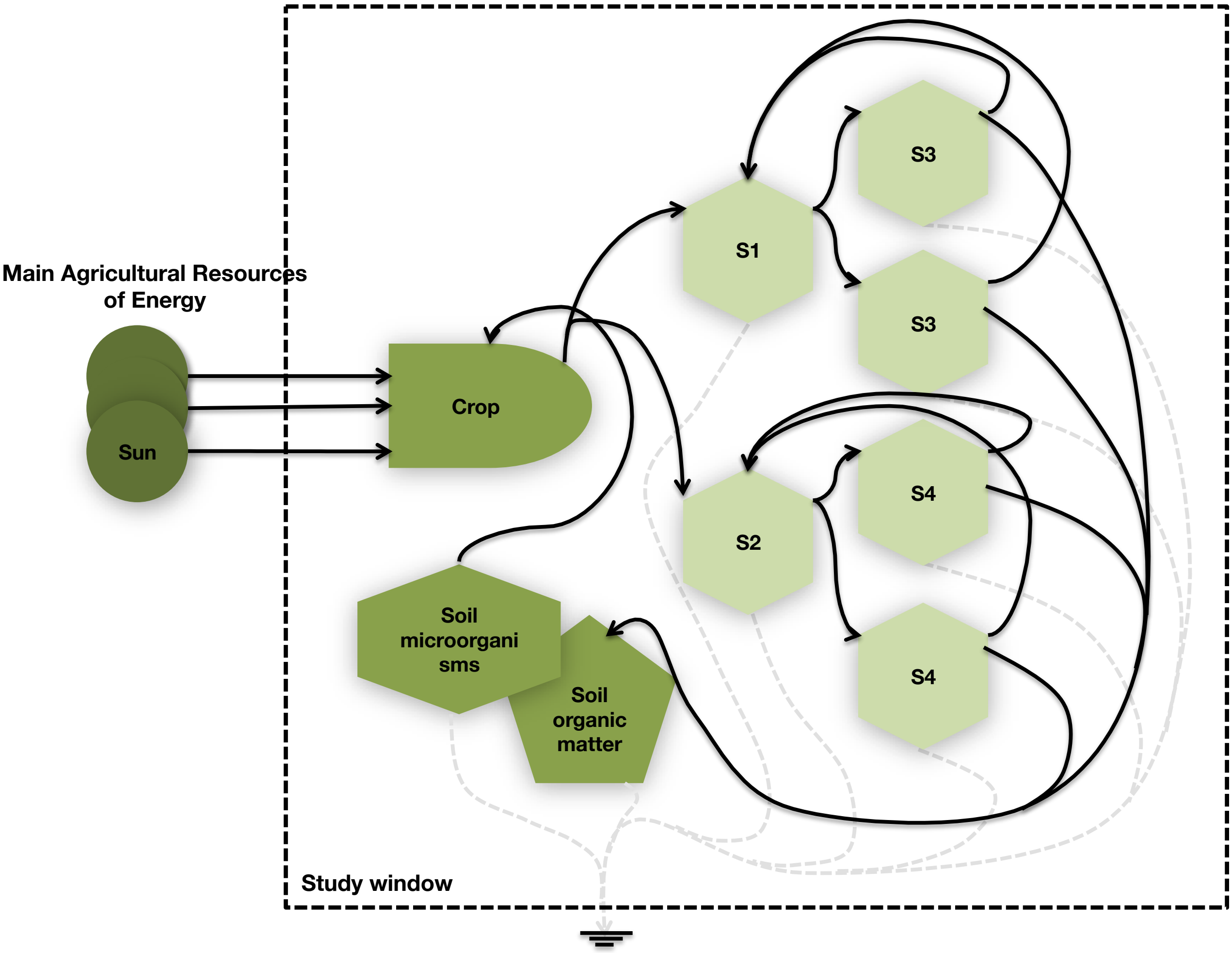
Fig.16. Modification purposed for emergy calculation of biodiversity according Odum

Emergy diagram

The emergy representations results from transforming and fixing the food chain into the emergy diagram using appropriate symbols.

In the agro.ecosystems food chain, like in other natural ecosystems, the energy is recirculated from crop to animals and then to soil, in form of death organic matter. The organic matter of soil is discomposed by soil organisms that mineralize the organic tissues producing new nutrients for plan absorption. That means that biodiversity energy is afterwards inverted in crop growth. However not all the energy reaches to the plant due to energy losses from life animal and soil erosion.

Fig.17. Emergy diagram for biodiversity



Emergy and energy equations

Biodiversity emergy

According to the emergy diagram, the emergy of both kinds of biodiversity (at crop and landscape level) is given by the source of energy outside the study window. This emergy is equal to the "Main Agricultural Resources" which in turn, is the symbol that congregates renewable, purchased inputs and labour. So formula for emergy calculations would be the same that those raised equation in biomass energy section.

Biodiversity complexity

Biodiversity complexity is expressed as the logarithm (in base 2 or “e”) of the number of connection at the emergy chain (only those which go forward the emergy chain):

$$\text{Complexity (bits)} = \log_2 \left(\text{N}^{\text{o}} \text{ of conections}\right)$$

$$\text{Complexity (nits)} = \ln \left(\text{N}^{\text{o}} \text{ of conections}\right)$$

Transformity is the value that results from dividing emergy by complexity.

Aesthetic

Benefit

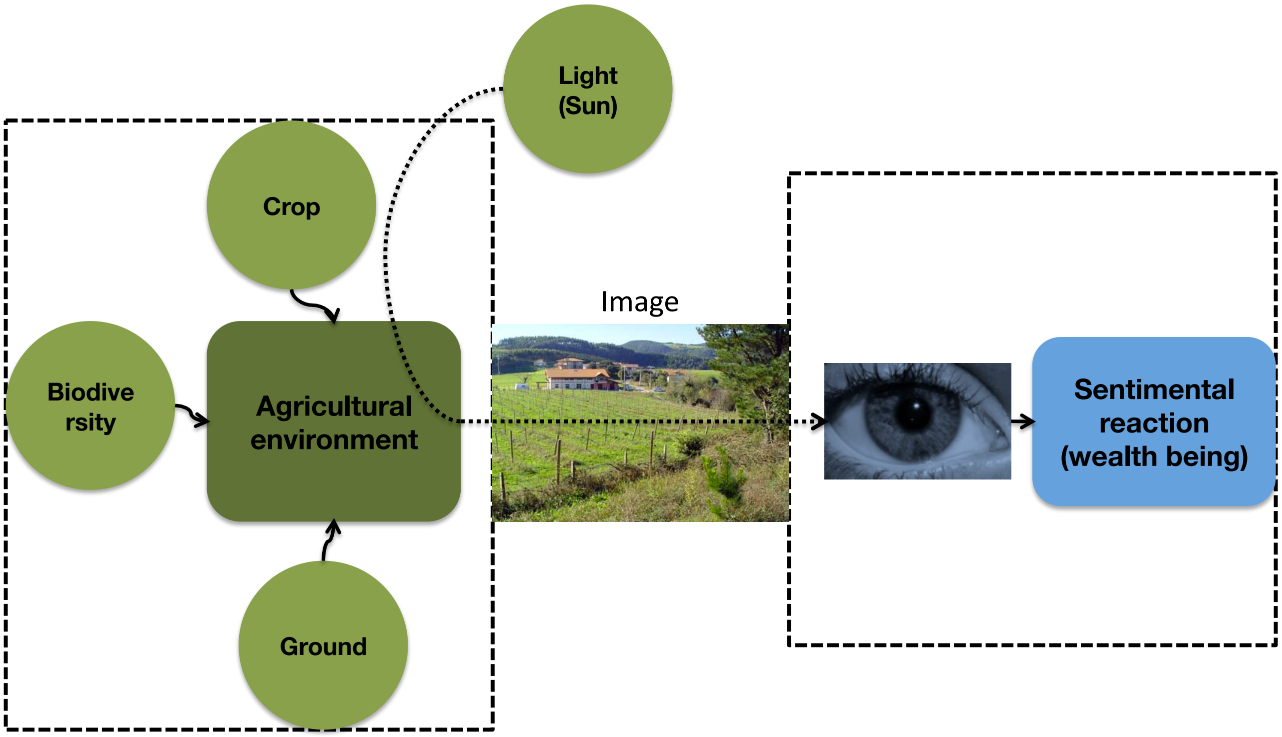
Landscape promotes human welfare (Costanza et al., 1997) and provides the environment in which some business can develop, such as rural tourism.

Emergy and energy parameters

The wealth-being as a consequence of the aesthetic aspect from agricultural areas can be understood as the human reaction in the sentimental plane to the landscape external stimulus. Analyzing this sentence, two aspects can be deduced; the first one is that the human reaction (and therefore the benefit) is created on the basis of an image that borns from croplands and their environments and the second one that the emergy for generating that image is the emergy needed for the content of the image and the energy needed for transporting the image.

Then it can be conclude that the energy that outflows from the agro-ecosystems is the energy of the light reflected by the components of the agricultural landscape and the emergy is the energy required for creating and transporting that image.

Fig.18. Process definition

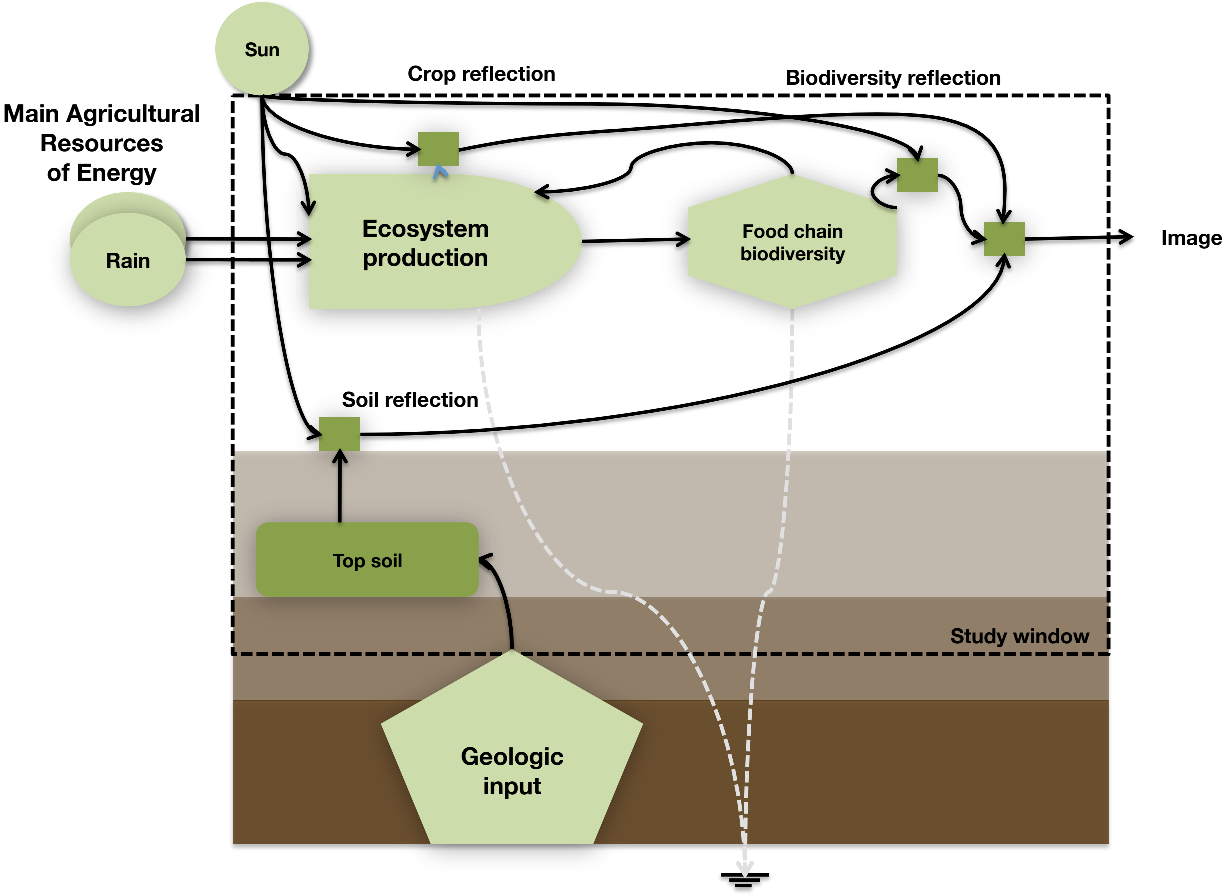


Emergy diagram

According to the studied phenomenon agricultural image is composed by three main elements; Ground, crops and biodiversity. Therefore, the energy for creating those components and the energy for creating the image is the necessary energy for the aesthetical benefit, i.e. the sum of those energies are the emergy for landscape image. The biodiversity emergy, as it is written in the previous chapter, is the emergy derived form crop production into natural food chain, so if only the crop emergy is taken into account, it also included the emergy for biodiversity creating and is therefore avoided double counting, When it is written "the energy for creating the image" is talked about taken on account all the light energy that inflows the study window (not only the absorbed light as in biomass calculations).

The image, in aesthetical analysis, is the energy outflow from agricultural boundaries. This image is the result from adding all the electromagnetic waves in the strip of the phantom correspondent to the visible one that are reflected from crops, ground and definitively from all the landscape components.

Fig.19. Aesthetic service emergy diagram in the agricultural sector



Emergy and energy equations

Aesthetical emergy

According to previous paragraphs, emergy can be solved by using:

$$\text{Aesthetical emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\text{Geologic input emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+\text{Crop emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

All terms in emergy equation are already detailed in other sections of the Methodology.

Image energy

The image is conformed by the reflected electromagnetic waves reflected by the surface of the agronomical environmental components. The light reflection in crops has been measured as the albedo. So the energy of light proportion that correspond to albedo will be the light energy reflected and therefore the image energy:

$$\text{Image energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$\text{Land area dedicated for biomass production }(\text{ha})\cdot\text{ Average insolation}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot(\text{Albedo})$$

Results

In this section are showed the emergy and transformity values for each ecosystem service as a sum up. Results are obtained using the formulas written at the Methodology section using the information and calculation compiled in the Appendix A.

All values are presented as one unique table in order to make easier future analysis at the Discussion section.

Table 1. Results obtained from calculations in Appendix A

Ecosystem Service	Natural Value	Transformity	Emergy
Biomass Production	108.06 GJ/yr./ha	1.77E+04 seJ/J	3.22E+15 seJ/yr./ha
Pollination	71,83 GJ/yr./ha	2.14E+10 seJ/J	2.9E+15 seJ/yr./ha
Pest Control	170 individuals/m^2	5.29E+06 seJ/J	2.44E+13 seJ/yr./ha
Erosion Control	2.44 Mg/yr./ha	1.12E+06 seJ/J	1.6E+15 seJ/yr./ha
Nitrogen Cycle	56 kg N/yr./ha	6.29E+13 seJ/g	3.53E+18 seJ/yr./ha
Water Cycle	322 mm/yr.	1.16E+06 seJ/g	3.75E+15 seJ/yr./ha
Carbon Sequestration	0.33 Mg C/yr./ha	7.11E+08 seJ/g	2.35E+14 seJ/yr./ha
Biodiversity	-	-	3.22E+15 seJ/yr./ha
Aesthetic	1.09E+13 J/yr./ha	3.44E+02 seJ/J	3.75E+15 seJ/yr./ha

Results are exposed using the table before, whose values represent the main calculation variables in the Emergy method, such as the natural value, the transformity and the emergy value in as much as ecosystem services as possible. The natural value is the measurement that quantifies the amount of service offered by those energy crops specified at the Appendix A. The units adopted are those considered better, weighting the easiness of obtaining the figure and the fidelity to the method. The transformity as it is defined at the beginning, represents the amount emergy inverted by the ecosystem per unit of service or function produced. Depending on the units of measurement of the natural value, transformity units can vary from seJ/J (emergy per unit if energy transformity) to seJ/g (emergy per unit of mass transformity). In most cases transformity value has been obtained indirectly from the division of the emergy and natural values (directly or easily transformed to mass units). In the las column emergy values are shown, divided by a unit of area and time of reference.

As it can be seen according to the information founded the biomass production is quantified in one hundred and six point zero six Giga Joules per year and per hectare. The cost of energy by bee pollination is equal to seventy one point eighty three Giga Joules per year and hectare. The number of depredated insects in a year is equal to one hundred seventy individuals per squared meter. The energy lost in soil erosion is two point forty four Mega Joules per year and hectare. The number of kilograms stored in soil through different pathways and in different states after a year is fifty six. At the same time water stored in soils that belong to this kind of ecosystems and carbon sequestered are able to reach to three hundred twenty two millimeters per year and per hectare and zero point thirty three Mili grams per year and hectare respectively. Although it has not been possible to quantify the energy in biodiversity, aesthetics energy value is around one point zero nine raised to power of thirteen Joules per year and hectare.

The firs four transformity values and the last one, that correspond to biomass production, pollination, pest control, erosion control and aesthetic, are expressed as one point seventy seven raised to four, two point fourteen raised to ten, five point twenty nine raised to six, one point twelve raised to six and three point forty four raised to six solar emjoules per unit of energy respectively. On the other hand, those referred to the storage of an element or a compound (nitrogen, carbon and water), given the difficulties in calculating a way of expressing those quantities in energy terms, they have an emergy-mass transformity. Their values are six point twenty nine raised to thirteen solar emjoules per gram, seven point eleven raised to eight solar emjoules per gram and one point seventeen raised to six solar emjoules per gram for nitrogen, carbon and water storage.

Finally, in most cases emergy is a value directly obtained from the calculations that use the information collected in very different scientific articles.The maximum emergy value corresponds to the nitrogen storage with an emergy value of three point fifty three raised to eighteen solar emjoules per year and hectare. Otherwise, the minimum values is given by the pest control with two point forty four raised to thirteen solar emjoules per year and hectare. Intermediate values are almost every one raised to fifteen such as biomass production (three point twenty two raised to fifteen solar emjoules per year and hectare), pollination (two point nine raised to fifteen solar emjoules per year and hectare), erosion control (one point six raised to fifteen solar emjoules per year and hectare), water cycle (three point seventy five raised to fifteen solar emjoules per year and hectare), biodiversity (three point twenty two raised to fifteen solar emjoules per year and hectare)and aesthetic (three point seventy five raised to fifteen solar emjoules per year and hectare).

Now these values should be compared to those obtained by the economic method obtained by John R. Porter. How to find out the way of comparing these two different units is something explained in the next part, in the Discussion.

Discussion

This part of the project corresponds to detailed analysis of shown results in previous section that derive in concrete conclusions about Total Economic Value quality as an ecosystem service valuation methodology, social mentality characterization, industrial and political-economical solutions to current problems in agriculture.

The discussion consist of two parts; the first one consists on a both methodologies comparative analysis and the second part on the direct applications from calculating the ecosystem services in emergy terms. For the fist one John R. Porter´s report, titled "The Value of Producing Food, Energy, and Ecosystem Services within Agro-ecosystem", is used as source of information about the economic value of ES in energy crops.

Comparison methodologies

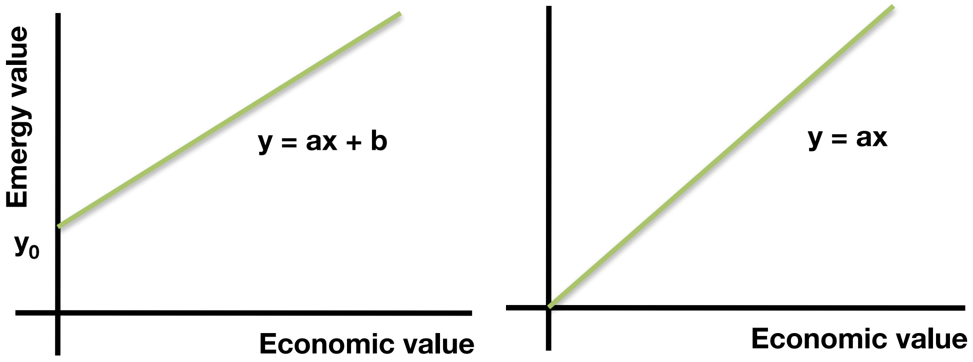
Emergy-Economic analysis

Theoretical introduction

The relationship between both methodologies is important due to the amount of information that can be extracted. This relationship is given by the trend lines that can be calculated using charts that represents the economic values of the ecosystem services against the emergy values of the same ES. Is necessary to clear that regressions just explains the behavior of one of the values while the other increases or decreases, but it not establish a causality effect between them.

Ideal Relationship and Real Relationship

Theoretically, two kind of relationships can be built; The Ideal Relationship and the Real Relationship. It is called the Ideal Relationship to the situation in which, conscious or unconsciously, humans “willingness to pay” is proportional to the environmental effort required for producing an ecosystem service. That means that humans leave an ego-centric point of view and it is substituted by an eco-centric perspective for valuing the ES. Mathematically this situation is translated into linear trend line between values of ES through both methodologies. But the ideal situation would not be so ideal if there is a different value for trend line intercept different form zero. If the value of higher than zero it means that there are emergy values which their values are zero, in other words, the economic valuation does not internalizes all the emergy values. However if the value is lower than zero it would mean that the economic valuation is not efficient, as for zero emergy it would payed a quantity of money.

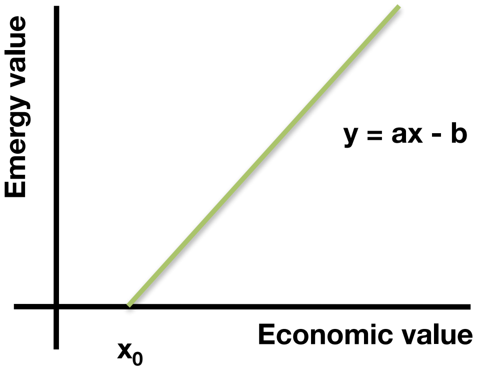


1.- Intercept higher than zero:

2.- Intercept equal to zero:

For x = 0 then y = a : There is an emergy value which is valued as zero dollars, in other words there are emergy values which has no economic valuations. Therefore the economic valuation does not internalizes all the ES values.

For x = 0 then y = 0 : There is no emergy values associated with zero dollars, in other words there are not emergy values which has no economic valuations. Therefore the economic valuation internalizes all the ES values.



3.- Intercept lower than zero:

For y = 0 then x = b/a :There are economic values for non emergy values. That means that the economic valuation is not efficient, there economic losses in ecosystem services valuation,

Fig. 20. Intercept possibilities and meaning.

Therefore the ideal situation should have the intercept equal to zero as a condition. The trend line with these characteristics represents the Ideal Relationship between methods using the observed values, i.e. this linear regression is the representation of the closest ideal situation to the current one.

> *"The Ideal Relationship is characterized by intercept equal to zero and linear trend line as an expression of complete internalization and an economic valuation according to environmental effort inverted"*

On the other hand the Real Relationship is the trend line without conditions (but the closest determination coefficient to one) that better explains the relationship between both methodologies. In this case, the independent term of the trend line shows if nowadays economic methodology really serves to internalize all emergy values.

> *"The Real Relation is characterized by the most fitted mathematic formula to real situation given by the observed values"*

Because of the high values obtained in emergy methodology, double logarithm scale is used. That means that the ideal Ideal Relationship Equation into double logarithmic scale is represented by an straight line with an slope equal to one and an intercept equal to the logarithm of the slope of the trend line in normal representation:

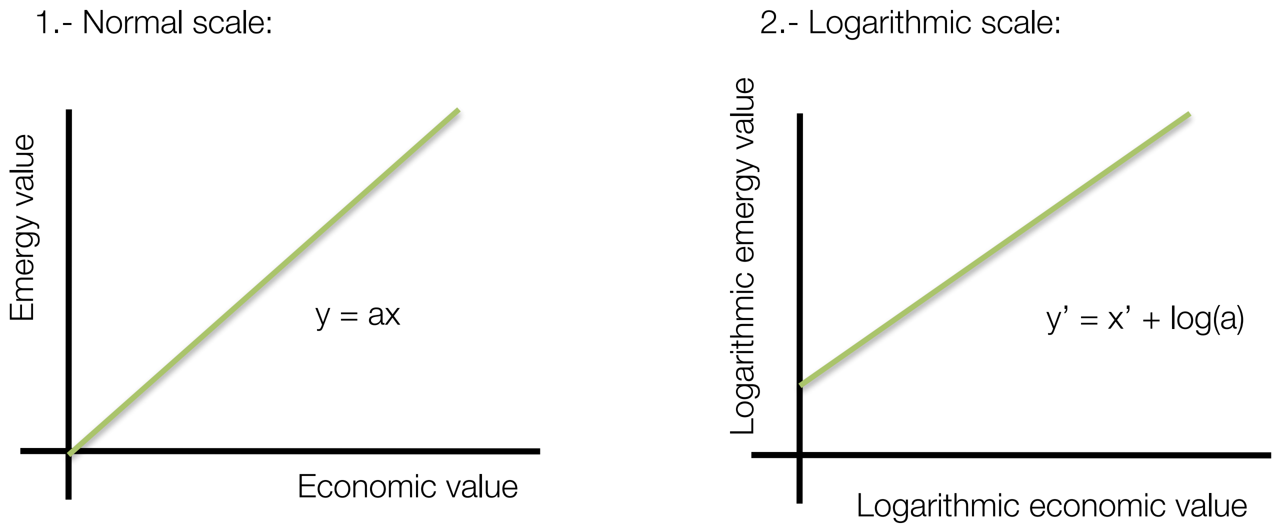


Fig. 21 . Equivalence of the Ideal Relationship in normal and double logarithmic scale

$$y = a \cdot x \Rightarrow \log(y) = \log(a \cdot x) \Rightarrow y' = \log(x) + \log(a) \Rightarrow y' = x' + \log(a)$$

Environmental mentality

Is called “Environmental Mentality” to the situation in which the Real Relationship and the Ideal Relationship are the same trend lines. That means that society values the environmental functions and services according to the necessary effort required from the natural environment.

The economic method is based on “willingness to pay” of society. However, this “willingness” is something variable along time. That´s why the economic valuation it is also something changeable. Concrete figures can be considered a snapshot of ecosystem services’ value. Therefore, the Real Relationship between methods is modified. That indicates that there could be a time in future in which Real Relationship and Ideal Relationship could be the same,i.e. human perspective (economic values) fits with environmental perspective (proportionality). It is believed that the motor to carry out the change of point of view is a more conscious society; consciousness about dependency relationships between mankind and its natural environment and about environmental efforts fort the maintenance of these relationships.

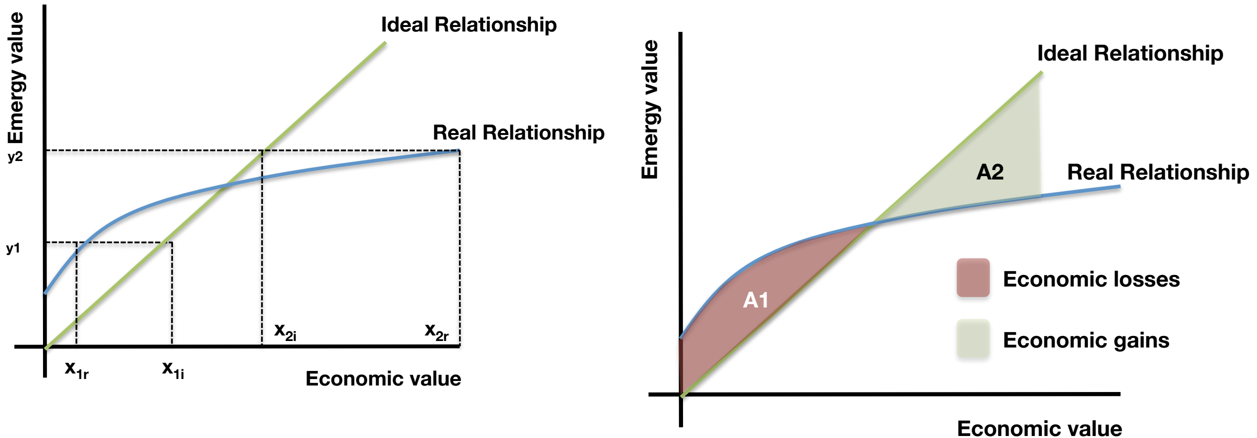
> *“When Ideal Relationship fits with Real Relationship then can be said that society has an Environmental Mentality”*

> “The determination coefficient from the Ideal Relationship trend line expresses how far is the society from

As the economic values are changing and therefore the represented points at the emergy-economy chart are differently located, the can be placed further or closer to reach the environmental mentality. This is mathematically translated into the determination coefficient of the Ideal Relationship. The further these points are from the environmental mentality the lower value of the determination coefficient. On the contrary, the closer the emergy-economy points are form the Ideal Relationship trend line, the closer is the “squared r” form one.

Environmental mentality virtually or namely equivalent

Although the Real Relationship can be very far from Ideal Relationship coincidence, economic valuation can be named as virtually or namely equivalent to environmental mentality. As it can be seen at the figure 17, on the same chart are represented both, Ideal and Real Relationships. According to this representation there are some emergy values that are currently economically undervalued regarding the ideal situation ($x_i > x_r$) and other in which current economic valuation is higher that economic value regarding the ideal situation ($x_i < x_r$). For the whole wide range of emergy value the economic losses and gains are given by the are between both functions. If gain area is equal to losses area, the it is said that the Total Economic Value (TEV) is virtually equivalent to the environmental mentality.



y_1 = Concrete emergy value
x_{1r} = associated economic value to y_1 emergy according to the real situation.
x_{1i}= associated economic value to y_1 emergy according to the ideal situation.
y_2 = Concrete emergy value
x_{2r} = associated economic value to y_2 emergy according to the real situation.
x_{2i}= associated economic value to y_1 emergy according to the ideal situation.

A1>A2 ; Current agricultural sector presents economic losses.

A1<A2 ; Current agricultural sector presents economic gains. The economic method is kinder.

A1=A2 ; Losses are equal to gains. The economic method is virtually equivalent to environmental mentality.

Fig. 22 . Area analysis between functions

For calculating those areas, first is necessary to clear the economic variable from functions in order to obtain another function in which the emergy value is the independent variable and the economic one is the dependent variable (for the Ideal and the Real Relationship) After that, both equations should be integrated and afterwards subtracted:

Virtually environmental mentality equivalence is defined as the situation in which economic losses and gains regarding the ideal situation, are offset in differential

1.- Transform the economic variable into the dependant one:

$y_r = f(x)_r \rightarrow x_r = f(y)_r$

$y_i = f(x)_i \rightarrow x_i = f(y)_i$

2.– Intersection points calculation (according to the example):

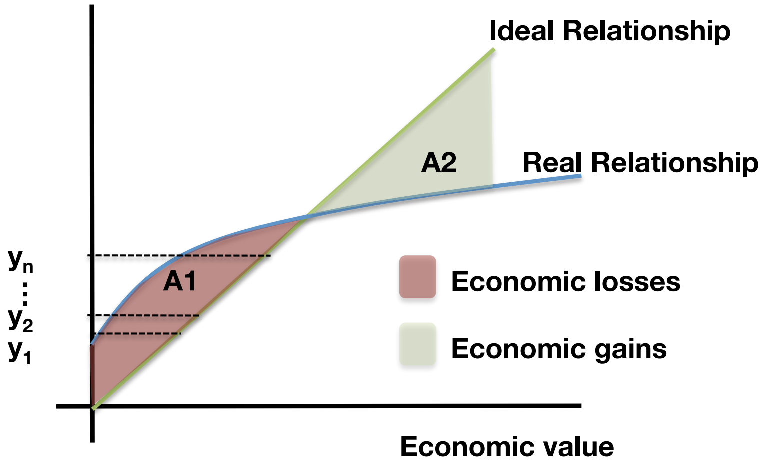
$f(y)_r = f(y)_i = y_{int.}$

3.- Area calculations:

gains = $\int_0^{y_{int.}} f(y)_r - \int_0^{y_{int.}} f(y)_i$

losees = $\int_{y_{int.}}^{y_{max.}} f(y)_i - \int_{y_{int.}}^{y_{max}} f(y)_r$ being y_{max} the maximum emergy value considered

However this analysis is useful in order to characterize the economic valuation applied to big areas with a big variability of cultivated crops and very different ES emergy value generated. Instead, for more concrete crops and areas the number of data valued is smaller and then the distribution of the emergy values can make the previous procedure not representative. Emergy values can be concentrated around the losses area or the gains area so there is no offsetting for that concrete crop or that area. In those cases is necessary to move from the differential analysis to the particular one.



y_i = emergy values for each ecosystem service for a concrete crop in a concrete country.

The distribution of the ecosystem services emergy value makes that every real economic value is lower than the ideal economic value so this concrete crop in this concrete country has economic losses

The distribution can also make the current economic valuation being higher than the ideal one. There is also a situation in which ES emergy distribution can make economic losses and gains being equal. That is called Environmental mentality namely equivalent.

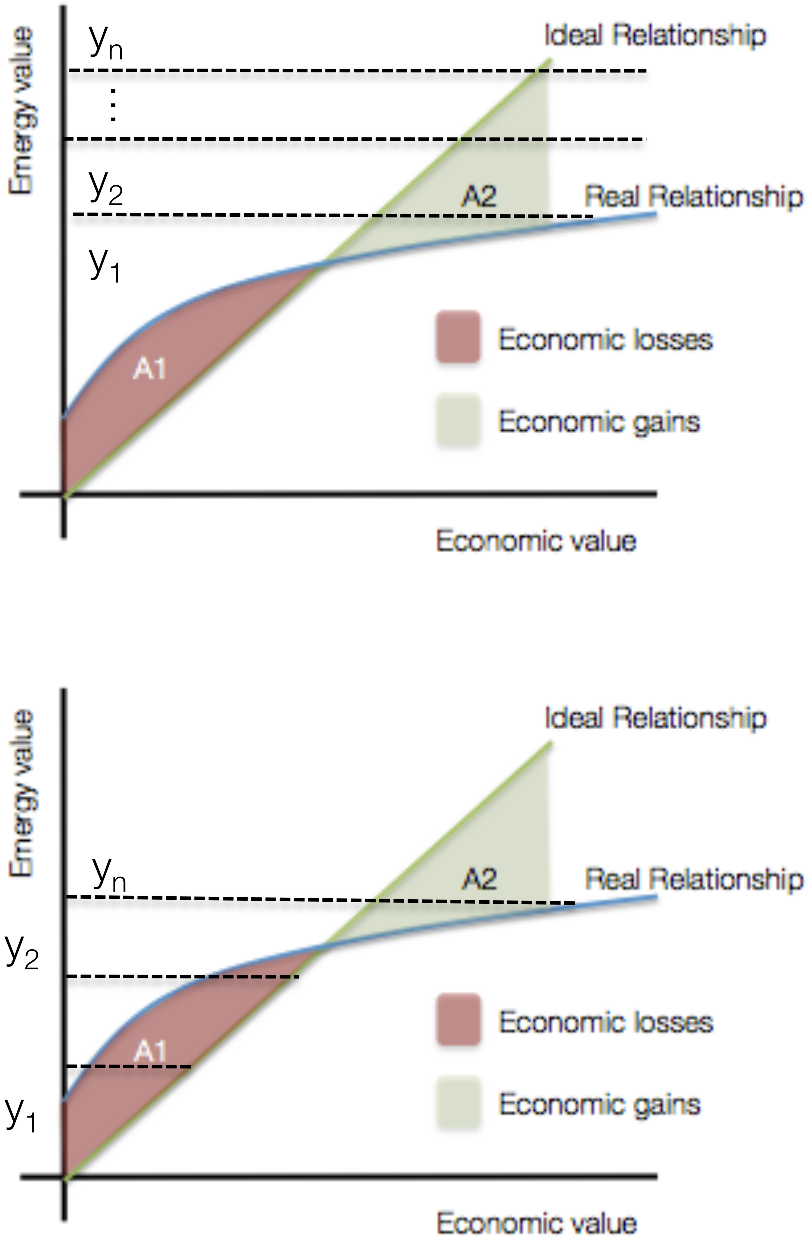


Fig. 23 . Concrete emergy values analysis

Mathematically that is expressed like:

$$\text{Economic valance} = \sum_{j=1}^{n}\left(f(y_j)_r - f(y_j)_i\right)$$

Mainly environmental mentality equivalence is defined as the situation in which economic losses and gains regarding the ideal situation are offset in particular analysis

So each emergy value of each ES has to be substituted in real and ideal formula and then subtracted. All results had to be summed. If the result from this procedure is equal to zero, then we can say that the economic valuation methodology is namely equivalent to environmental mentality.

Emergy-money ratio

Supplementary information can be extracted from relationships already done. The Ideal Relationship as it can be seen before, establish a relationship between emergy and economic values multiplying the economic term by a constant. That constant is the slope:

$$y = a \cdot x \rightarrow a = \frac{y\left(\frac{\text{seJ}}{\text{yr} \cdot \text{ha}}\right)}{x\left(\frac{\text{USD}}{\text{yr} \cdot \text{ha}}\right)} \rightarrow a = \frac{y}{x} \cdot \left(\frac{\text{seJ}}{\text{USD}}\right)$$

As it can be seen at the formula, the slope has seJ/USD units, so the slope form the trendline regarding the Ideal Relationship represents the energy money-ratio for ecosystem services. This factor is very useful as multiplying the economic value from ES already calculated in other studies, an approached emergy value can be obtained. Besides, contributes information about the area in which emergy-economy analysis is done, as is expected to be differences in this ratio between areas depending on the richness of the area not only in economy terms but also in natural resources.

Economy-emergy practical analysis

Ideal Relationship and Real Relationship

The first step for Economy-emergy analysis is calculating the trend lines regarding the Ideal Relationship and Real Relationship. For these analysis Nitrogen regulation value has been omitted as the concept and measurement of the benefit generated by agricultural environments are different in this study and John R. Porter´s study.

On the one hand, for Ideal Relationship, a normal chart has been developed in order to represent in “x” axis the economical values of the ES using TEV methodology and in “y” axis emergy values are represented. After that a trend line has been calculated (under the ideal situation conditions explained at the theoretical part; proportionality and independent term equal to zero). On the other, for the Real Relationship has been obtained a trend line from logarithmic values of the variables.

After that, the equation of the real situations is transformed to be represented on normal scale:

$$y' = 1.279 \cdot x' + 12.97 \rightarrow$$

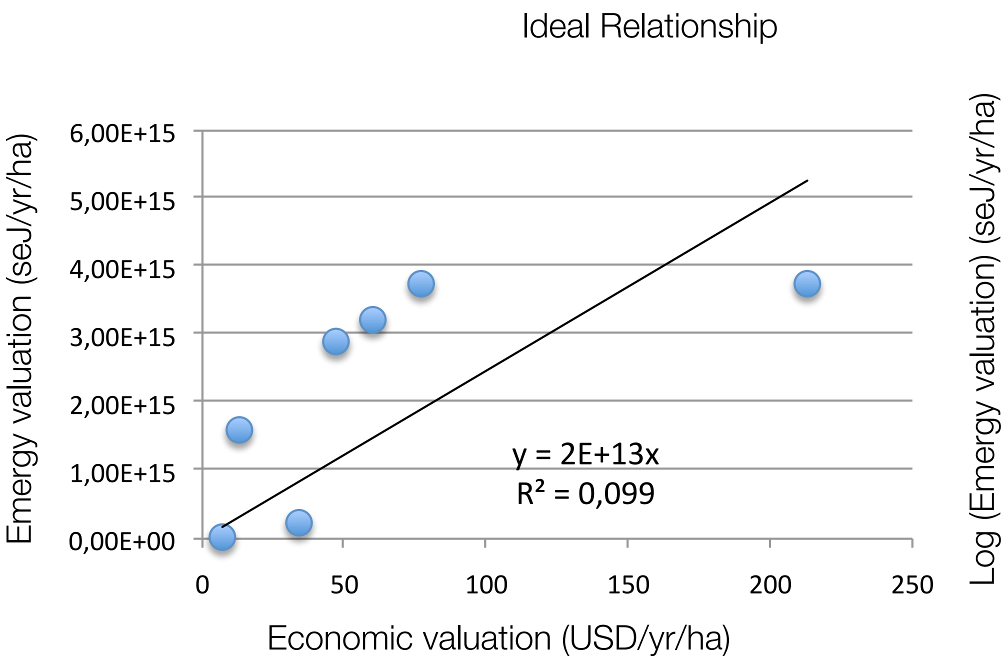
$$\log(y) = 1.279 \cdot \log\left(x\right) + 12.97 \rightarrow$$

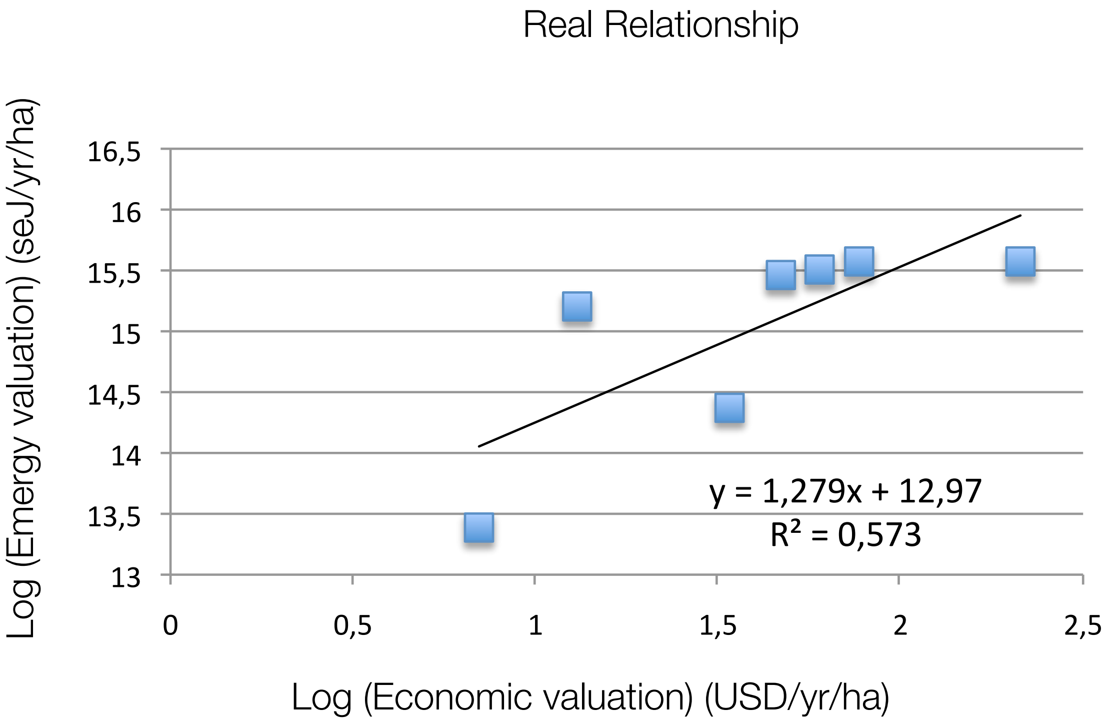
$$y = 10^{1.279 \cdot \log\left(x\right) + 12.97} \rightarrow$$

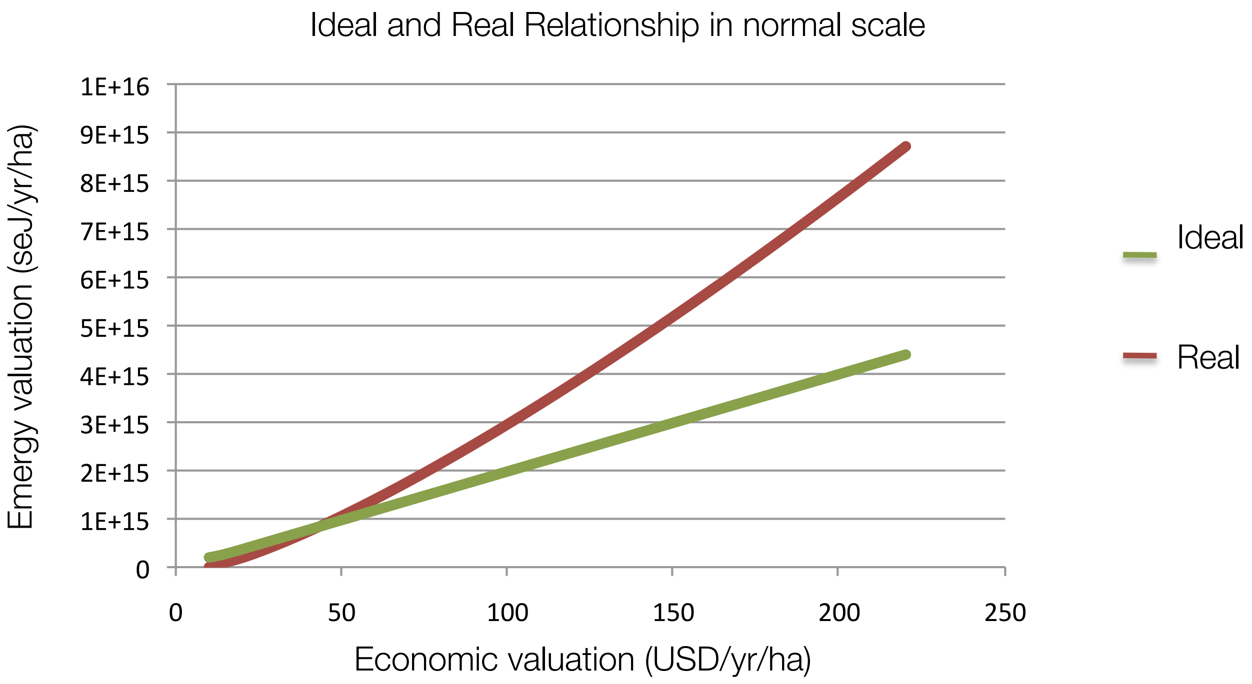
$$y = 10^{1.279 \cdot \log\left(x\right)} \cdot 10^{12.97} = 10^{12.97} \cdot x^{1,279}$$

Then, both formulas are represented together in order to make the analysis easier.

Fig. 24,25 and 26 . Real and Ideal Relationships and comparison







At glance, it can be seen that according to the generated formula, Real Relationship for the value equal to zero seJ/yr./ha the economic value is zero as well. That means that real situation internalizes al the emergy range values. Another thing very showy is that for lower emergy values (under around 1E+15 seJ/yr./ha) the current society is willing to pay more money that in the ideal situation. Instead, over 1E+15seJ/yr./ha current economic values are lower than those ones that corresponds to the ideal situation. Besides, emergy values are undervalued using TEV, so it can be expected almost with total security that there will not be virtually or namely equivalence to environmental mentality.

Danish mentality in economic valuation shows that as long as the emergy increases the unitary economic value of the last emergy unit added is smaller, in other words and simplifying ; Danish society gives more unitary economic value for those ES that implied less effort from the environment.

Environmental mentality

In order to know how far Danish society is from environmental mentality, it necessary to focus the attention on the determination coefficient in the Ideal Relationship. This values is equal to 0.099. Remembering the theory, closer values to zero means that current valuation is very far from the closer environmental mentality situation and closer to one, means just the contrary, that society's valuation is very close to environmental mentality. According to the value obtained Danish society is very far from environmental mentality as far as concerns ecosystem services, in other words they keep on valuing from an ego-centric point of view.

Environmental mentality virtually or namely equivalent

According to the mathematic steps:

1.– Clearing the emergy variable in both equations:

$$y_i = 2E+13 \cdot x_i \rightarrow x_i = 5E-14 \cdot y_i$$

$$y_r = 10^{12.97} x_r^{1.279} \rightarrow x_r = \left(\frac{y_r}{10^{12.97}}\right)^{\frac{1}{1.279}} = 7.23E-11 \cdot y_r^{0.78}$$

2.– Integrating:

$$\int x_i \cdot dy = \int 5E-14 \cdot y_i \cdot dy \rightarrow area_i = 2.5E-14 \cdot y_i^2$$

$$\int x_r \cdot dy = \int (7.23E-11 \cdot y_r^{0.78}) \cdot dy \rightarrow area_r = 4.06E-11 \cdot y_r^{1.78}$$

The minimum value for the differential analysis is zero and as maximum value here used the maximum emergy value of the ecosystem services here calculated (for energy crops and excepting nitrogen regulation emergy value) that corresponds to water cycle and aesthetics with 3.75E15 seJ/yr./ha. So:

$$\text{Differential economic analysis} = area_r - area_i$$

$$= 4.06E-11 \cdot \left[y_r^{1.78}\right]_0^{3.75E+15} - 2.5E-14\left[y_i^2\right]_0^{3.75E+15} =$$

$$2.14E+17 - 3.52E+17 = -1.38E+17$$

The result is in USD/yr./ha units, so globally the economic losses for agriculture basing the ES valuation on TEV instead of Emergy methodology. Using the formula, it is obtained negative value for areas subtracting that means that in general TEV nowadays undervalues the ES and there is no virtually equivalence on environmental mentality.

For particular analysis:

$$\text{Economic balance} = \sum_{j=1}^{n}\left(f(y_j)_r - f(y_j)_i\right) = \sum_{j=1}^{n}\left(7.23\text{E-}11\,y_j^{0.78} - 5\text{E-}14 \cdot y_j\right)$$

Being y_j all the emergy values already calculated for energy crops:

ES emergy value	Real economic value	Ideal economic value	Subtract
3,22E+15	9,02E+01	1,61E+02	-7,08E+01
2,90E+15	8,31E+01	1,45E+02	-6,19E+01
2,44E+13	2,00E+00	1,22E+00	7,81E-01
1,60E+15	5,23E+01	8,00E+01	-2,77E+01
3,75E+15	1,02E+02	1,88E+02	-8,59E+01
2,35E+14	1,17E+01	1,18E+01	-3,96E-02
3,75E+15	1,02E+02	1,88E+02	-8,59E+01
		TOTAL	-3,31E+02

Table 2. Particular real and ideal economic values

In table number two it is seen that economic balance for pest control is positive, that means that actually this ecosystem service is overvalued regarding the ideal situation. Carbon sequestration value is very close to zero, which means that this ES valuation almost belongs to the environmental mentality. However the rest of the values are negative, therefore most of them are undervalued. As the economic balance is different from zero (total quantity) there is no namely equivalence with the environmental mentality for the energy crops in Denmark. Even more, nowadays energy crops agricultural sector is loosing 331 USD/yr./ha.

Emergy-money ratio

The Ideal Relationship trend line slope is equal to 2E+13 seJ/UDS. That means that for ES in energy crops in Denmark, the emergy-money ratio is one order bigger that for human services (2E+12 seJ/yr./ha; Odum, 1996). As this is the first time that emergy-money ratio is calculated it can not be compared to other crops or countries.

Emergy-Emergy analysis

In order to make comparable results from both methodologies (Emergy and Economic valuation) results are needed to convert into the same measurement unit. In this case is decide to convert the economic results into emergy values using the emergy per dollar ratio used for human services.

The logic is that economic valuation, according to Costanza, can be understood as the costs of human services required to substitute natural functions and services and Odum affirms that "*the average quotient of emergy per per unit of money ratio is a useful index for evaluating emergy where data and human services are given in monetary units".* So emergy valuation from economic measurement can be obtained as:

$$\text{Emergy} = \text{Economic value} \cdot 2\text{E}{+}12 \frac{\text{seJ}}{\text{USD}}$$

Doing that for each ecosystem service:

Ecosystem service	Emergy-economic value	Emergy value
Biomass Production	1,20E+14	3,22E+15
Pollination	9,40E+13	2,90E+15
Pest Control	1,40E+13	2,44E+13
Erosion Control	2,60E+13	1,60E+15
Nitrogen Cycle	5,88E+14	3,53E+18
Water Cycle	1,54E+14	3,75E+15
Carbon Sequestration	6,80E+13	2,35E+14
Biodiversity	-	3,22E+15

Ecosystem service	Emergy-economic value	Emergy value
Aesthetic	4,26E+14	3,75E+15

Table 3. Emergy values from obtained for each ecosystem service through both methodologies.

At glance all the emergy values from the economic valuation are at least one order smaller than the emergy values obtained thought the methodology developed in this work. That means that using the economic valuation the ES are undervalued owing to the subjectivity of the individuals and the fact of forgetting to include time as a factor a value required for ecosystem services.

Applications

Industrial applications

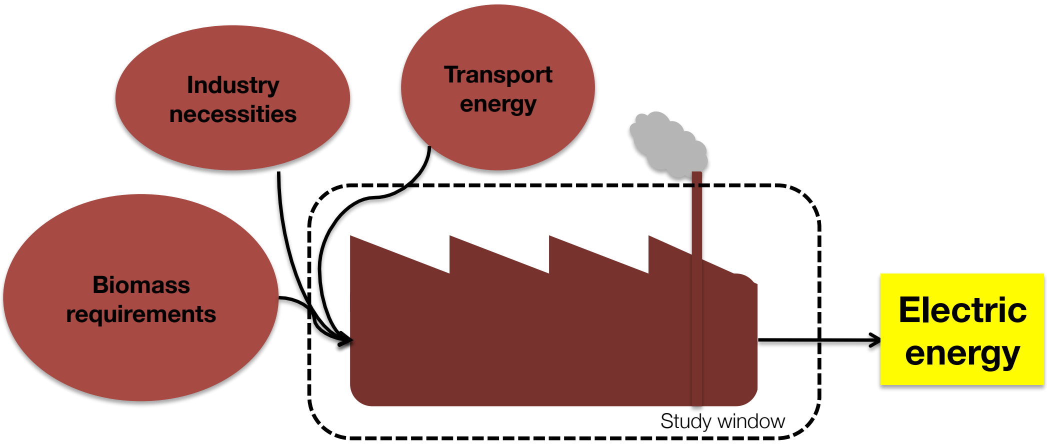
Introduction

Biomass production transformity is lower than transformity for fossil fuels (1.77E+04 seJ/J for biomass production and 6.6E+04 seJ/J for fossil fuels according to Odum calculations), even more, producing one joule of biomass requires almost 4 times less effort that one joule of fossil fuels.

However, that is not all the truth as biomass has to be process in order to obtain usable energy, so more energy has to be inverted in biomass in order to produce one usable joule. That is traduced in a bigger transformity for biomass energy generation. If the usable energy from biomass has finally a lower transformity than fossil fuels, that would mean that biomass energy production requires less effort from environment, is therefore more efficient and renewable.

These characteristics are targets that society is looking for in energy sources so the efforts had to focused on building Biomass Industrial Plants that fulfill that requirement, in other words, Biomass Industrial Plants with transformities lower than fossil fuels:

Fig. 27 . Emergy diagram approach for electricity production from biomass



Sources of energy for this industrial process have been divided in three groups; Biomass requirements, Transport energy necessities to move biomass from plots to the industrial plant and industry expected necessities. This groupings just attends to formula construction interests in order to obtain a geographical factor that allows to determinate which location minimizes transformities to obtain one lower than fossil fuels.

Building an industrial plant according to renewability and efficiency targets

In mathematical language the restrictions written below can be expressed as:

$$T_{BP} < T_{ff}$$

Being T_{BP} the transformity in a biomass plant and T_{ff} the transformity from fossil fuels. According to the energy inputs written above:

$$\frac{E_b + E_t + E_i}{\text{Electricity}} < T_{ff}$$

Being E_b the emergy needed in form of biomass, E_t the energy inverted in transporting the biomass from plots to the industrial plant and E_i the energy of the rest of the industrial requirements that are necessary to make it work. In this last group are included workers, electricity, water, etc. All of each groups can be expressed using more detailed functions:

$$E_b = \text{Area} \cdot \text{crop yield} \cdot \text{Energy content} \cdot T_b$$
$$E_t = d_t \cdot c_f \cdot \text{Energy content} \cdot T_{ff}$$
$$\text{Electricity} = \text{Area} \cdot \text{crop yield} \cdot \text{Energy content} \cdot Ef.$$

The emergy of the biomass consumed by the plant depends on the area, the crop yield in biomass terms and the transformity of that biomass. The transport emergy results from multiplying the distance traveled (d_t), the consumption of fuel in volume per distance units (c_f) and the transformity for fossil fuels (T_{ff}). The electricity generated depends on the efficiency in transforming the joules contained in biomass into electricity joules (Ef.). Introducing these formulas into the previous one:

$$\frac{\left(\text{Area}\left(\text{ha}\right)\cdot\text{crop yield}\left(\frac{\text{T}}{\text{ha}}\right)\cdot\ \text{Energy content}\left(\frac{\text{J}}{\text{T}}\right)\cdot\text{T}_{\text{b}}\left(\frac{\text{seJ}}{\text{J}}\right)\right)+\left(\text{d}_{\text{t}}\left(\text{km}\right)\cdot\text{c}_{\text{f}}\left(\frac{\text{l}}{\text{km}}\right)\cdot\ \text{Energy content}\left(\frac{\text{J}}{\text{l}}\right)\cdot\text{T}_{\text{f}}\left(\frac{\text{seJ}}{\text{J}}\right)\right)+E_i}{\text{Area}\left(\text{ha}\right)\cdot\text{crop yield}\left(\frac{\text{T}}{\text{ha}}\right)\cdot\ \text{Energy content}\left(\frac{\text{J}}{\text{T}}\right)\cdot\text{Ef.}} < \text{T}_{ff}$$

It can be simplified as:

$$\frac{\left(\text{T}_{\text{b}}\right)}{\text{Ef.}}+\frac{\left(\text{d}_{\text{t}}\cdot\text{c}_{\text{f}}\cdot\ \text{Energy content}\cdot\text{T}_{\text{f}}\right)+E_i}{\text{Area}\cdot\text{crop yield}\cdot\ \text{Energy content}\cdot\text{Ef.}} < \text{T}_{ff} \rightarrow$$

$$\frac{\left(\text{d}_{\text{t}}\cdot\text{c}_{\text{f}}\cdot\ \text{Energy content}\cdot\text{T}_{\text{f}}\right)+E_i}{\text{Area}\cdot\text{crop yield}\cdot\ \text{Energy content}\cdot\text{Ef.}} < \text{T}_{ff}-\frac{\left(\text{T}_{\text{b}}\right)}{\text{Ef.}}$$

However, in this formula there are some terms which are correlated. For example the distance traveled depends on the area covered. Another term that depends on area is the emergy of the industry as the more area covered, the more biomass quantity inflows the industry and the more requirements (as workers, electricity, water, etc.) are necessary. That means that both variables can be expressed as a function depending on the area covered:

$$\frac{\left(f(A)\cdot\text{c}_{\text{f}}\cdot\ \text{Energy content}\cdot\text{T}_{\text{f}}\right)+f'(A)}{\text{A}\cdot\text{y}} < \ \text{Energy content}\cdot\text{Ef.}\left(\text{T}_{ff}-\frac{\left(\text{T}_{\text{b}}\right)}{\text{Ef.}}\right)\rightarrow$$

$$\frac{\left(f(A)\cdot\text{c}_{\text{f}}\cdot\ \text{Energy content}\cdot\text{T}_{\text{f}}\right)+f'(A)}{\text{A}\cdot\text{y}} < \ \text{Energy content}\cdot\left(\text{Ef.}\cdot\text{T}_{ff}-\left(\text{T}_{\text{b}}\right)\right)$$

In the formula below, it can be seen that finally most of the terms depending on biomass plant location (area, distance, yield) are at one side of the "< " sign and on the other are the constants of one project as the energy content of the crop is an invariable constant and also does both transformities. The efficiency of the plant is a variable that depends on the on technology evolution. In turns this evolution takes place along time. However, the purpose of this section is to find a formula that allows to chose a location for a determinate project in a concrete time, so this term, here remains invariable.

This formula can be expressed as there has to be a geographic factor lower than a project constant:

Fig. 29 . Area covered according to the distance traveled

$$F_g < K_p$$

Application of the formula

In this section an hypothetic situation is raised in order to show how formula has to be used;

“Danish government has decided to create a new Biomass Burning Plant. According to the technological development, the efficiency nowadays in converting the biomass into electric energy is around 0.3 percent. It has been decided that straw would be the main source of energy of this industrial plant”.

Knowing this, engineers are expected to find the best location for the biomass plant according to the targets specified before (renewability and efficiency).

1.- Calculating project constant

According to the given information, the constant of the project can be calculated. This figure will be used later as the restrictive quantity for the geographic factor:

$$k_p = \text{Energy content} \cdot \left(\mathrm{Ef} \cdot T_{ff} - T_b\right) = 18.5 \cdot \left(0.3 \cdot 6.6\mathrm{E{+}04} - 1.77\mathrm{E{+}04}\right) = 3.89E + 04$$

This formula has been filled in using information provided by Borjesson’s article, in which is specified that straw energy content is 18.5 GJ per Mg of dry weight. The biomass transformity is that one obtained in this project as a general transformity for energy crops.

2.- Determining industrial emergy formula:

After calculating the project constant is necessary to define the formula that joins both parameters, industrial emergy and area covered. This formula can be obtained by representing on a chart the values of industry necessities emergy and the area covered. The bigger the area covered is, the more requirements as it is needed to process more biomass quantity. Trend lines can be used in order to make an approach.

$$E_i = f'(A)$$

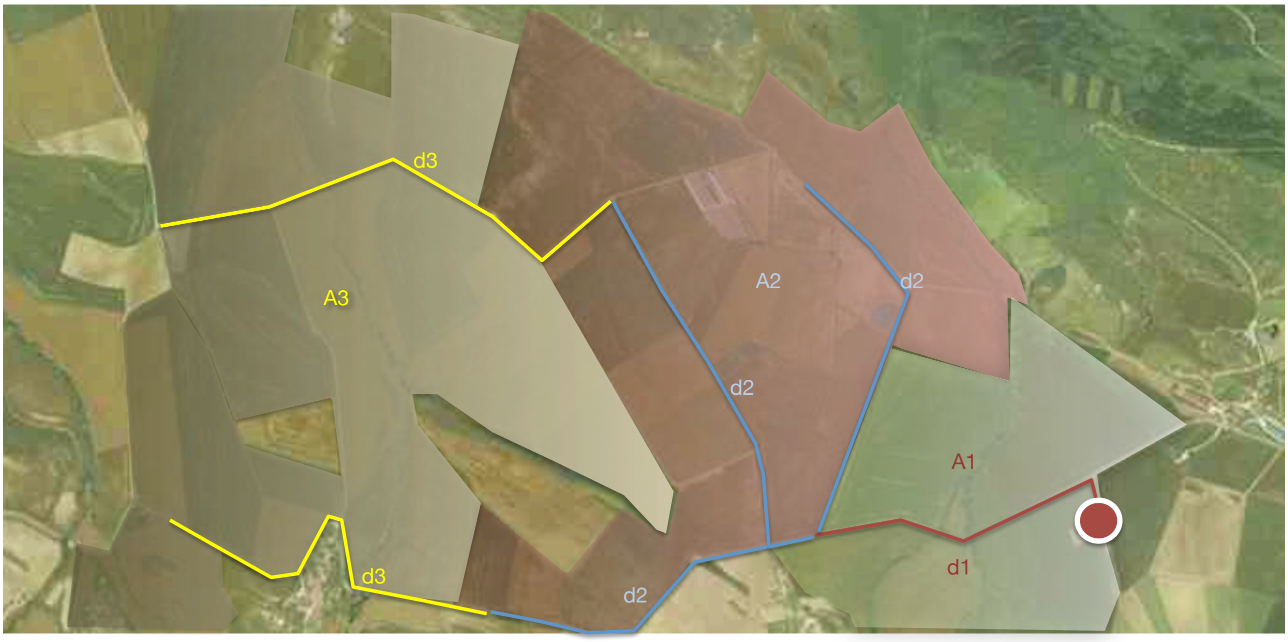
3.- Distance traveled dependence

The distance traveled can be also represented as an area function. In this case a concrete location is valued in order to demonstrate how the function has to be founded. Keeping on with the hypothesis, it has been decided that one of the interesting locations for biomass construction is that one showed below:

Fig. 28 . Possible industrial plan location and area that can be covered

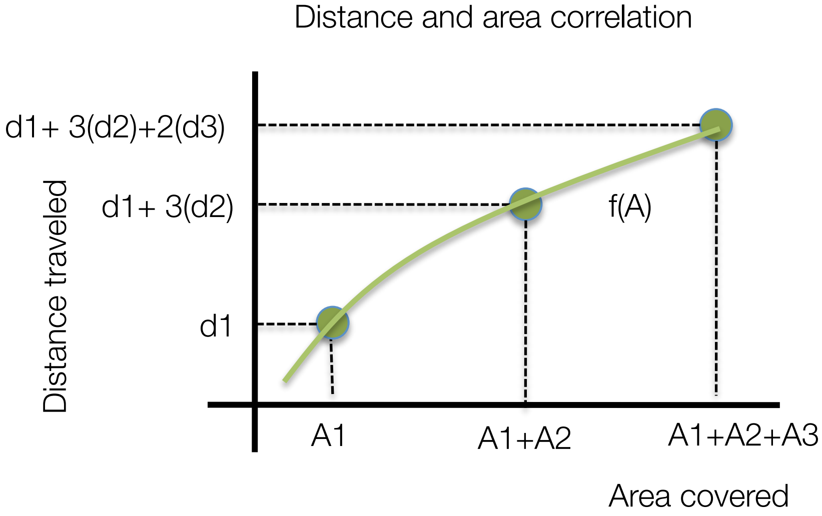
The area covered represent those plots where wheat is cultivated and it is possible to collect the straw. From this map can be extracted some distance traveled values regarding the area covered as it is illustrated below. The more data collected, the more accuracy of the model and the closer the results will be from real values:

Fig. 31 . Behavior scheme of biomass collecting



The distance written with the same number and color are same distance in order to make easier the representation and calculation to build the chart:

Fig. 30 . Area covered vs distance chart



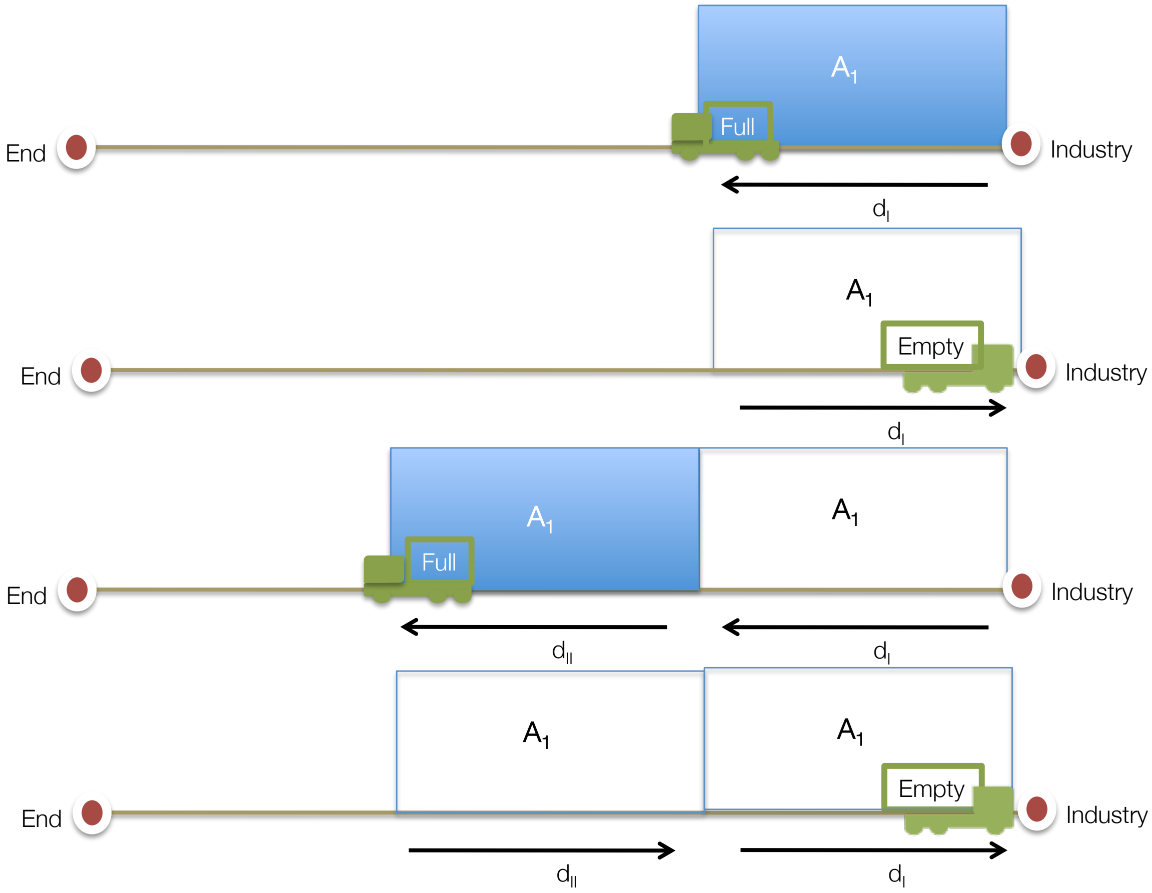
This chart allows to find the function that relates the area covered and the distance is necessary to travel to cover a concrete area. However this distance not represent the total distance traveled to transport biomass from plots to the industry. It has to be taken into account the capacity of the transport that is going to be used. When it is completely charged, it has to come back to the industry plant to unload. But how far the transport would have to turn round:

$$A_1 = \frac{\text{Transport capacity}\left(\text{T}\right)}{\text{Yield}\left(\frac{\text{T}}{\text{ha}}\right)} = A_1\left(\text{ha}\right) \rightarrow f(A_1) = d_I$$

So the truck at the beginning can reach to a distance of d_I without turning around. Once the truck has reached to d_I, the truck is full, so he has to carry back the biomass collected traveling again a distance of d_I. In other words, the distance traveled by the truck to cover an area equal to A1 is d_I times two. Once the truck is empty, it has to travel to a distance in which the area covered is equal to two times A1. One A1 corresponds to the area already collected and the second one corresponds to the new area that the the truck has to cover to be full of biomass again so:

$$A_2 = 2 \cdot A_1 \rightarrow f(A_2) = d_{II} \rightarrow d_t = 2 \cdot d_I + 2 \cdot d_{II}$$

This means that for covering an area A2, first the truck reaches to d_I, then the truck is full, so it comes back to the industry. After that the truck reaches to d_{II} where it is again completely full, so he has to travel again a distance of d_{II} to reach again to the industry:



And so is on, till reaching to area covered being equal to the total area available:

$$A_n = A_t$$

So finally the condition raised at the beginning should be valued for each A_i:

For A_1:

$$A \rightarrow f(A_1)=d_I \rightarrow d_t=2\cdot d_I$$

$$A_1 \rightarrow f'(A_1)=E_{i1}$$

$$\frac{d_t\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_i}{A\cdot y}<3.89E+04 \rightarrow \frac{2\cdot d_I\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_{i1}}{A_1\cdot y}<3.89E+04$$

For A_2:

$$A_2 \rightarrow f(2\cdot A_1)=d_{II} \rightarrow d_t=2\cdot d_I+2\cdot d_{II}$$

$$A_2 \rightarrow f'(2\cdot A_1)=E_{i2}$$

$$\frac{d_t\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_i}{A\cdot y}<3.89E+04 \rightarrow \frac{\left(2\cdot d_I+2\cdot d_{II}\right)\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_{i2}}{A_2\cdot y}<3.89E+04$$

For A_n:

$$A_n \rightarrow f(n\cdot A_1)=d_n \rightarrow d_t=2\sum_{j=1}^{n} d_j$$

$$A_2 \rightarrow f'(n\cdot A_1)=E_{in}$$

$$\frac{d_t\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_i}{A\cdot y}<3.89E+04 \rightarrow \frac{\left(2\sum_{j=1}^{n} d_j\right)\cdot c\cdot \text{Energy content}\cdot T_{ff}+E_{in}}{A_n\cdot y}<3.89E+04$$

This operations has to be made till finding the inflection point in which the conditions is not met to the area in which is met or vice versa. Then the maximum area that meets the condition is the area used later to calculate the electricity production and the requirements for the industry.

This procedure should be done for every location available. The most recommended area will be that one in which the condition is met, producing the maximum quantity of electricity

Conclusions

Here is written the sum up of all those things raised on the discussion derived from this project. In order to understand completely this section, discussion has to be read firstly.

Theoretical conclusions

Emergy values against economic values:

The representation of the emergy values against the economic values is valuable as:

I. The representation allows approaching a two kinds of trend lines; The Ideal Relationship and the Real Relationship. The ideal relation represents the situation in which ES are economically valued as something proportional to environmental effort. The Real Relationship corresponds to the most fitted trend line that correlates both valuation methods for current values.

II. The Real Situation trend line can be used to quantify approximately the economic or emergy value for unknown services.

III. The intercept of the Real Situation trend line offers information about the complete or incomplete internalization of the ES in the economic valuation: If the intercept value is higher than zero, then there is a range of emergy values that wouldn't be paid. If the value is equal to zero all emergy values are internalized. If it is lower than zero, it means that the economic valuation is not efficient as null emergy has an economic value.

IV. The determination coefficient from the real situation serves as a measure of the environmental mentality of the studied society, i.e. is a measure of how society considers the environmental effort required to perform a service.

V. The slope of the Ideal Relationship trend line represents the seJ/USD ratio for services provided by nature, and can be used to make comparisons between countries.

VI. The area between the Ideal Relationship and the Real Relationship trend lines serves a measure of the equivalence of the current economic valuation to the environmental mentality. If the area is higher than zero that means that current economic method generally speaking overvalues the ES regarding the economic value of the ideal situation. If the value is lower than zero then the current ES are undervalued by the Total Economic Valuation (TEV). If the value is equal to zero and the Real Relationship internalizes all emergy values, then it could be said that the current economic valuation is equivalent to the environmental mentality. If the analysis is carried out for all emergy range, then the equivalence is known as virtual environmental mentality equivalence but if it is carried out for concrete ES values of a crop in a country then TEV is considered namely equivalent to the environmental mentality.

Economic methodology regarding the emergy valuation

The economic valuation offers a snapshot of the current perception from society about services provided by nature. However the emergy methodology obtains almost invariable values based on physical variables, some of there unconsidered in the TEV (such as time). Maybe, the apparition of greater ecological awareness will make society conscious about the environmental effort required for some functions and therefore society will reach to environmental mentality.

Practical conclusions

A more exhaustive study in ES would provide data enough to characterize in a more accurate way the trend line that relates the dollars with solar emjoules. So results from this project are only a demonstration of the potential of the analysis and an approach of the situation in Denmark.

Emergy values against economic values

1. The current economic valuation internalizes all the range of emergy values.
2. The determination coefficient of the Ideal Relationship is equal to 0.099 which means that Danish society is very far from environmental mentality as far as concerns ES valuation.
3. The slope of the Ideal Relationship trend line is equal to 2E+13 seJ/USD which is equal to emergy-economy ratio in Denmark to achieve an ideal valuation.
4. ES valued under 1E15 seJ in Denmark are overvalued. However for this figure up, the ES with higher emergy values are undervalued. The economic losses in energy crops at Denmark are quantified in 331 USD/yr./ha.
5. The TEV currently can not be considered virtually or namely equivalent to environmental mentality for energy crops in Denmark.

Emergy-emergy analysis

The TEV undervalues the ES owing to the subjectivity and the fact of forgetting time as a factor of value

Biomass emergy and transformity

The transformity of biomass is lower than that one for producing fossil fuels (1.77E+04 seJ/J for biomass production and 6.6E+04 seJ/J for fossil fuels according to Odum calculations), so it is deduced that the environmental effort for producing one joule contained in biomass is at least four times that effort required for producing one joule of fossil fuel. Therefore the also the fossil fuels can be considered a more quality and concentrated source of energy.

Biomass transformity can be used in finding a proper location for a biomass combustion plant that can make that electricity transformity from biomass would be lower than fossil fuels' transformity, making this electricity generation more efficient and with less effort required from the environment. In order to do that it has to be checked that the geographic factor would be lower than the project constant for every possible location:

$$\frac{\left(\mathrm{d_t} \cdot \mathrm{c_f} \cdot \text{ Energy content} \cdot \mathrm{T_f}\right) + E_i}{\text{Area} \cdot \text{crop yield}} < \text{ Energy content} \cdot (\mathrm{Ef} \cdot \mathrm{T}_{ff} - \mathrm{T_b}) \rightarrow \mathrm{F_g} < \mathrm{K_p}$$

Limitations

Most of the limitations in this project are joined to the lack of concrete data needed to calculate the emergy values for the ecosystem services. It has been used a lot of information that belongs to different studies with the consequent error. Climate variations between studies, different species data recorded are the sources of error accepted in order to use those figures as indicative figures for non studied values that are required. Also some decisions have been taken in order to simplify calculations. In conclusion, results from this project are indicative results for energy crops in Denmark, being the methodology and data analysis the main contributions to scientific research.

Future perspectives

Future researches has to focus their attention on minimizing the errors here committed: That implies researching more accurately the ecosystem services and functions, how they work, recording useful data for emergy analysis. It is suggested also to develop a project in which in the same plot, emergy and economic analysis would be done in order to minimize the climate differences in data collected.

Appendix A

In this section emergy calculations for each service are detailed. That includes exposing the sources of information and data collected, logical calculation reasonings an the mathematical operations.

Biomass production

Renewable inputs

Solar energy and emergy

Land area in agriculture: 10,000 m^2/ha.

Average insolation in Denmark: 3.63E+03 MJ/m^2/yr. (Andrew C. Haden, 2003).

Albedo: 0.3 (Andrew C. Haden, 2003).

$$\text{Solar energy}\left(\frac{J}{yr\cdot ha}\right)=10{,}000\left(\frac{m^2}{ha}\right)\cdot 3.63E{+}09\left(\frac{J}{m^2\cdot yr}\right)\cdot(1\text{-}0.3)=2.54E{+}13\left(\frac{J}{yr\cdot ha}\right)$$

$$\text{Solar emergy}=2.54E{+}13\left(\frac{J}{yr\cdot ha}\right)\cdot 1\left(\frac{seJ}{J}\right)=2.54E{+}13\left(\frac{seJ}{yr\cdot ha}\right)$$

Wind energy and emergy

Land area in agriculture: 10,000 m^2/ha.

Height reference: 1000 m (Andrew C. HAden, 2003)

Average wind speed on the surface in Denmark: 7 m/sec. (Andrew C. Haden, 2003).

Air density: 1.23 kg/m^3 (Andrew C. Haden, 2003).

Transformity: 1.5E+03 (seJ/J) (Odum, 1996).

$$\text{Wind energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=1{,}000(\text{m})\cdot 10{,}000\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 1.23\left(\frac{\text{kg}}{\text{m}^3}\right)\cdot\left(\frac{0.4\cdot 7\left(\frac{\text{m}}{\text{sec}}\right)}{0.6}\right)^2\cdot\frac{1}{2}=1.34\text{E+08}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Wind emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=1.34\text{E+08}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.5\text{E+03}\left(\frac{\text{seJ}}{\text{J}}\right)=2.01\text{E}+11\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Chemical Potential Energy (CPE) and Rain emergy

Land area in agriculture: 10,000 m^2/ha.

Precipitation: 834 mm/yr (Andrew C. Haden, 2003). This value has been verified through other meteorological sources of information.

Gibbs Free Energy; 4.94 J/g (Odum, 1996).

Run off coefficient: 0.0683 (Andrew C. Haden, 2003).

Transformity: 1.82E+04 (seJ/J) (Odum, 1996).

$$\text{Chemical Potential Energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$834(\text{mm})\cdot 0.001\left(\frac{\text{m}}{\text{mm}}\right)\cdot 10000\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 1\text{E+06}\left(\frac{\text{g}}{\text{m}^3}\right)\cdot 4.94\left(\frac{\text{J}}{\text{g}}\right)\cdot(1\text{-}0.0683)=3.84\text{E+10}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Rain emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$3.84\text{E+10}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.82\text{E}+04\left(\frac{\text{seJ}}{\text{J}}\right)=6.99\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Geochemical input

Land area in agriculture: 10,000 m^2/ha.

Heat flow: 1E+06 J/m^2 (Odum, 1996).

Transformity: 3.44E+04 seJ/J (Odum, 1996).

$$\text{Geochemical input}\left(\frac{J}{yr\cdot ha}\right)=10000\left(\frac{m^2}{ha}\right)\cdot 1E{+}06\left(\frac{J}{yr\cdot m^2}\right)=1E{+}10\left(\frac{J}{yr\cdot ha}\right)$$

$$\text{Geochemical emergy}\left(\frac{seJ}{yr\cdot ha}\right)=1E{+}10\left(\frac{J}{yr\cdot ha}\right)\cdot 3.44E+04\left(\frac{seJ}{J}\right)=3.44E+14\left(\frac{seJ}{yr\cdot ha}\right)$$

Purchased inputs

Pesticides

According to the Danish Statistic Databank, for the year 2007, 1.53 kg/yr./ha of pesticides were used in Danish agriculture. Other sources, as the work paper of John R. Porter, which was written at the year 2009,The amount of pesticides used in the experiment was around 1.35 Kg/y.r/ha (obtained as the sum of kilograms of actives ingredients of insecticides, fungicides and herbicides). In Sweden, some researches about energy crops show that the necessities of pesticides were 1kg/yr./ha. The amount of pesticides was calculated in the last study at the year 1996. This scientific article also includes an estimation of the quantities that are expected to be used by the year 2015, so it allows to make an interpolation between them for the year 2009. After that, the amount of pesticides is 0.8 kg/yr./ha. Two first measurements can be consider quite similar, but not the last one.

The results variability can be caused by mainly three reasons; The first one is the differences between agro-climate conditions in Denmark and Sweden. Denmark is warmer than Sweden, which makes Danish agriculture more susceptible to pest attack. The second source of variability is the kind of crop; the study from Sweden is referred exclusively to energy crops, but the other ones belong to general agriculture. The third reason is time. So the most correct source of data is that one given by John R. Porter, as it is recent in time, is located in Denmark and works with crop species that could be used for energy production.

Pesticides used: 1.35 kg/yr./ha (John R. Porter, 2009).

Transformity: 1.5E+10 seJ/J (Odum, 1996).

$$\text{Pesticides emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=1.35\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{g}}{\text{Kg}}\right)\cdot 1.5\text{E+10}\left(\frac{\text{seJ}}{\text{g}}\right)=2.03\text{E+13}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Fertilizers emergy

In this point, the statistic data provided by the “Statitkbanken” about the total supply of mineral fertilizers of pure nutrients, expressed in kilograms per hectare of phosphorus, potassium and nitrogen were 5, 22 and 83 respectively. In the report title “Energy analysis of biomass production and transportation” the interpolation between data estimated for 2015 and real data at 1996 in the same measurement units are 25, 34, 103. Here different crop necessities is more influent than climate and therefore Borjesson (Study in Sweden) recorded data is used for fertilizers calculations:

Amount of nitrogen: 103 kg/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

Amount of Phosphorus: 11 kg/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

Amount of Potassium: 24 kg/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

Phosphorus transformity: 3.8 E+09 seJ/g (Andrew C. Haden, 2003).

Potassium transformity:1.78E+10 seJ/g (Andrew C. Haden, 2003).

Nitrogen transformity: 1.1E+09 seJ/g (Andrew C. Haden, 2003).

$$\text{Nitrogen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=103\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{g}}{\text{Kg}}\right)\cdot 2.8\text{E+09}\left(\frac{\text{seJ}}{\text{g}}\right)=3.91\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Phosphorus emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=11\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{g}}{\text{Kg}}\right)\cdot 1.78\text{E+10}\left(\frac{\text{seJ}}{\text{g}}\right)=1.96\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Potassium emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=34\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{g}}{\text{Kg}}\right)\cdot 1.1\text{E}+09\left(\frac{\text{seJ}}{\text{g}}\right)=3.74\text{E}+13\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Mechanical equipment emergy

Embodied energy in mechanical equipment:1.3025 GJ/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

Embodied energy transformity: 24 MJ/kg (Borjesson, 1996).

Transformity: 6.7E+09 seJ/kg (Andrew C. Haden, 2003).

$$\text{Mechanical equipment quantity}\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)=\frac{1.3025\left(\frac{\text{GJ}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{MJ}}{\text{GJ}}\right)}{24\left(\frac{\text{MJ}}{\text{kg}}\right)}=54.3\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Mechanical equipment emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=54.3\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 6.7\text{E}+09\left(\frac{\text{seJ}}{\text{kg}}\right)=3.64\text{E}+11\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Fuel emergy

Average hours machinery use: 15.7 h/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

Average motor consumption: 11.08 l/h (interpolating data from Borjesson (1996) for the year 2009).

Diesel energy coefficient: 38.7 MJ/l (Elseiver, 1992).

Transformity (motor fuels):6.6E+04 seJ/J (Andrew C. Haden, 2003).

$$\text{Fuel emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$15.7\left(\frac{\text{h}}{\text{yr}\cdot\text{ha}}\right)\cdot 11.08\left(\frac{\text{l}}{\text{h}}\right)\cdot 38.7\left(\frac{\text{MJ}}{\text{l}}\right)\cdot 1\text{E}+06\left(\frac{\text{J}}{\text{MJ}}\right)\cdot 6.6\text{E}+04\left(\frac{\text{seJ}}{\text{J}}\right)=$$

$$4.73\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Services: Labour

Total employees in Agriculture according to the “Statistikbanken” by the year 2008 are 25,770. The average earnings of these farmers per month range from 25472 DKK to 29448 DKK depending on if they are employees of the local or central government and raises to 48,126 DKK in the private sector. In this study the money pid for the service of farmers by the central government will be taken a reference as the public sector shows the minimal input of energy needed for the existence of this service. So:

Total employees in agriculture: 25,770 individuals (Statistikbanken, 2008).

Average earning per month: 27,500 DKK/month/individual (Statistikbanken, 2008).

1 USD = 4.98721 DKK (exchange value at November 2009).

Total arable land in Denmark: 1.62E+12 seJ/USD (Andrew C. Haden, 2003).

$$\text{Services emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=\frac{27{,}770\left(\text{individuals}\right)\cdot 27{,}500\left(\frac{\text{DKK}}{\text{month}\cdot\text{individual}}\right)\cdot 12\left(\frac{\text{month}}{\text{yr}}\right)\cdot 1.62\text{E}+12\left(\frac{\text{seJ}}{\text{USD}}\right)}{4.98721\left(\frac{\text{DKK}}{\text{USD}}\right)\cdot 2{,}667{,}895\left(\text{ha}\right)}=$$

$$=1.05\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Total emergy input: 3.22 E+15 (seJ/yr./ha)

Biomass energy

The average of energy per hectare and year for different crops at the year 2009; 189.06 GJ/yr./ha (interpolating data from Borjesson (1996) for the year 2009).

$$\text{Transformity}\left(\frac{\text{seJ}}{\text{J}}\right)=\frac{3.22\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{186.09\left(\frac{\text{GJ}}{\text{yr}\cdot\text{ha}}\right)\cdot 1\text{E}+09\left(\frac{\text{J}}{\text{GJ}}\right)}=1.77\text{E}+04\left(\frac{\text{seJ}}{\text{J}}\right)$$

Transformity : 1.77E+04 (seJ/J)

Pollination

As it can be seen in John R. Porter´s work paper, Salix spp. are the energy crop species with more costs incurred by farmer, because pollination services must be contracted. That means that the natural effect of pollination in these plants is lower than in others. Owing to the fact that in this study lower emergy is looked for, Salix is used to calculate the minimum value of pollination in energy crops.

Bee emergy

A hive consumes the 68% of the honey produced (Southwick and Pimentel). In this study is then estimated that the bee´s requirements of nectar and pollen are 259 and 24 kilograms per year respectively. Knowing this, these necessities should be joined to an energy crop area and then calculate the emergy for maintaining that given area.

Pollen production in some Salix species range from 1666-4957 grains of pollen per anther (Peeters and Totland, 1999) and nectar from 10-575 grams of sugar per hectare (Hocking, 1968). Nectar sugar concentrations in our case are of 41%, which means that sugar in nectar necessities rises to:

$$\text{Sugar from nectar}\left(\text{kg}\right) = 259\left(\text{kg}\right)\cdot 0.41 = 106.19\left(\text{kg of sugar}\right)$$

So:

$$\text{Energy crop area needed}\left(\frac{\text{ha}}{\text{hive}\cdot\text{yr}}\right) = \frac{1.06\text{E+}05\left(\dfrac{\text{g of sugar}}{\text{hive}\cdot\text{yr}}\right)}{200\left(\dfrac{\text{g of sugar}}{\text{ha}}\right)} =$$

$$= 531\left(\frac{\text{ha}}{\text{hive}\cdot\text{yr}}\right) \text{ of Salix spp. needed}$$

This figure is very high but agrees with Southwick and Pimentel information as 531 hectares is equal to a circle with a 1.3 km radio and they state that "w*ith good food sources distance from the hive can be limited to 1-2 km far"* (Gary 1978; Root, 1975).

In spite of being agree, the variance of nectar production by Willow species is very high as some sources of information affirm that grams of nectar sugar from Willow catkins in one squared meter (mean from female and male flower production)can reach to 1.17 (Kay, 1985) which leads to an energy crop area needed of around 10 hectares. This 10 hectares are equal to a circular surface with a radio of 178 m long.

Anyway, the emergy for creating nectar is 3.22E+15 seJ per year and per hectare. If total nectar is consumed then the emergy per year and per hectare for a hive maintenance is the same that the emergy for nectar production. However common sense states that all the nectar produced is not all the nectar consumed. Due to the lack of data referring to this question, a big percentage of consumption is stated (90%). Therefore the emergy per hectare destined to hive maintenance is 1.9E+15 seJ per year and per hectare.

In case of pollen, it is impossible to join that amount of grains produced by trees (measured in grains of pollen per anther)with the pollen necessities (measured in milligrams). No mass per pollen grain factor was founded. In spite of all, in this study is estimated the minimum emergy needed for service existence. Nonetheless a flower visited by a pollinator to collect pollen can be also visited for nectar, i.e. there is a superposition between flowers visited for nectar and pollen collection. In our case the superposition is equal to 1, in other words, all flowers visited for pollen recollection are also visited for pollen collection. As they are co-products, the emergy for creating both is the same. That means that it is only taken into account the number of flowers of the source of food which requires more flowers to visit. Nectar energy represents 82% of the energy input in a hive and 12 millions of kilometers flied against 3.5 millions in pollen (Southwick and Pimentel, 1981). That means that more flowers are required for nectar collection than pollen, so emergy for nectar consumption is the only measure needed for hive emergy maintenance calculations.

Pollen emergy

PEC data (see Pollination subsection, Methodological section) is not founded, so approximations are made to obtain a value (keeping on with policy of minimum emergy input). Therefore, as 1 results impossible, 0.9 is assumed. It is analogous for the degree impact which is assumed 0.15. This last figure is based on the study made by Karrenberg et al. at the year 2002 in which four Salix species pollination were studied. He states that "*more than 85% of the variance in fruit and seed precocious flowering fit with the wind pollination syndrome".*

In this last study, ovules per fruit average are recorded (10 ovules per fruit), so are the average fruit per catkin(46.5 as the most common value) and so are catkins per plant (202 as the most common value). So:

$$\text{Pollen grains needed/tree} = 10\left(\frac{\text{ovules}}{\text{fruit}}\right)\cdot 46.5\left(\frac{\text{fruits}}{\text{catkin}}\right)\cdot 202\left(\frac{\text{catkins}}{\text{plant}}\right)\cdot \frac{0.15}{0.9}\left(\frac{\text{pollen grains needed}}{\text{ovule}}\right)=$$

$$=1.54\text{E}+04\left(\frac{\text{pollen grains needed}}{\text{tree}}\right)$$

Pollen transformity is not easy to calculate as pollen grains production per anther can vary from 5600 to 1600 grains (Peters and Totland,1999). Besides Salix species are grouped in three different types according to their stamen characteristics; with more than two stamens, with two separated stamens and those ones formed by two connate stamens (Ohashi,2000) which makes difficult to raise a mean figure. There is also big variability in the amount of flowers per catkin (96-183; Elqvist et al., 1988). For calculations, minimum values are taken:

$$\text{Pollen transformity}\left(\frac{\text{seJ}}{\text{grain}}\right)=\frac{3.22\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{1600\left(\frac{\text{pollen grains}}{\text{anther}}\right)\cdot 2\left(\frac{\text{anthers}}{\text{flower}}\right)\cdot 96\left(\frac{\text{flowers}}{\text{catkin}}\right)\cdot 200\left(\frac{\text{catkins}}{\text{tree}}\right)\cdot 20{,}000\left(\frac{\text{trees}}{\text{yr}\cdot\text{ha}}\right)}=$$

$$=2.62\text{E}+03\left(\frac{\text{seJ}}{\text{grain}}\right)$$

$$\text{Pollen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=1.54\text{E}+04\left(\frac{\text{pollen grains needed}}{\text{tree}}\right)\cdot 20{,}000\left(\frac{\text{trees}}{\text{yr}\cdot\text{ha}}\right)\cdot 2.62\text{E}+03\left(\frac{\text{seJ}}{\text{grain}}\right)=$$

$$=8.07\text{E}+11\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

That means that total emergy in pollination is:

$$\text{Pollination emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=8.07\text{E}{+}11\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+2.9\text{E}{+}15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=2.9\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Pollination energy

The energy value of the flights is predicted calculating the energy spent by kilometer (4.6 kcal/km; Southwick and Pimentel, 1981) and the distance traveled for supplying for food (15.6 millions of km; Southwick and Pimentel, 1981) for multiplying them (17,160 kcal; Southwick and Pimentel, 1981). The variation of the area covered is big, however 531 ha are used:

$$\text{Pollinaiton energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=\frac{17{,}160\left(\frac{\text{kcal}}{\text{yr}}\right)\cdot 4186\left(\frac{\text{J}}{\text{kcal}}\right)}{531(\text{ha})}=1.35\text{E}+05\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Pollinaiton transformity}\left(\frac{\text{seJ}}{\text{J}}\right)=\frac{2.9\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{1.35\text{E}+05\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)}=2.14\text{E}+10\left(\frac{\text{seJ}}{\text{J}}\right)$$

Pest control

Predator emergy

In our case, the crop in which pest control emergy is quantified are cereals (that also belong to emergy crops group). According to John R. Porter research, the most common pests in cereals are three aphids species: *Rhopalosiphum padi, Sitobiion avenae, Metopoliphium dirhodu.* Very few data has been founded about measurement of their biological characteristics (weight, biomass ingested, etc). In order to fill in the formulas, not only the specific data but also the average data from other similar species are used for unknown variables.

The predation rate in cereals has been measured for *S. avenae.* Unfortunately these quantifications are not global as they represent the background mortality of this aphid along two months (spring time). However, those months represent the period with most predation activity of the year so it would be taken as a representation of whole year activity. In order to estimate the number of individuals hunted per year, mortality pattern has been raised using data from Winder et al., supposing that the main cause for mortality figures is predation. The number of individuals death is calculated integrating the background mortality trend line between the dates of the study. That results in 170 individuals death in a year.

According to the equation written at the methodology section the other unknown variable is the biomass ingested by this phitophagous, which is a data even more difficult to find. Auclair in 1963, measured the percentage of body weight ingested by different aphid species. This research shows that this characteristic is very specific from each specie as there are big variabilities in data registered. In spite of all, in order to obtain an approximation, a mean of data has been calculated (35.04% of body weight ingested per hour). Given this units, it is also necessary to include the number of hours that a complete life cycle in aphids lasts. For *Rophalosiphum padi* life cycle lasts between 144 and 336 hours (Dixon, 1977). The body weight it is also needed and it varies from 0,5 to 9 milligrams, being 1 milligrams the most common value of body weight (Llewellyn and Brown, 1985).

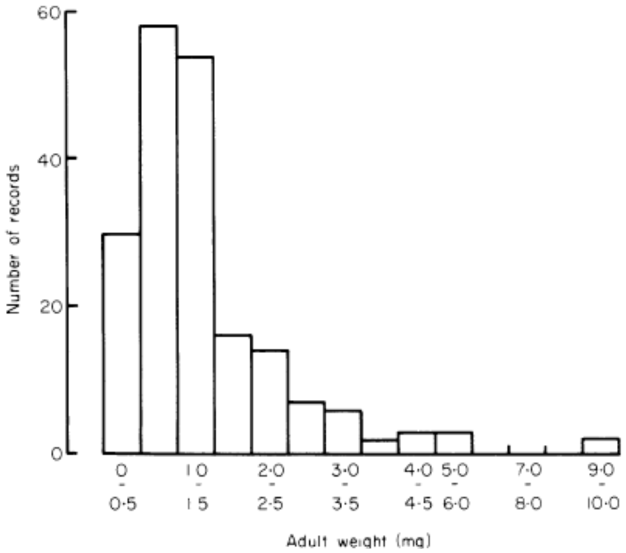


Fig. 29 . Body weight of an adult according to Llewellyn and Brown, 1985

The biomass consumed by aphids is essentially fluids form plant and dissolved compounds from the phloem and cellular liquids. To convert the mass value in energy terms, it is known that "*for carbohydrates, starch and wood is assumed 4 kcal/g: for proteins, wool, etc.,about 5 kcal/g dry; for fats and oils about 7-9 kcal/g*" (Odum, 1996). Therefore, in order to simplify energy calculations we will use the value of 4 kcal/g.

$$\text{Energy of biomass ingested by phitophagous}\left(\frac{\text{J}}{\text{yr}\cdot\text{individual}}\right)=$$

$$=0.35\left(\frac{\%}{\text{h}}\right)\cdot 0.001(\text{g of body weight})\cdot 144\left(\frac{\text{h}}{\text{yr}\cdot\text{individual}}\right)\cdot 4\left(\frac{\text{kcal}}{\text{g}}\right)\cdot 4186\left(\frac{\text{J}}{\text{kcal}}\right)=$$

$$=8.44\text{E}+02\left(\frac{\text{J}}{\text{yr}\cdot\text{individual}}\right)$$

So for pest control:

$$\text{Pest control emergy} =$$

$$= 8.44\text{E+02}\left(\frac{\text{J}}{\text{yr}\cdot\text{individual}}\right)\cdot 1.7\text{E}+04\left(\frac{\text{seJ}}{\text{J}}\right)\cdot 170\left(\frac{\text{individuals}}{\text{m}^2}\right)\cdot 10{,}000\left(\frac{\text{m}^2}{\text{ha}}\right)=$$

$$= 2.44\text{E}+13\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Hunting energy

It has been founded that other aphid species energy content (*T. Salignus*) ranges between 5.6 and 6.1 calories per milligram of dry weight (Llewellyn, 1972). Although our species of aphids are different, given the paucity of data referring to this quantity, this value is taken as a representative value of energy content in our aphids species (using the mean of 5.85 cal/mg).

The dry weight of an individual of *Rophalosiphum padi* is not available in bibliography searched, but the fresh weight varies from 777 to 330 micrograms according to Dixon. In order to transform to dry weight it is known that the dry weight in *T. Salignus* represents the 20% of fresh weight of the aphid so this figure is used for calculations given the lack of information regarding *Rophalosiphum padi´*s dry weight. Using the number of aphids hunted at the previous section, is obtained that:

$$\text{Hunting energy value}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=554\left(\frac{\mu\text{g fresh weight}}{\text{individual}}\right)\cdot 0.2\left(\%\text{ of dry weight}\right)\cdot 5.85\left(\frac{\text{cal}}{\text{mg}}\right)\cdot 1\text{E}-03\left(\frac{\text{mg}}{\mu\text{g}}\right)\cdot 170\left(\frac{\text{individuals}}{\text{m}^2\cdot\text{yr}}\right)\cdot 1\text{E}+04\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 4.186\left(\frac{\text{J}}{\text{cal}}\right)=$$

$$= 4.61\text{E}+06\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

Therefore the transformity:

$$\text{Transformity} = \frac{2.44E+13\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{4.61E+06\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)} = 5.29E+06\left(\frac{\text{seJ}}{\text{J}}\right)$$

Erosion control

Emergy of soil organic matter formation

As it is mentioned at the methodology section all rain emergy should be considered as all the water exercises a mechanical friction against the ground surface releasing soil particles, so:

$$\text{Chemical Potential Energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=834\left(\frac{\text{mm}}{\text{yr}}\right)\cdot 0.001\left(\frac{\text{m}}{\text{mm}}\right)\cdot 10{,}000\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 1\text{E}+06\left(\frac{\text{g}}{\text{m}^3}\right)\cdot 4.94\left(\frac{\text{J}}{\text{g}}\right)=$$

$$=4.12\text{E}+10\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Rain emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=4.12\text{E}+10\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.82\text{E}+04\left(\frac{\text{seJ}}{\text{J}}\right)=$$

$$=7.5\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

The source of data used to fill in these formulas are the same data used in biomass subsection of the Appendix A.

For wind is almost the same. Wind absorbed represents the energy of wind dispersed because of the friction between plant and ground with the wind. The energy of wind not absorbed contributes to erosion by transporting soil particles outside the plot. In conclusion, both wind fractions should be quantified as sources of energy for erosion process:

$$\text{Wind energy} = \frac{1000(\text{m})\cdot 10{,}000\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 1.23\left(\frac{\text{kg}}{\text{m}^3}\right)\cdot 7^2\left(\frac{\text{m}^2}{\text{sec.}^2}\right)}{2} = 3.01\text{E}+08\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Wind emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = 3.01\text{E}+08\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.5\text{E}+03\left(\frac{\text{seJ}}{\text{J}}\right) = 4.52\text{E}+11\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

For the emergy of the weathering bedrock, "*it is assumed to be equal to steady state erosion rates*"(Cohen et al., 2006). In conventional agriculture in Denmark it has been quantified 6.22E+04 g/yr./ha erosion rates in grasslands, 7.62E+05 g/yr./ha at cereals and pulses crops and 6.38E+06 g/yr./ha in winter cereals (Hansen and Nielsen, 1995). The number of hectares destined to this crops in Denmark are very similar between them so the mean of these figures can be used as an erosion rate without making a big mistake. It is also known that short rotation woody crops, such as Salix, promotes a reduction in soil erosion compared to conventional agriculture reaching an improvement close to 90% (comparing maize and short rotation woody crops with 5 and 4 % of slope respectively). Here, a lower percentage is used for two reasons; the first one is because of the slope (the difference is bigger as the slope increases) and owing to the crops used to compare erosion rates (maize erosion rate could be bigger owing to irrigation).

The transformity for rock weathering ranges from 1.09E+09 seJ/g (Odum, 1996) to 3.8E +09 seJg (Brown and Bardi, 2001). Keeping on with the policy of minimum emergy value, the transformity selected for emergy calculations will be 1.09E+09 seJ/g.

$$\text{Geologic input}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = 2.44\text{E+06}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.09\text{E}+09\left(\frac{\text{seJ}}{\text{g}}\right) = 2.66\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Geologic input}_{\text{Short rotation crop}}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = 2.44\text{E+06}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot 1.09\text{E}+09\left(\frac{\text{seJ}}{\text{g}}\right)\cdot 0.2 = 5.32\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

The crop contribution is considered the 10% of residues from harvesting that remains at the plot and contributes to soil organic matter production:

$$\text{Organic matter emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=3.22\text{E+15}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)\cdot 0.1=3.22\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Emergy of organic matter formation}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=\ 7.5\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+4.52\text{E+11}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+5.32\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+3.22\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=1.6\text{E+15}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Energy loss in soil erosion

According to Andrew C. Haden, organic matter lost is calculated firstly and then multiplied by the energy of the organic matter (5.4 kcal/g according to Odum, 1996 and Andrew C. Haden, 2003).

$$\text{Soil organic matter lost}\left(\frac{\text{g of O.M.}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=2.44\text{E+06}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot 0.026(\%\ \text{O.M. in soil})=$$

$$=6.34\text{E+04}\left(\frac{\text{g of O.M.}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Energy loss in soil erosion}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=6.34\text{E+04}\left(\frac{\text{g of O.M.}}{\text{yr}\cdot\text{ha}}\right)\cdot 5.4\left(\frac{\text{kcal}}{\text{g}}\right)\cdot 4186\left(\frac{\text{J}}{\text{kcal}}\right)=$$

$$=1.43\text{E}+09\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

Here the erosion rate is not reduced by the improvement of short rotation woody crops because their soil also contains higher percentages of organic matter (O.M.) and it could compensate in energy loss the soil erosion rate improvement in those kind of crops. However is not enough data to prove that and calculate the energy loss in soil organic matter through erosion in short rotation woody crops so conventional agriculture energy loss is used for transformity calculations.

The transformity is:

$$\text{Transfromity}\left(\frac{\text{seJ}}{\text{J}}\right)=\frac{1.6\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{1.43\text{E}+09\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)}=1.12\text{E}+06\left(\frac{\text{seJ}}{\text{J}}\right)$$

Nitrogen cycle

Emergy calculations

As it is seen in the methodological section, main sources of nitrogen for agricultural soils are crop residues, fertilizers and the biological fixation from the atmosphere. The main studies about nitrogen dynamics are made in wheat cultivation areas. This cereal is also an energy crop, therefore its benefit production is taken as representative for whole energy crops in nitrogen cycle.

There are studies in which nitrogen fixation is quantified as 345 kg/yr./ha in cereal crops. This figure multiplied by its transformity (10.2E+12 seJ/g of N fixed according to Lefroy and Rydberg,2003) results in the emergy of nitrogen fixation. Fertilization emergy is the same than that calculated for biomass production so:

$$\text{Fixation emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=3.45\text{E+05}\left(\frac{\text{g}}{\text{yr}\cdot\text{ha}}\right)\cdot 10.2\text{E+12}\left(\frac{\text{seJ}}{\text{g}}\right)=3.52\text{E+18}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Nitrogen emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=103\left(\frac{\text{kg}}{\text{yr}\cdot\text{ha}}\right)\cdot 1000\left(\frac{\text{g}}{\text{Kg}}\right)\cdot 2.8\text{E+09}\left(\frac{\text{seJ}}{\text{g}}\right)=3.91\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Total}=3.91\text{E+14}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+3.52\text{E}+18\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=3.52\text{E+18}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Emergy of nitrogen storage

According to the formulas purposed by Hansen et al., net input nitrogen and nitrogen losses are required to estimate the nitrogen storage in soil. Nitrogen net input in Danish conventional wheat agriculture varies from 25 to 155 kg N/yr./a, i.e. an average of 90 kg N/yr./ha (Hansen et al., 2000). Gaseous losses by volatilization and denitrification processes represent 3-7 kg/yr./ha (Aulakh at al., 1983, and Aulakh et al., 1982) and from the studies nitrogen leaching is around 29 kg/yr./ha. So:

$$\Delta N_{soil} = 90\left(\frac{kg}{yr \cdot ha}\right) - \left(29\left(\frac{kg}{yr \cdot ha}\right) + 5\left(\frac{kg}{yr \cdot ha}\right)\right) = 56\left(\frac{kg}{yr \cdot ha}\right)$$

Then the transformity:

$$\text{Nitrogen storage transformity} = \left(\frac{3.52E+18\left(\frac{seJ}{yr \cdot ha}\right)}{5.6E+04\left(\frac{g}{yr \cdot ha}\right)}\right) = 6.29E+13\left(\frac{seJ}{g}\right)$$

Water cycle

Emergy of water cycle

In this case, calculations are simplified in order to obtain an orientative figure of emergy in soil water storage. In methodology section is conclude that whole emergy of crop should be included as it creates especial conditions for water filtration and storage in soil and also represents an storage itself as water is the most common component in plant tissues. According to the formula raised before and the calculations made in this section, water cycle emergy is:

$$\text{Water cycle emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = 3.22\text{E}{+}15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) + 5.32\text{E}{+}14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right) = 3.75\text{E}{+}15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Soil water energy

The amount of water stored in soil ranges from 212 to 432 mm for salix and cereal cultivation respectively (John R. Porter, 2009) being for pastures an intermediate value. In our case given that all crops are being valued, an intermediate water storage quantity is used for transformity calculations (322 mm/ha).

$$\text{Transformity of soil water storage}\left(\frac{\text{seJ}}{\text{g}}\right) =$$

$$= \frac{3.75\text{E}+15\left(\dfrac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{322\left(\dfrac{\text{mm}}{\text{yr}}\right)\cdot 10{,}000\left(\dfrac{\text{m}^2}{\text{ha}}\right)\cdot 0{,}001\left(\dfrac{\text{m}}{\text{mm}}\right)\cdot 1\text{E}+06\left(\dfrac{\text{g}}{\text{m}^3}\right)} =$$

$$= 1.16\text{E}+06\left(\frac{\text{seJ}}{\text{g}}\right)$$

Carbon cycle

Carbon assimilated transformity

There are differences in literature about the total carbon absorbed by Salix species. It ranges from 2.96 Mg C/yr./ha (Zan et al., 2001) to 6 Mg of C/yr./ha (John R. Porter, 2009) including intermediate values such as 4.5 Mg of C/yr./ha (Lemus and Lal, 2002). According to the figure calculated by Lemus and Lal:

$$\text{Carbon assimilated transformity}\left(\frac{\text{seJ}}{\text{g of CO}_2}\right)=\left(\frac{3.22E+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{4.5E+06\left(\frac{\text{g of CO}_2}{\text{yr}\cdot\text{ha}}\right)}\right)=7.11E+08\left(\frac{\text{seJ}}{\text{g of CO}_2}\right)$$

Carbon sequestered emergy

However there are several losses that contribute to reduce the final amount of carbon located in agricultural soils as it is explained before. Soil organic carbon is reduced to 0.33 Mg C/yr./ha (West and Marland, 2002; Lemus and Lal, 2005; Post and Kwon, 2000) or 0.36 Mg C/yr/ha (average from Grogan and Matthews, 2002) depending on the source of information. The emergy then results from multiplying 3.3E+05 g C/yr./ha by carbon assimilated transformity:

$$\text{Carbon sequestered emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=$$

$$=3.3\text{E}+05\left(\frac{\text{g of C}}{\text{yr}\cdot\text{ha}}\right)\cdot 7.11\text{E}+08\left(\frac{\text{seJ}}{\text{g of C}}\right)=$$

$$=2.35\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Biodiversity

Biodiversity emergy

The emergy for maintaining the biodiversity of food chain depends on the energy absorbed by first “producers” from the environmental sources of energy(what here are called “Main agricultural resources of emergy”). Therefore, it is conclude that the emergy for biodiversity maintenance is the same that for biomass production,i.e. 3.22E+15 seJ/yr./ha.

Biodiversity complexity

No studies are founded about the number of species involved in agricultural environments and the predation relationships between them. In consequence, transformity is not calculated.

Aesthetic

Aesthetical emergy

At this point of the Appendix, main resources are already calculated. In aesthetic, the main sources are the geologic input and crop emergy, so:

$$\text{Aesthetic emergy}\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=5.32\text{E}+14\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)+3.22\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)=3.75\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)$$

Image energy

Image energy is given by the light reflected from agricultural surface (albedo light):

$$\text{Image energy}\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)=10{,}000\left(\frac{\text{m}^2}{\text{ha}}\right)\cdot 3.63\text{E}+09\left(\frac{\text{J}}{\text{m}^2\cdot\text{yr}}\right)\cdot(0.3)=1.09\text{E}+13\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)$$

$$\text{Aesthetical transformity}=\frac{3.75\text{E}+15\left(\frac{\text{seJ}}{\text{yr}\cdot\text{ha}}\right)}{1.09\text{E}+13\left(\frac{\text{J}}{\text{yr}\cdot\text{ha}}\right)}=3.44\text{E}+02\left(\frac{\text{seJ}}{\text{J}}\right)$$

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