Introducing Permaculture to Economic Ecosystems - the Integrative Analysis Method

Michael Schlauch*

Contents

1 Theory and methodology

Since the beginning of ecological economics as a scientific discipline, its most common and influential notion has been that the economy is embedded within its supporting ecosystems. This challenges the paradigm of unlimited growth and leads to the recognition that the economy cannot outgrow its material basis (cf. Meadows et al., 1972). Economists acknowledge that it rather has to evolve within the carrying capacity of its surrounding ecosystems (Costanza, 1989, p. 2). However, the starting point of this section is not to solve ecological problems caused by the economy, but rather to use ecological notions specifically for the examination of economic problems. Therefore, I proceed by specifying the necessary requisites of a suitable method and introduce transdisciplinary and systemic aspects of permaculture. Then I develop the concept of economic ecosystems and its characteristics as a general category to which any economic system can adhere. The aim is to translate practical guidelines from permaculture into the context of economics and assign a set of ten questions that enhances the inquiry of economic policies and models. Together with the modelling method of "energy diagrams" they are useful devices for grasping hidden dynamics and building new insights for better ecosystem oriented functioning. This way permaculture principles become resourceful tools for resolving economic problems during the integrative analysis.

1.1 Developing an integrative approach for complex ecology and economics

Having learned that the economy is embedded in the greater ecological system of the earth, we can characterise economies by processes that are in common with natural ecosystems. Energy flows and resource processing, selection due to competition and cooperation, self-regulation and adaptation are common foundations upon which ecological knowledge can build new insights. We may refer to economies that are viewed from that perspective as *economic ecosystems*. The literature about these kinds of economic ecosystems exhibits a great variety of conclusions and conflicting arguments when it begins to treat the details of how to resolve related economic problems. Whereas neoclassic exponents, defending the idea of the substitutability of ecosystem services, tend to portray the ecological debate as ideological and "very hard to argument with rationally" (Solow, 1997, p. 267), others question the scientific premises for motivating both economic and qualitative growth (Paech, 2009). Bioeconomicst Nicholas Georgescu-Roegen (1975, p. 367) discusses Hermann Daly's concept of the steady state economy with respect to its reliance on irreversible processes and physical laws, concluding that "a steady state may exist in fact only in an approximated manner and over a finite duration". As this was not enough divergence, even attempts to integrate energy-related concepts of biophysics into economics risk the fallacies of reductionist natural science. This is the case if they are used as means to "engineer society" in a technocratic manner as it was pointed out with respect to social considerations within Howard T. Odum's work on system ecology (Hammond, 1997, p. 200).

It seems that the fundamental problem at hand is the enormous complexity of social and ecological systems. Traditional approaches are accustomed to cope with closed systems that have defined boundaries, measurable performance indicators and actors with foreseeable rational behaviour. This is simply not possible with more complex social systems because these properties are either out of reach or vary depending on the observer's expectations, his world-view and the scale of the examined system. In order to obtain conclusions that are closer to reality, there is a need for an analysis method that takes into consideration different assumptions and perspectives on systemic, economic and ecological dynamics. We can refer to a similar analysis as an *integrative analysis* and additionally distinguish it from an integrated analysis that rather concentrates on the processing of a large amount of information and data from different origins under a single viewpoint.

The "Soft Systems Methodology" (SSM) put forth by Peter Checkland attempts to avoid reductionism of natural science and offers useful practical guidance to develop such a method (Checkland, 2000, p. 36). The purpose is to avoid the limitations that come from assuming systems as real and describing resulting models and modifications from one supposed external viewpoint. Instead, it concentrates on finding a "systemic process of inquiry" that helps to build conceptual models as "devices to stimulate, feed and structure" debate (Checkland, 2000, p. 26). The latter produces new insights to act upon. Systems are then referred to as "purposeful activity systems", i.e. systems that consist of human actors that take purposeful actions. These are not taken as real,

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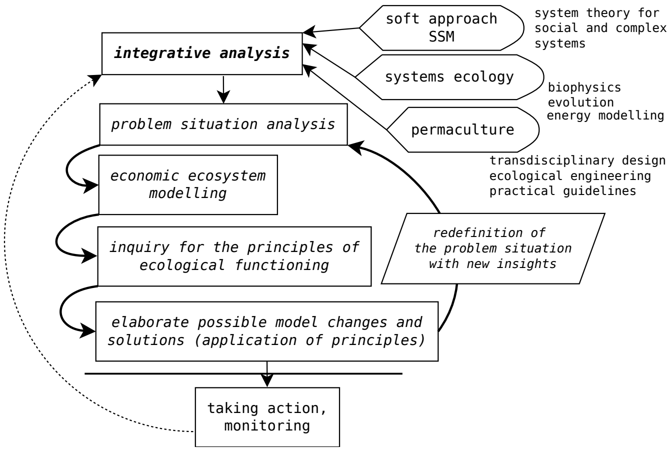

Figure 1: Overview of the integrative analysis - this graphic shows the strategy of the integrative analysis and its various steps that are analogue to the four-activities model of the SSM. Additionally, it displays the theoretical framework that has been adopted in order to make conceptual models of economic ecosystems. This way resulting proposals are inspired by the functioning of healthy and stable ecosystems.

but as continually changing perceptions from different points of view. Models are "working models" not claiming any "permanent ontological status" (Checkland, 2000, p. 20). Resulting solutions are valid for the observed situation and may not be purported as universal laws. In its recent form the SSM consists of 4 contemporary and iterative activities: a problem situation analysis, the drafting of relevant conceptual models, debate for changes and solutions as well as taking action (Checkland, 2000, p. 21). Hence, the constituting rules of a method that adopts the SSM are that it has to assume systems as mere "social constructions" instead of real entities, use "explicit intellectual devices to explore situations" and create holistic "purposeful activity models" based on declared world-views (Checkland, 2000, p. 38).

An integrative analysis of economic ecosystems would adopt the SSM in order to fulfil its goals adequately. But it has to be modified by supplying an additional framework through which economic ecosystems understood as merely perceived systems can be viewed macroscopically. This way an emphasis on underlying evolutionary and biophysical dynamics can be given.

1.2 Permaculture viewed as a systems science

Permaculture is important for our analysis as it is an ecosystem management methodology that shares many characteristics with the SSM. It copes with open systems that interact continuously with their surrounding environments and have no defined boundaries. It is often argued that permaculture offers no universal solutions. They rather depend on the individual evaluation of the local situation. The design process is characterised by an iterative circle of action and learning which conveys a large importance to the role of nature which continually adjusts itself (Holmgren, 2011, p. 16). The "birds-eye-view" often mentioned in permaculture textbooks summarises the concept of the interconnectivity and the functioning of ecosystems on a very large scale. That scale is not visible from a usual human viewpoint (Mollison, 1988, p.95). In ecology, a "macroscopic" view "rises above" and shifts from finding mechanistic explanations among parts of systems to grasping the big picture of systemic ecological dynamics (Odum, 2007, p. 2).

It should not be surprising that the shortcomings of a reductive scientific approach centred around the optimization of single performance indicators devised by humans became first evident within forestry and agriculture. These are the branches of production that are most exposed to ecological disturbances. In fact, the aim to preserve "permanent" characteristics and functioning of an ecosystem is not new. The idea of a "permanent forest" introduced by Alfred Möller (1922) challenges the forestry practice of that time. The latter was marked by vast woodland clearings succeeded by the growing of tree monocultures. Soon this idea was not only applied to wood production, but also considered as a new possibility to grow food with "permanent tree crops" in agriculture (cf. Smith, 1953). Inspired by other pioneers that have taken this path, among them Masanobu Fukuoka (1978), permaculture, a neologism composed of the words "permanent" and "agriculture", originated with the book "Permaculture One" by Bill Mollison and David Holmgren in 1978 and was developed into a holistic agricultural system with "Permaculture Two" by Mollison (1979). With the training of permaculture designers and its growing worldwide diffusion, permaculture became a community driven project of applied systems thinking that transcends the scientific boundaries of agriculture, leading eventually to a new understanding of the term permaculture as "permanent culture" (Scott, 2007, p. 2). This makes it a very important discipline for the sustainable design of society as a whole. In fact, the effects of ecological disturbances may increasingly go beyond the scope of agriculture and forestry. To a large extend, permaculture can be described as "ecological engineering" in the sense defined by Howard T. Odum (2007, p. 363): whereas environmental engineering "concerns primarily technology and processes before connecting with nature" in order to solve problems, ecological engineering "matches technology with the self-design of connecting ecosystems" with the intend to help them "self-organise a symbiotic interface" with human production systems. This is echoed by the dictum "work with nature, rather than against it" in permaculture (Mollison, 1988, p. 15). Anthropocentric human behaviour thus transforms into behaviour of "enlightened self-interest" which includes ethics of sustainable and sensible application of technology (Mollison, 1988, p. 3).

Although the permaculture movement has gained momentum recently, there is still much potential for its ideas to enter and enrich academic discourse as well as a need to verify its conclusions on the basis of empirical research (Morris, 2012). Until now its most criticised weak points have been lacking peer-reviewed scientific diffusion and missing empirical documentation (Scott, 2007, p. 12). Like any idea that originated from profound theories, popularity and diffusion comprises an increasing simplification which makes it easier to be adopted. But to many practitioners, the popular image of permaculture as a magic set of rules for "gardening plus ergonomics" displays a great amount of confusion and distortion that has come with it (cf. Harper, 2013).

For that reason, another intention of this thesis is to identify the underlying ecological foundations of permaculture as an "energy conscious" methodology (cf. Peeters, 2011, p. 425). I put it into the context of the scientific developments around energetic and evolutionary aspects of ecology during the past hundred years. As a matter of fact, initial permaculture ideas where motivated by the energetic analysis of Odum, connecting system energy flows with principles of good ecologies (Mollison, 1979, p. 3). The relevant theories of system ecology (Odum, 2007) and research about the linkages between the "bioeconomy" and thermodynamic laws (Georgescu-Roegen, 1986) are influenced by the work of Alfred Lotka who first integrated biology with physical laws, drafting the discipline of "biophysics". He thus laid the ground for an embedded economic theory in the beginning of the 20th century (Bobulescu, 2013, p. 3). Influential thoughts of physicist Schrödinger (1945) on life and the emergence of the Society for General Systems Research during the 1950s are additional inputs. The latter one has been of great importance for the development of the SSM (Checkland, 2000, p. 11).

In summary, it can be said that there are two main branches that we examine in order to develop new conceptual models for the inquiry of economic policies. One basis is permaculture, which, as an influential branch of ecological engineering practises a large set of ecological notions and complies in many ways to a "soft" systemic approach. The other one is the ecological analysis of economic ecosystems from a macroscopic viewpoint as formulated by Odum and other system theorists.

1.3 Elaborating the main characteristics of economic ecosystems

The scope of ecological inquiry is how living systems organise themselves and how they evolve during a longer time scale. Therefore, evolution plays an important role in the analysis of ecosystems. Next to evolution, another key concept in our analysis is energy. The following subsections introduce thermodynamic laws in living systems. After discussing useful qualitative aspects of the embodied energy analysis and the role of the entropy law in economic ecosystems, I analyse the principle of maximum empower as a reference for natural optimization. Later, this becomes the basis for modelling economic ecosystems and the recognition of organisational patterns within them.

Energy and thermodynamics in living systems

Obviously, natural selection has to conform with physical laws as many life supporting processes deal with the transformation of matter within energy constraints. Thermodynamics offers interesting insights when considering its implications not only to inorganic, but to living systems and their evolution (cf. Bobulescu, 2013, p. 6). The second law of thermodynamics explains the manifestation and dissipation of available energy (Odum, 2007, p. 33).

Definition 1. ***The second law of thermodynamics****: the entropy of a "closed system continuously (and irrevocably) increases toward a maximum", that means that the available energy is continuously transformed into unavailable energy until it disappears completely (Georgescu-Roegen, 1975, pp. 351-352). Or: heat flows by itself only from the hotter to the colder body, never in reverse.*

Definition 2. ***Entropy*** *is a measure of the amount of unavailable energy (unavailable energy divided by temperature). It has been defined by Clausius (1864, p. 35) as the transformation-content, i.e. dissipative energy use, of a thermodynamic system.*

All living organisms feed upon available energy to create structures and functional organization. Many energy-related, biophysical theories recognise the fact that every energy transformation requires some of the available potential energy to be dispersed. Therefore, also living beings need surplus thermal entropy, i.e. the emission of unusable heat, in order to continue life (Schrödinger,

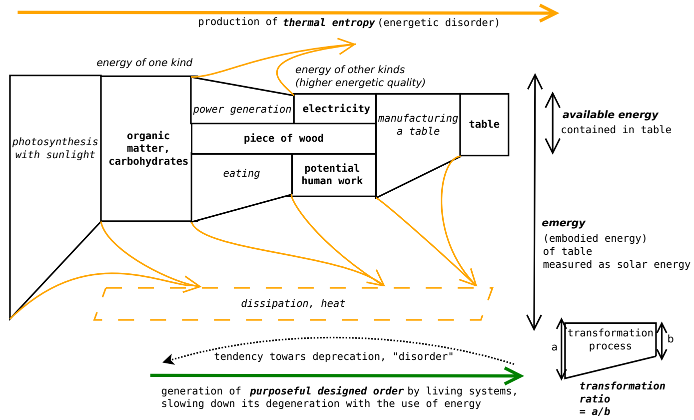

Figure 2: Energy transformations during the fabrication of a table - this graph shows, in a very simplified manner, the natural and artificial production of things from an energy-related perspective. Every transformation process requires a substantial part of the available energy to dissipate. This way thermal entropy increases unless energy constantly enters the system from an external source (sunlight). The available energy is used to create and maintain the order and structures that were purposefully designed by living organisms. The energetic "cost" (emergy) of such commodities can be expressed with the necessary amount of available energy that has entered the system in order to create them. Every energy form is characterised by its solar "transformity", that is the product of all transformation ratios during all processes beginning with sunlight. We can estimate the amount of emergy of a commodity by multiplying the remaining available energy with the solar transformity at a given time period (Odum, 2007, p. 73).

1945, note to chaper 6). Only few economists, such as Georgescu-Roegen (1975, p. 352), made efforts in researching how the entropy law applies to the human economic sphere as well. There has been a general lack of attention for the fundamental role of energy transformation in economics. In response, some scientists tried to assess energy with relation to dissipation as quantitative measuring unit with the concept of "embodied energy" (Costanza, 1980, p. 1224).

Definition 3. ***Embodied energy*** *is generally defined as the sum of all the energy required to produce any goods or services.*

Embodied energy represents not the energy physically stored in an object, but the overall energy that systems require to produce objects directly and indirectly. Different energy kinds have different quality levels depending on how much transformation processes and dissipation is needed to create them. The "embodied energy analysis" seeks to take account of that when evaluating the energetic "cost" for the supply of any good or service.

It has to be noted that calculations that implement different accounting methods can diverge extremely and partial analysis may create underestimated results. Odum and Barrett (2004, chapter 3) extensively analysed energetic processes along all organisms of the ecological pyramid. H. Odum et al. (1983) made an effort to incorporate even social structures, capital, technology, knowledge, human labour, information into embodied energy calculations. They try to avoid the conflation of different energy kinds often making embodied energy calculations underestimate the real energetic cost (cf. Odum, 2007, p. 68).

Emergy as a conceptual device for energy-related valuations

To distinguish Odum's approach, which has a more pronounced sensibility towards the differences in energy quality, ecologists coined the term *emergy*, the "energy memory" which "records the available energy previously used up, expressed in units of one kind", usually in units of embodied solar energy ("emjoules", "emcalories") (Odum, 2007, p. 100 note 2). The conventional embodied energy analysis often produces improper results by summing up the energy quantities of different energy kinds. Instead, the quantities first have to be converted to a common energy kind with the use of the respective transformation rations. Hence, in order to calculate the amount of emergy of one commodity as shown in figure 2, there is a need to know all transformation ratios (transformities) along the process chain.

Definition 4. ***The transformation ratio*** *is the quantity of available energy used up during a transformation process divided by the quantity of residual energy contained in the output.*

Definition 5. ***Emergy*** *records the available energy used up for the creation of any good or service, expressed in units of solar energy.*

Definition 6. ***Solar transformity****, often only referred to as (absolute) transformity of an energy kind, is a particular transformation ratio that stands for all solar emergy used up divided by the residual energy contained in the output (Odum, 2007, p. 73).*

Definition 7. ***Empower*** *describes the emergy consumed per time unit, analogue to power which refers to the usage of energy.*

It is almost impossible to measure transformities exactly. For example, it is difficult to assess how much sunlight the earth ecosystem needs to produce one calorie of coal. Hence, emergy values always involve a critical amount of uncertainty. Apart from that, there are two strictly theoretical argumentations against the use of an "energy currency" which stands for the usage of the emergy concept as a mere quantitative measure.

The first one is directed against the tendency to combine energy measures and monetary values in order to add deprecation and generation of "natural capital" into the gross domestic product (cf. Costanza et al., 1997). According to Odum, this results in "double counting" as it adds an additional quantity of "natural values" to the global buying power that has never been purchased by anyone. Instead, it has only been estimated by scientists (Odum, 2007, p. 280 note 3).

The second, more consequential line of argumentation questions the general applicability of emergy quantities as an objective value indicator. For example, Kenneth Boulding, an important exponent of the general systems theory, remarks in a critique of Odum's book "Energy Basis for Man and Nature" that all values eventually are human values created by human evaluations (Hammond, 1997, p. 202). Odum describes emergy of a product as memory of the available energy used up during its direct and indirect production. However, he doesn't explicitly declare how a mere consumption of a quantity of available energy theoretically suffices to postulate any value. In ecology, the distinction between waste and useful, i.e "high-emergy", commodities occurs from the observation of the life-supporting functions of balanced natural ecosystems ex post facto. Such observation can be, for instance, that heated sand would contain less emergy than fertile forest soil. Nonetheless, Odum misses out on providing the means to assess the energetic value of things when their purpose cannot be clearly deduced from natural functioning. This means, when nature can't define what is useful and what is waste. This happens every time there is a human decision to be made between either one desired and another undesired outcome that would both require the same natural emergy input, let's say for example between an artificial lake or a forest plantation in a future nature reserve on dismissed urban land. So in the end, we inadvertently enter the "soft" conceptual paradigm of SSM: emergy valuations are either influenced on the observer's judgements or depend on empirical observations given by the nature's past and present development. Taking these points into consideration, we can use emergy measures as hints for the further empirical exploration whether an ecological system fulfils its purpose (efficacy) and estimate its efficiency and its effectiveness. The modelling of the "3Es", efficacy, efficiency and effectiveness, belongs likewise to the soft modelling approach in SSM (Checkland, 2000, p. 30). In that sense, the embodied energy analysis is nothing else than a powerful inquiry device.

The important, qualitative aspect of the emergy analysis can be clarified for example by considering whether our current civilisation is possible without the input of fossil fuels. Nonetheless the sun energy that hits the earth is 4 orders of magnitude greater than our annual consumption (Smil, 2006, p. 23), according to Odum (2007, p. 370) photosynthetic production is only capable of sustaining 30% of society's current emergy demand.

Maximum empower within economic ecosystems

With respect to the integration of available energy as a quantitative physical principle of biological evolution, one influential discovery has been the hypothesis of the *maximum power principle* by Alfred Lotka (1922). It laid the foundations for the formulation of Georgescu-Roegen's bioeconomic theory (Bobulescu, 2013, p. 8) and was updated with scientific developments from ecology by Odum.

Definition 8. ***The principle for maximum power*** *states that, under the assumption of no input constraints, evolution advantages those life forms which manage to divert most available energy to the preservation of their species (Lotka, 1922, p. 147). When observing ecosystems with different energy scales that consist of organisms that make use of different energy kinds, the principle is more correctly stated by replacing energy with emergy, expressing a collective tendency towards* ***maximum empower****.*

On account of evolutionary processes take place on the group-scale, the principle asserts that those ecosystems prevail that process the available energy and resources in such way that achieves the highest possible throughput of emergy for life purposes (Odum, 2007, p. 37). The difference is the finding that nature equally acknowledges high level transformation processes, although these metabolise the same amount of emergy transforming much less absolute energy. Therefore, it is important to clarify Lotka's principle by stating it as the principle of "self organization for maximum empower" (emjoule per second), not just power (Jorgensen et al., 2004, p. 18).

All in all, natural selection tends to make emergy flux through a system a maximum under the assumption that there is an unused residual of available energy (Lotka, 1922, p. 148). Lotka (1922, p. 150) states also that this principle may be modified by other forces when a system encounters input constraints. In that case, the efficiency of energy transformation plays an increasingly important role. A demonstrative example of this phenomenon is given by the observation of ecological successions (Mollison, 1988, p. 64). Many layers of additional high level transformation processes are added by animals finding additional niches. This continues until the climax community is reached Where available energy is converted more efficiently into life-supporting functions (Odum, 2007, p. 150). Thus, the main characteristics of economic ecosystems can be described with thermodynamic laws, an approximate emergy analysis and evolutionary dynamics towards maximum empower.

1.4 Modelling the organization of ecosystems - the energy systems language

As Georgescu-Roegen (1975, p. 353) remarks, some organisms, like green plants which store part of the solar radiation, "slow down entropic degradation". It is of high interest how nature manages to maintain live while reducing energetic cost and thermal entropy production at the same time. Energetically important organisms like green plants are embedded within complex ecological networks and depend on the interaction with other consuming organisms. According to Odum (2007, p. 63), ecological principles govern a large portion of the transformations with different energetic quality. He states that spatial organization, the intensity of actions and signals, stored quantities and material concentrations derive from the energetic organization of organisms. Odum called this the "energy hierarchy" analogue to the concept of the "ecological pyramid", where some organisms at the top execute control over lower organisms and eat them. In order to avoid misleading "humanised" interpretations of natural ecosystems, we may alternatively refer to the "energy hierarchy" as *energy succession*. The energy succession would be a more flexible concept of a sequence of energy conversions and transactions between previous scales of organisms and consecutive scales. Latter organisms typically process a smaller quantity of one energy kind that however belongs to a higher quality level and has a greater solar transformity. We define different energy-related quality levels according to their emergy density. While the energy succession begins with high quantities of materials and high energy flows, consecutive scales transform less quantity of more elaborated material that has a greater emergy density (Tilley, 2004, p. 122).

Thus the emergy flux increases along the energy succession and organisms inhabit increasing areas that are their interaction and nourishment territories. E.g. humans subsist on very large areas which they manage in a unique manner using technology and tools which reside outside their bodies.

Definition 9. *The **energy succession** is a conceptual device to examine the organisation of living systems by attributing the quantity of emergy involved in processes. Patterns of self-regulation and interaction can be identified by following the various energy transformations from the origin of the necessary inputs to the final usage.*

Now we may view this concept by modelling the previously mentioned example of a green plant and its surrounding ecological network in a forest, displayed in figure 3. The figure also demonstrates the use of the "energy systems language" and its symbols as introduced by Odum (2007, p. 25 et seq.). The energy systems language is used to show main parts as well as existing pathways and relationships of systems in terms of energy, a measure "that is found in everything" (Odum, 2007, p. 25). As we turn further to the right of the energy diagram, energy quality increases. This visualization allows for a faster assessment of limiting factors, risks, additional unknown influences and the overall resilience of a system. Organisms are alimented by non-linear autocatalytic processes. Typically this means exponential, but not necessarily

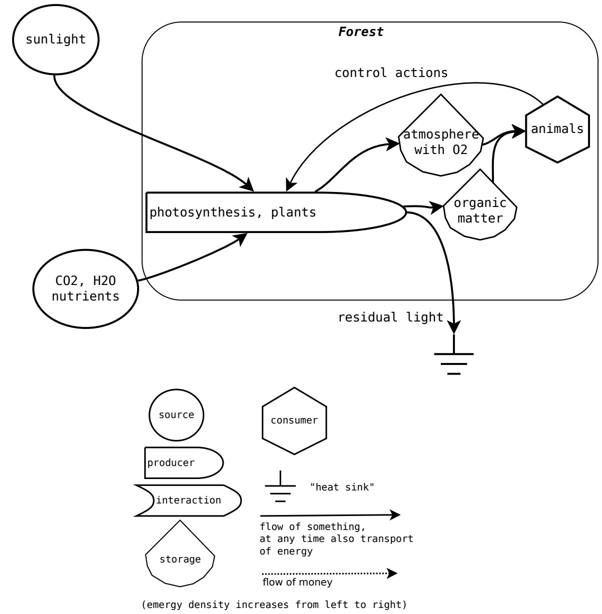

Figure 3: Energy diagram of a forest - an own representation of a forest using the energy systems language. Plants produce organic matter, bind sun energy and thereby slow down entropy production minimizing the dispersion through heat and reflection. Animals nourish themselves from photosynthetic production, i.e. residual processed material provided by plants. More valuable and energy-costly products reside further on the right side. Species transform their input into valuable coordination tasks during consumption. E.g. bees pollinate plants, herbivores feed back and distribute humus and seeds, others limit parasites. The energy diagrams in this paper are made with the software "Dia" and a custom shape set developed by the author. Below the diagram there is the disambiguation of the symbols of the energy systems language as utilised by system ecologists.

fast, reproduction of species within their environmental constrains (Odum, 2007, p. 46) .

Definition 10. *In ecology, **autocatalytic** processes take place when the creation of something is amplified by its output. For example, a population with a high rate of reproduction encounters exponential growth until other necessary resources become limiting factors.*

In our example, the trees of a forest expand their leaf coverage and increase photosynthetic production until all the area is covered. This process is accompanied by a minimum of necessary energy dispersal, i.e. the production of entropy, displayed by an outgoing flow towards the heat sink (three horizontal lines). Leafs are not able to capture all the energy present in sunlight as some of it gets passed or reflected. In line with this, as muscles use up organic energy for movement they must expel heat as well. As shown in the diagram, producers like these are depicted with the production symbol (rectangular form with one rounded side). The thickness of ingoing and outgoing flow arrows is based on the energy quantity transferred. Resource and energy supplies often fluctuate due to natural events, such as changing climatic conditions during seasons, and also because of corresponding pulses in production among species, such as deciduous leafs of trees in winter. In order to even out the supply of nutrition and to be able to release work afterwards, organisms build up storages which we discussed earlier as means to reduce entropy production (Odum, 2007, p. 79). For instance, wood cells store reserves in the tree trunk. The organic matter and atmospheric oxygen stored in this way are represented by the storage tank symbol (triangle with the lower side curved).

Producers leave some of their output unused. Initially this would be wasted along with residual energy. But in line with the *maximum empower principle*, consecutive species in the energy succession find a way to process and value materials that have a higher energy quality (Odum, 2007, q. 163). In a forest, these are wildlife species, like bees that eat nectar or animals that eat fruits and herbs, as depicted in fig. 3. These are displayed as consumers (hexagon). They also execute important feedback pulses and control actions, e.g. pollination done by bees. Hence in the diagram, animals like bees reside on the right side of plants and determine a greater emergy flux. If we split up the diagram and zoomed in to view more details, we could see how such relations take place also between different animal species and subsystems. The famous predator-prey relationship describes how interdependence and regulation through two pulses, the reproduction of the prey and the predator which hunts, keeps the system stabilised and inside its external resource limits (Odum, 2007, p. 156). In permaculture, there is an enormous emphasis on maintaining and establishing this kind of self-stabilizing mechanisms which are composed of positive nurturing feedbacks, negative feedbacks that "constrain or control" the parts of a system (Holmgren, 2011, p. 72). The capacity of autoregulation is often missing in artificial monocultural environments which is why they depend heavily on human intervention.

Definition 11. *We can circumscribe* ***autoregulation*** *as a composition of feedback loops that, in their simplest form, provide either positive feedbacks that amplify the original action, or negative feedback that constrains the original action while reacting to external conditions.*

In like manner we can zoom out and view the ecosystem "forest", depicted with a curved frame in fig. 3, as a subsystem in relation to other units. Then we obtain a clear view on what has been described earlier as "economic ecosystem". Humans depend on wildlife and organic production in many ways. In the forest example, the most obvious are food and wood. Different emergy levels exist within human organisation as well. We may asses them depending on the necessary input of capital, time and natural resources. As with units of an ecosystem, we can position artefacts such as buildings, machines and institutions as well as intellectual constructs like knowledge, technology and networks of social relations along the energy succession (Odum, 2007, figure 9.7). Accordingly, we connect units with energy carrying flows of matter as well as with flows of information and social interaction which are equally characterisable with the emergy they use up. One exception is money as a unique social commodity especially designed for the exchange and coordination of flows which is depicted with dashed lines (Odum, 2007, pp. 252-253).

Now, that we are able to model society as an ecosystem, the striking question of the integrative analysis becomes whether an economy can also adopt nature's beauty and elegance in self-organization. With respect to this method, there is an important additional aspect that distinguishes the "soft" integrative approach presented in this thesis from other applications of the energy systems language. As pointed out earlier, emergy values are not universally valid. Likewise, the positioning in the energy diagram has to be seen as a result from the creator's conceptual model. In conclusion, we note that various models are possible based on different interpretations of the functioning of the observed reality. The "energy systems language" can display these conceptual models of economic ecosystems based on the flows, storages, producers, consumers and interactions along the energy succession either from distance or more in detail. After the problem analysis and the energy-conscious modelling of the economic ecosystem, the subsequent inquiry focusses on distinguishing and selecting desirable outcomes and model changes with the help of ecological principles.

1.5 The inquiry principles for ecological optimization

Beginning with the early, more practical "Mollisonian Permaculture Principles" described by Mollison (1988, p. 35) we now have 12 more generic permaculture principles that were devised by Holmgren (2011). They give an overview of the most important strategies nature applies in order to be more energy efficient and to balance its functioning. Our purpose now is to find criteria for the evaluation of economic ecosystems that incorporate the underlying knowledge that comes from those principles. Now, Holmgren's 12 permaculture principles are adapted for economic ecosystems. The result is the following sequence of questions and evaluation criteria:

1. **Are there excessive supplies that produce waste and reduce efficiency?** In nature, organisms often encounter the phenomenon of saturation when the supply of particular resources is excessive. This means that much energy is wasted or could have been used otherwise if the system was more stable and balanced. As I pointed out above, in the long run natural ecosystems tend to reduce excess as new species find niches and adapt by utilizing superfluous resources (Odum, 2007, p. 57). Excess can be a sign that this process is hindered by something. Permaculture responds to that fact by wanting to eliminate any form of waste (Holmgren, 2011, p. 111).

2. **Do interventions manipulate transformation processes near to the origin of problems?** In permaculture, many interventions concentrate on "catching and storing energy" right before it degrades (Holmgren, 2011, p. 27). Detecting the dissipation of resources and energy provides new possibilities for sourcing energy. For example, storing run-off water for irrigation on the rooftop or mountain rather than on the bottom avoids unnecessary pumping afterwards (cf. Holmgren, 2011, p. 30). Although society is far more complex, problem sources without a defined location can also be interpreted as places where dissipation is happening. For the cost efficient resolution of problems it is crucial that interventions concentrate on these sources instead of coping with a number of downstream consequences. Problems are not the only hints for possible "storages", i.e. the possibilities of obtaining currently dissipated resources. Near and careful observation may discover remaining potentials to produce a qualitatively more valuable commodity out of the same inputs.

3. **Does the system neglect yields or losses that are recognisable from additional perspectives?** The principle "provide a yield" reminds constantly of the fact that every effort emitted by an actor requires a benefit in order to be sustainable on the long run (cf. Holmgren, 2011, p. 55). The maximum power principle states that ecosystems essentially maximise their useful output by absorbing and transforming as much energy as possible. Whereas in ecology utility can easily

be translated as the capacity to support life functions, this doesn't suffice to define usefulness within complex multilevel systems. In the end, new types and collective expressions of life can be found on the scale of croups, communities, institutions and organisations and their pursued objectives. Utility is perceived differently from various viewpoints and conditioned by the social characteristics of human behaviour. Thus, to optimise a system for a chosen indicator implies always a trade-off that neglects other perspectives. Any attempt to quantify the general "yield" of a system, therefore, cannot be limited to one single measure.

4. **What are the most lasting developments and what would be the long-term outcome?** In order to obtain processes that are less wasteful, more effective and stable, it is beneficial to consider larger time-scales. Within complex systems it becomes increasingly difficult to distinguish between impulsive changes and more durable effects. A short-term focus easily hides slow processes that have greater consequences within a longer time scale. The permaculture principle "use small and slow solutions" acknowledges the fact that it needs small, widely ingrained and incremental alterations to improve a system as a whole (Holmgren, 2011, p. 181). Small changes are also more resistant against brief and sharp disturbances. Usually, but not exclusively, small and slow solutions take effect in a more decentralised manner and depend less on external enticements.

5. **Are actions intrinsically motivated and do they respond to feedback signals?** We already emphasised the role of autoregulation within complex social systems that function on different scales. Permaculture practitioners endow the principles of self-regulation by "applying self regulation and accepting feedback" (Holmgren, 2011, p. 71).

   In psychology, there has been the distinction between those actions that are performed because of external motives and actions performed because of intrinsic motivation. In economics however, this concept is quite novel (cf. Frey and Jegen, 2001, p. 4). According to Deci (1971, p. 105) , "one is said to be intrinsically motivated to perform an activity when one receives no apparent reward except the activity itself".

   Definition 12. ***Intrinsic motivation*** *comes from within the person. Intrinsically motivated behaviour does not require rewards apart from those that emerge from the activity itself.*

   Intrinsic motivation results in a more effective behaviour as it has a competitive advantage over external incentives. Ecosystems consist of interdependent organisms that organise themselves through reinforcing feedback loops. Individual organisms may perceive such dynamics as intrinsic as long as they benefit from them. This way they do not need additional rewards coming from outside the system. Reconsidering the forest example of figure 3, animals may eat parasites without the need of benefiting plants to "pay" a reward. Equally, the action of collecting nectar is intrinsically connected to pollination, without the plant having to "negotiate" with the bee.

   The existence of intrinsically motivated behaviour makes it possible for a policy maker to value both autonomous regulation processes and already achieved synergies by identifying and acknowledging intrinsic motivation. This is also of great importance when economic policies are introduced to encourage a certain behaviour. Often those regulations don't achieve the desired outcome because they are based on an economic theory that undervalues intrinsic motivation and rationalises human behaviour. This leads to the anomaly of "monetary incentives crowding out the motivation to undertake an activity" (Frey and Jegen, 2001, p. 4).

   This is especially the case with respect to the "informal" economic sphere. According to Guha-Khasnobis et al. (2014, p. 6) the notion of informal can be summarised as being outside the reach of different levels and mechanisms of official governance. However, there is various evidence for the unsound usage of the informality concept in the policy discourse. Specifically, the incorrect association of the informal with unstructured has been a "powerful impetus for interventions that have often led to disaster" in various occasions (Guha-Khasnobis et al., 2014, p. 7). The idea is that the informal sector may already have structures in place that are potentially governed by autoregulation and intrinsic motivation.

   Definition 13. *The* ***informal economy*** *can be described as the total economic activity that is outside the reach of different levels and mechanisms of official governance. Following this definition, the attribution of being informal depends on the kind of governance. This way there is no clear split between formal and informal; rather, there is a continuum (Guha-Khasnobis et al., 2014, p. 5).*

6. **What are the scarcest inputs and are they potentially renewable?** With respect to Odum we have found that along the energy succession there is a corresponding distribution and concentration of material. Scarce and limiting resources have negative effects on all scales. In a society information, knowledge and relations can also become limiting inputs. Ecosystems cope with limiting inputs by providing a metabolism that produces renewable resources and services. That is why the effort to "use and value renewable resources and services" is an important permaculture principle (Holmgren, 2011, p. 93). Moreover, it has been noted that there is no free recycling and that "available matter" degrades "into unavailable states" just like available energy (Georgescu-Roegen, 1986, p. 7). Hence it becomes increasingly important how and under what expense of time and energy recycling occurs.

7. **How much is the cost of interaction and sharing?** Collaboration between organisms evolves if there are less obstacles and reduced efforts of adaptation (Odum, 2007, p. 150). Permaculture pursues this with the aim to "integrate rather than segregate" (Holmgren, 2011, p. 155). The right positioning of units accounts for an easier development of stable relationships. Whenever there is a potential for collaboration between two organisms, the cost of interaction and sharing resources has to be reduced by bringing them closer to each other. With respect to economic ecosystems there are many additional possibilities to reduce interaction costs. These include removing obstacles, reducing communication barriers and providing for regular and stable occasions of interaction and learning. With these measures one can manage to "use

and value diversity" which is another permaculture principle (Holmgren, 2011, p. 203).

8. **What unavailable or speculative information does exist?** As an ancient Socratic teaching tells us, one person difficultly knows what one doesn't know about. This stands figuratively for the huge undetected sphere of uncertainty compared with collected or uncollected available information. The permaculture principle "observe and interact" puts an emphasis on monitoring without prejudices and reflection prior to taking action (Holmgren, 2011, p. 13). A "soft" approach to the manipulation of systems has to be conscious about its own limitations, unavailable information and assumptions that are taken based on speculation. Otherwise interventions and actions can have consequences that are contrary to their presumed outcome. Moreover, what is even more disastrous, their negative effects may not be detected as such. A strategy of "design from patterns to detail" (Holmgren, 2011, p. 127) concentrates on the observation of the system as a whole and entails macroscopic research with less reductionist tendencies.

9. **What margins or centres are significantly dynamic?** If we wanted to search for the places with the highest emergy flux, we would have to look at the spatial organisation of economic ecosystems. In natural ecosystems, boundaries between differently structured zones or events may offer opportunities "for creating spatial and temporal niches" and higher biodiversity (Mollison, 1988, p. 76). Margins are enriched by inputs that originate from the different adjoining zones, e.g a forest and a lake. This causes permaculture to "use edges and value the marginal" as another main principle (Holmgren, 2011, p. 223). In society margins exist not only between spatial zones, but also between particular time segments, within groups, disciples and cultures. In some cases centres also offer these kinds of interfaces and, therefore, attract high emergy inputs, e.g. the centre of a city (cf. Odum, 2007, p. 203).

10. **Are proposals continuously adapted to changing conditions?** It is almost impossible to control complex systems completely as they evolve. The envisaged integrative approach takes account of that and concentrates on interventions to be beneficial and balanced. Because those manipulate the reality from which our conceptual system models are deduced, they have to be updated constantly. The resolution of problems within living systems is never finished entirely. Economic problem solving may only alter system conditions and the behaviour of the different actors. In order to achieve stable results, it is necessary to "creatively use and respond to change" (Holmgren, 2011, p. 239). In other words, designers or policy makers should not forget to insert themselves in the systems they conceptualise and close the feedback loop between themselves and the rest by continuously adapting proposals to reality.

2 Outlining the integrative analysis method

Recalling fig. 1, we introduced the integrative analysis method as an iterative procedure of different steps. These steps are the problem situation analysis, economic ecosystem modelling, the inquiry for the principles of ecological functioning and the recapitulation of action proposals and open questions that emerged during the inquiry. In consideration of the last step this sequence can then be repeated by redefining the problem situation and viewing it in relation to a widened context of additional actors and relations. An exemplary analysis was done starting with considerations of the European Commission (2010) on current labour market challenges. As the full analysis would exceed the scope of this paper, I'll just outline the general procedure and refer the reader to the long version of this paper for in depth analysis.

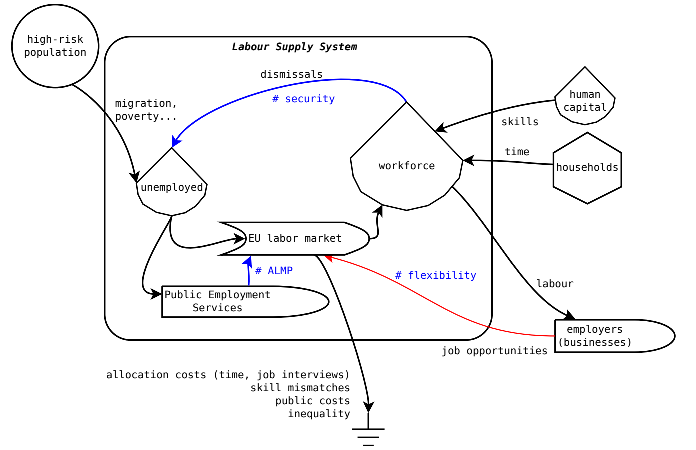

Figure 4: The system of labour supply - the supply of labour viewed as an energy diagram. It shows actors and flows that directly condition the labour market. Inefficiencies and waste flows end in the lower heat sink. Flows coloured in red are limiting factors. Furthermore, some key proposals of the EU Commission are positioned in the diagram (blue).

2.1 Iteration 1 - a systemic view on labour supply

As pointed out in the first section, the integrative analysis is an iterative sequence of modelling and inquiry inspired by the four activities model of the SSM. After assessing the main statements given in the communication of the European Commission (2010), an initial labour market system was modelled in order to discuss main policy proposals regarding unemployment. The set of ten questions given in 2.5. as a key element of the integrative analysis helped in amplifying the inquiry and raising important questions for the deeper understanding of labour market challenges.

The first conclusion of the first iteration model in figure 4 is that it delivers limited results to consider unemployment as a phenomenon that depends on the mere interplay between unemployed, employed and employers on the labour market. A clearer view on labour has to be aware of the origin of skills, of the conditions for the creation of job opportunities and of possibilities to reduce the negative side effects and the social costs of the labour market.

2.2 Iteration 2 - the role of labour in the economy

Thus, the subsequent iterative step concentrates on the connections between labour supply and the overall economy understood as production system. The model in figure 5 is still deduced from conventional viewpoints and from proposals of the European Commission, but this time with respect to the overall economy.

The inquiry of the second extended system model has shown that many EU proposals can be enhanced with the reduction of inefficiencies that cause flows to the "heat sink". New problem fields have emerged that require a deeper understanding about the

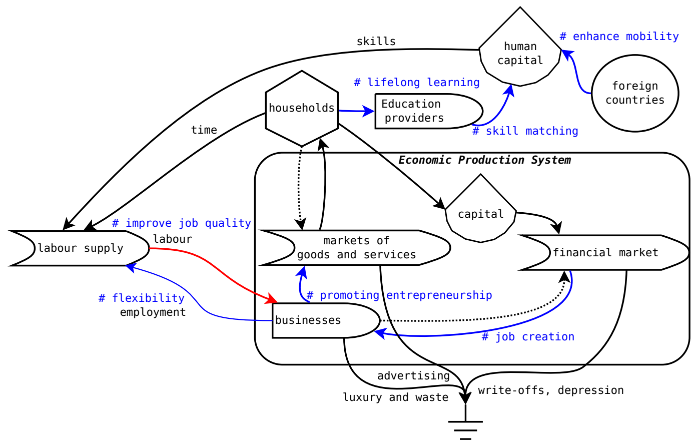

Figure 5: The system of economic production - the classic economic production process that includes capital, labour, households and businesses as represented by conventional economic understanding. It shows indirect connections to the labour market that are worth analysing.

social and informal aspects of the economy and the role of the environment. One conclusion is that unemployment is not a solitary problem. It is connected to social and ecological boundaries of a growing economy, beginning with the fact that available time dedicated to consumption is limited so that satisfying consumption itself, and thereby demand, reaches a maximum.

2.3 Iteration 3 - introducing ecological principles on the macroscopic scale

The third iteration aims for new practical solutions to the extended problem field that has been elaborated in the previous iterations. Fig. 6 shows both the labour supply system and the production system of the previous iterations as bundled units in relation to *natural production*, the *informal economy*, *social capital* and *cultural life*. Natural production and ecosystem services provide essential inputs for the human society. The inquiry of such an extended model is able to give insight to many dynamics that were hidden previously.

Despite its simplicity, it already provides many clues either on how to soften the negative effects of unemployment or to create

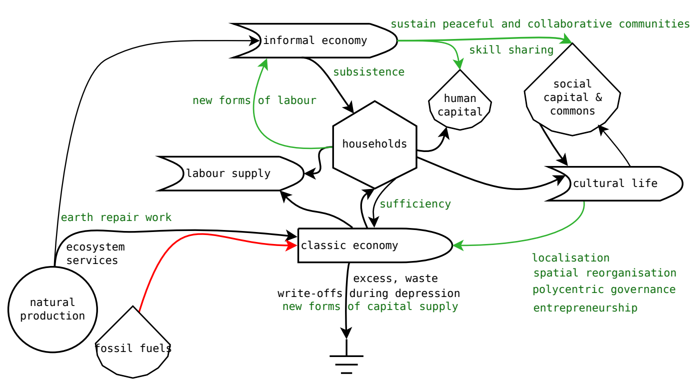

Figure 6: A macroscopic view on an "economic ecosystem" - the previous displayed systems viewed within their larger context. The graphic puts the economy in relation to its environmental and social interconnections. This time, the diagram also contains additional action proposals deriving from the integrative analysis.

new occasions of employment that are beneficial in new ways. Among the former possibilities are schemes of subsistence and sufficiency as well as new forms of labour that are less intensive and more suitable for the diverse needs of persons. With regard to the latter kind of measures there is an increasing need for "earth repair", the maintenance of ecosystem health, and community development in order to promote peaceful and collaborative communities where people, among many other things, share their skills with each other. Other proposals that enhance the efficiency of markets, especially with regard to unwanted external effects (environmental and social costs), are related to localisation, small-scale governance as well as the holistic planning of cities and buildings.

3 Conclusions

In closing, one can suppose how an integrative analysis can be used to analyse a problem in consideration of many different scales, layers and aspects and evaluate various policy proposals. The integrative analysis method integrates four main considerations about ecological organisation.

First, human civilisation is a subset of the earth ecosystem. The general characteristics of ecosystems apply also for economies as they can both be described in terms of energy, transformations and interactions. This leads to the concept of economic ecosystems.

Second, different energy forms have different energetic qualities depending on the amount of energy expended in the process of their creation (emergy). This means also that resources and organisms with a high emergy concentration contribute differently to the functioning of ecosystems.

Third, living systems follow patterns that we can perceive while tracing their organisation along the "energy succession". These patterns relate to the interplay between producing units, units that control high emergy resources and the resulting capacity of autoregulation. A useful visualisation tool is the energy diagram which uses the "energy systems language".

Fourth, evolution appears to have a propensity towards "maximum empower", that is the greatest possible absorption of available energy in order to sustain as much life as possible. As done in permaculture, sustainable ecosystems can be used as an inspiration in order to deduce design principles that help all actors achieve the best use of resources and energy. The integrative analysis adopts those principles as criteria for the inquiry of conceptual models of economic ecosystems.

Moreover, economists may have difficulties to resist the temptations of treating emergy evaluations as economic values or avoid claiming to make objective judgements while not undertaking further research. Thus, in order to anticipate the flaws of reductionism, the integrative analysis adopts the methodical sequence of the SSM. The latter is especially fitted for the evaluation of complex perceptions of systems by different actors and viewpoints.

In this paper I briefly outlined the sequence of the integrative analysis to the problem of unemployment and corresponding labour market challenges in three iterations. During the analysis, the scope of the problem broadened. New questions about the EU Commission's strategy to deal with the upcoming challenges for the labour market have been raised. The given modelling method has been particularly able to view the EU strategies for innovation and job creation, labour market flexibility and security, mobility and education from different perspectives. The integrative analysis has provided a way to establish interconnections and compatibilities between proposals that are based on a more conventional economical approach on the one side and alternative suggestions on the other side. This makes it possible to combine many separate economical ideas to form a coherent whole. Such a synthesis may give important insights not only to face the challenges of the labour market or any other economic problem. It enables us to choose policies and actions that are consistent with diminishing energy supply as well as social and ecological disturbances. This way policy proposals address also the global challenges that our society is beginning to face during an era of post-growth and energy decline.

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