Emergy and environmental policy making: H.T. Odum´s legacy for planetary survival

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ABSTRACT

Economies still rely on a "user value" concept, i.e. a resource or a good is valuable if the market competition assigns to them a huge monetary value based on demand or if their work potential (exergy) is higher and therefore makes them more "useful" within technological and economic processes, no matter how much work was invested by biosphere to generate them. The innovative Odum´s emergy concept (Odum, 1996) reverses the assessment, by making value to rely on the biosphere work to generate and make available ("donor value") resources and services used within our economies. Such assessment is performed by converting all driving flows of available energy (exergy) into flows of solar equivalent energy (emergy), that becomes the new value assessment currency, depending on nature, not on market.

An appropriate evaluation should take into consideration the present and future availability of resources, their renewability and therefore the sustainability of a society relying on them. Odum´s "donor-side" approach is a real innovation in policy-making, in that it includes space and time scales assessments for the evaluation of the value of a resource. Market (monetary) evaluations depend on demand (user-side) and demand (and currency) is different in each country and among countries; instead, the evaluation of space and time scales as well as the available energy driving resource generation do not depend on demand nor countries and allow resources to be assessed by means of the same unit, sej (solar emjoule) and may give rise to a set of value and performance indicators based on one unique currency.

Developing and comparing emergy-based economic, environmental and social evaluations of human-dominated and natural processes allows a comprehensive evaluation of costs, performance, resilience and sustainability of individual activities, technologies, regulatory decisions, investments, trade, by means of a unique and comparable currency. Therefore, it makes it possible to generate a clear and informed discussion among stakeholders, businesses, policy-makers about the needed transition from a market-based to a nature-based economy. In short, Odum´s emergy approach might be and could be the tool for policy makers and stakeholders to realize that a new science-based and nature-based pattern is possible and to figure out how this pattern could be.

Keywords: Emergy, Policy-Making, Odum´s Legacy, Planetary Survival, Prosperous Way Down

1. Introduction: Emergy and policy-making worldwide

As the global ecological and environmental problems continue to intensify, an increasing number of people have realized the importance of promoting global ecological protection, sustainable development and environmental governance. International agreements and programs such as the Paris Agreement (Owolabi et al., 2024), the European Climate-Energy Inclusive Agenda (European Environment Agency, 2013), and the "two-carbon" target (China Daily, 2022) have been signed and tentatively implemented in recent years. However, most of the world's resources are still being used in unsustainable and unscientific ways. Most people and policy-makers pay more attention to market value than to resource quality and resource use efficiency. While gaining more economic benefits, the environmental sustainability is being disregarded. Therefore, it is necessary to integrate resource use, production activities, economic benefits and environmental impacts to form an innovative, comprehensive and sustainable policy making framework.

Ecologist H.T. Odum deeply understood such a broader and deeper accounting necessity in the 1970s and came up with the Emergy concept and approach, as the basis of very innovative research and policy strategies for the next generations of scholars and policy-makers. Its Emergy theory emphasizes that the biosphere work is the basis for the generation of energy and material resources and any further production of goods or services. The total biosphere support to a process determines the emergy value of a product as an important measure of the productivity and sustainability of a system (Odum, 1996). Unlike traditional economic evaluation methods, such as GDP and cost-benefits analysis, the emergy approach links the value of resources and services to the evolution and dynamics of systems and species on Earth, of course including human societies and their economic system. Therefore, focusing on human societies, the emergy approach considers not only the direct use of resources, but also all indirect uses of energy and materials by biosphere and humans (such as resource generation and further consumption for resource extraction, production, transportation, and waste disposal). This broad life-cycle perspective enables emergy valuations to deeper reflect the relation of economic activities with the surrounding environment. Odum pointed out in his research that the emergy method can help policy-makers to identify energy bottlenecks and potential sustainability risks in any system, thus providing a scientific basis for policy adjustment (Odum H.T. & Odum E.P., 2000; Odum H.T. & Odum E.C., 2001, 2006).

In recent years, significant progress has been made in the application of emergy methods to sustainable assessment and policy development. In the evaluation of economic policy, Brown and Ulgiati (2001) applied the emergy method to a tourism case study, in order to develop a carrying capacity approach to business policies, based on resource consumption and land use, thus providing a scientific basis for policy-makers (Brown & Ulgiati, 2001). They also explored how the theoretical framework of the emergy method evolved over time within Odum´s research (Brown & Ulgiati, 2004), from ecosystems to larger scale systems including the economies of humans, from energy quality assessment to a rigorous definition of the emergy approach as a "donor-based" evaluation technique, towards a method to evaluate the different energy and resource use and their pulsing evolution patterns in different countries (Odum, H.T. & Odum, E.C., 2006). The emergy concept and approach was quickly accepted and applied by worldwide researchers in a large number of sectors, in so demonstrating its suitability for systems understanding and appropriate policy-making. It is very important to underline that the emergy approach uses performance and environmental indicators that can be always compared, within sectors and among sectors, being expressed or calculated by means of the same conceptual pattern and unit, taking into account not only the direct costs of resources, but also the value of ecosystem services and natural capital, as well as the space, time and natural activities required for resource production. The comprehensiveness of emergy indicators makes their use easier and clearer to policy-makers and stakeholders.

Brown and Vivas (2005) have developed an emergy based Landscape Development Intensity Index and applied it to compare natural systems, forests, pastures, agricultural areas, housing, industrial and urban areas, in so designing a hierarchy of the intensity of human use of landscapes, useful to measure the disturbance gradient generated by human activities. The LDI was then applied to the investigation of wetland mitigation and restoration banks (Reiss et al., 2014). The Authors assessed the ecological conditions of wetland restoration banks by calculating the LDI at different scales (wetland assessment area and bank scale). The study showed that the average LDI index of the investigated wetland area was 3.2, and the average LDI index of bank scale was 7.8, indicating the sensitivity of different scales to human disturbance. In addition, they proposed to use the LDI index to optimize the credit rating of wetland mitigation banks, highlighting the important impact of landscape scale on ecological function.

In urban governance, the emergy method is widely used for urban health assessment and resource management. For example, Liu et al. (2009) evaluated the health status of 31 provincial capitals in China by means of the emergy method, and found that the distribution of urban health level first increased and then decreased from coastal to inland. They also found a negative correlation among indicators of urban health level and economic development level in China and suggested policies for urban planning optimization. In a like manner, Santagata et al. (2020) applied the emergy approach to highlight the positive urban development within a circular economy framework.

In terms of energy systems, Brown et al. (2012) discussed the application of Emergy in evaluating energy system efficiency and environmental performance, by comparing thermal (oil driven) and photovoltaic power production. Their study shows that the emergy value per unit of electricity (UEV) generated by thermal power production (5.69E+05 sej/J) is significantly higher than that from photovoltaic power production (1.45E+05 sej/J), with Emergy Yield Ratios (performance indicator) of 6.8 and 2.2, respectively. Not only the UEV of photovoltaic power production is lower, but it relies on renewable energy resources and is therefore more sustainable. The study sheds light on the tradeoffs between efficiency and environmental performance of different energy technologies.

The development of circular economy provided a new research direction to combine the emergy method with options for economic improvement. Geng et al. (2013) proposed the evaluation of circular economy performance and effectiveness by means of the emergy indicators system, in so proposing a scientific, emergy-consistent circular economy strategy for China.

Rotolo et al. (2014, 2018) applied the emergy analysis method to the agricultural sector (production of soybeans, corn, wheat and other crops in Argentina), with special focus on water and energy demand, global production sustainability and trade abroad. They found that although the crop output continued to increase, the environmental performance indicators (e.g. EYR, ELR, ESI, %REN) showed a declining trend over time, indicating production systems to be more dependent on external and nonrenewable resources. In particular, the Authors focused on corn trade with importing countries, pointing out that both Argentina farmers and importing countries received a smaller percentage of the total emergy traded in the form of raw corn (respectively, 73% and 76%,), while a non-negligible fraction of emergy was diverted (emergy embodied respectively in the form of less or more money paid) to national and international trading companies.

In the context of the Chinese Belt and Road Initiative, the Emergy method has been instrumental in evaluating the environmental and resource implications of trade relations between China and ASEAN (Association of South-East Asian Nations) countries, as a trade case study. Tian et al. (2024) conducted an extensive study using emergy accounting to assess the sustainability of China´s provincial economic systems and their trade dynamics. Their findings revealed that the sustainability of sample provinces decreased over time, with ASEAN countries such as Indonesia, Malaysia, Singapore, Thailand, and Vietnam playing significant roles as resource suppliers. The study also highlighted trade and environmental resource exchange imbalances between China´s pivotal provinces and ASEAN countries, emphasizing the need for more sustainable and equitable trade policies.

In the field of mobility, Huang et al. (2018) performed an emergy analysis of nine land transportation modes in China, including private cars, taxis, city buses, long-distance buses, subways, ordinary trains and high-speed trains (passenger transport), to evaluate the energy and emergy costs and environmental impacts of different transportation modalities in China. Results indicated that well designed urban public transportation and ordinary passenger and commodity trains can improve the environmental efficiency of the mobility system, compared to private cars, highway truck transport and high-speed trains, which show instead a larger demand on resources.

The integration of Life Cycle Assessment (LCA) with Emergy Accounting (EmA) significantly enhances the capacity to evaluate environmental impacts and resource efficiency. Santagata et al. (2020) developed a LEAF (**L**CA & **E**mA **A**pplication **F**ramework) protocol that systematically implements these methodologies to assess the environmental performance of complex systems. Applying this framework to the traditional, high quality Amalfi paper production system, their work demonstrated the effectiveness of utilizing renewable and local energy and material resources in mitigating environmental burdens. The research underscored the synergistic value of combining LCA's consumer-oriented perspective with EmA's biosphere-centric viewpoint, thereby generating a holistic perspective on system performance.

Other emergy scholars extended the EmA application to the perspective of sustainable supply chain management, in order to show that the emergy method could effectively evaluate the energy and resource use efficiency in production processes and therefore drive policy-making alternatives (Alkhuzaim et al., 2021). In such an industry field, Liu et al. (2021) conducted emergy analyses of key sectors of the steel industry, evaluating and comparing the environmental and economic sustainability of different outputs over the step-by-step production process, quantifying the emergy demand and the environmental impact of each intermediate product. Results allowed policy suggestions for the environmental sustainability of the steel industry.

The use of the emergy approach in a variety of economic, societal and cultural fields is assessed in this paper, with the aim to discuss its applicability to different sectors and processes and, even more important, its suitability to be the basis for a comprehensive policy making, capable to complement and integrate conventional evaluation and operative tools generally used in economic and social strategies. The present Section 1 - Introduction aims at showing how emergy was applied to different social and economic sectors, providing an environmental picture of resource use sustainability and possible policy making strategies, according to Odum´s vision and legacy. Section 2 - Materials and Methods describes the emergy method and explains the meaning of its main indicators. Section 3 - Results from a number of case studies and sectors (urban and landscape systems, trade, human health, climate policies) show how the emergy approach can yield appropriate, effective and policy-telling performance indicators. Section 4 - Discussion points out how emergy indicators can be used as the basis of innovative, environmentally friendly and agreed upon policies to originate a more sustainable societal and economic development pattern; finally, Section 5 - Conclusion designs the take home lesson and the needed steps towards an integrated and scientifically based new tool for sustainable policy making.

2. Materials and Methods

Resources are wealth. When populations were small and the human use of the environmental resources was negligible compared to its size, wealth consisted of a nation´s forests, soils, some minerals, fisheries as well as the rain and sunlight falling on its landscape. Wood was the only concentrated energy source available, together with passive use of solar energy (warming houses, driving photosynthesis, cooking). When population increased, these resources were no longer enough to support its growth. Intensive use of coal first and also oil and natural gas later replaced the previous environmental services, allowing the increased extraction of minerals, in turn requiring additional use of fossil fuels, making renewables (mainly hydro and wind) a very marginal support to the economy. As Odum used to say (1971) "*our potatoes are partly made of oil*". Both renewables, as well as mineral and fossil resources had the double advantage to be relatively abundant (compared to the demand) and fully free or very cheap, which allowed and still supports the growth of an economy that assigns value depending on the relation demand-availability. Economies still rely on a "*user value*" concept, which means that a resources are valuable based on their availability (abundance or scarcity) and work potential (exergy). The market assigns to a resource a higher monetary value when its work potential is higher and makes it more "useful" within technological and economic domain. That value can be attributed to a resource when it is considered able to address specific needs (work potential) and generate an increased market demand (monetary value) is only partially true: no value is assigned to the work of biosphere to generate resources. Instead, the innovative Odum´s emergy concept reverses the assessment, by making value to rely on the direct and indirect work of the biosphere to generate resources and services and make them available (*donor value*) to our economies. National and local governments make decisions based on available money. When money (from GDP, from taxes) is not enough, they make decisions by increasing the national debt, to be charged to future generations. A reverse policy can be making decisions based on the emergy value of resources (available or imported biosphere work potential), to be captured and used for the wellbeing of a country or urban population.

2.1 What emergy is, how can it be calculated.

Emergy Accounting (EmA) is a comprehensive method to evaluate the quantity and the quality of resources used in production and consumption processes. It is defined as the "available energy" of one kind (usually solar) directly and indirectly required to generate a product or a service (Odum, 1996; Brown & Ulgiati, 2004; Brown and Ulgiati, 2016). For the sake of clarity, the thermodynamic meaning of "available energy" is the work potential of a given resource (sometimes also named "exergy", Szargut et al., 1988). The emergy approach analyses a process product by tracing back to the raw materials and energy supporting all its generation steps and quantifying them in common units (e.g., solar equivalent joules). Here, for further clarity, the EmA procedure can be shortly summarized as follows. First, an inventory of input flows is generated for each intermediate or final process (most often extracting data from statistical or Life Cycle Assessment databases. The inventory is organized in a Table, structured as (a) locally renewable, (b) locally nonrenewable, (c) imported, and finally (d) Labor&Services input flows. The process product (electricity, refined minerals, goods) is also included as output flow in the inventory. Each input flow is then converted into emergy flows, by means of conversion factors named UEV (Unit Emergy Value) according to a procedure described in Brown and Ulgiati (2016). All the emergy flows resulting from the

conversion procedure are summed up into a total emergy U (with or without including the emergy value of L&S). The latter is finally divided by the process product, in order to calculate the UEV of the product, i.e. the emergy needed to generate one unit (kg, J, m^3, …) of the investigated product. Emergy definition is summarized by Eqs. (1)
and (2):

$$U= \Sigma U_i=\Sigma_i f_i*UEV_i \qquad (1)$$

$$UEV_i=U_i/f_i \qquad (2)$$

where U= total emergy used (sej) by the system under study; U_i= total emergy used associated to a certain flow; f_i=different inflows to the system (as J, g, hr and currency units); UEV_i =Unit Emergy Value (emergy invested per unit product) of the i-th flow (sej/J; sej/g; sej/hr; sej/unit currency), with UEV of solar radiation assumed equal to 1 by definition.

For the sake of clarity, it is important to highlight that while monetary flows depend on market dynamics and therefore may change over time, biophysical flows capture a number of characteristics of traded resources that are more likely to remain constant and therefore may support longer-term decision-making strategies. In addition, there is another aspect associated to commodity trade that needs elaboration. Each traded resource or commodity is described by two flows. One flow is the emergy of the raw material, which is its production cost by nature over the entire supply chain from resource generation to processing and final delivery by humans. The other flow is the emergy of Labor and Services. Labor includes the direct human activity performed within the system's boundaries. Services include the indirect activity related to the infrastructure and the indirect labor chain that make the process possible at the larger scale of the economy. Emergy embodied in L&S takes into account the resource investment in know-how, education, training and infrastructure (Ulgiati and Brown, 2014; (Geng et al., 2017). In the larger scale of a national or regional economy, a system diagram can be represented as in Figure 1, with renewable emergy inflows, R, from the left side, locally nonrenewable resources (e.g. deep heat) within the boundary (N), imported inputs (I) entering through the top side (including L&S) and the output product(s) exiting through the right side towards the outside market. A money flow entering from the right side represents the payment for the Labor and Services associated to the imported flows. Finally, degraded resources (entropy outflows) are represented by outflows converging to the heat sink positioned in the lower side of the boundary. The system diagram clearly represents the donor-user side perspective, allowing the assessment of the amount of emergy U needed to generate the final product(s) or service(s) of the system to the final user (market).

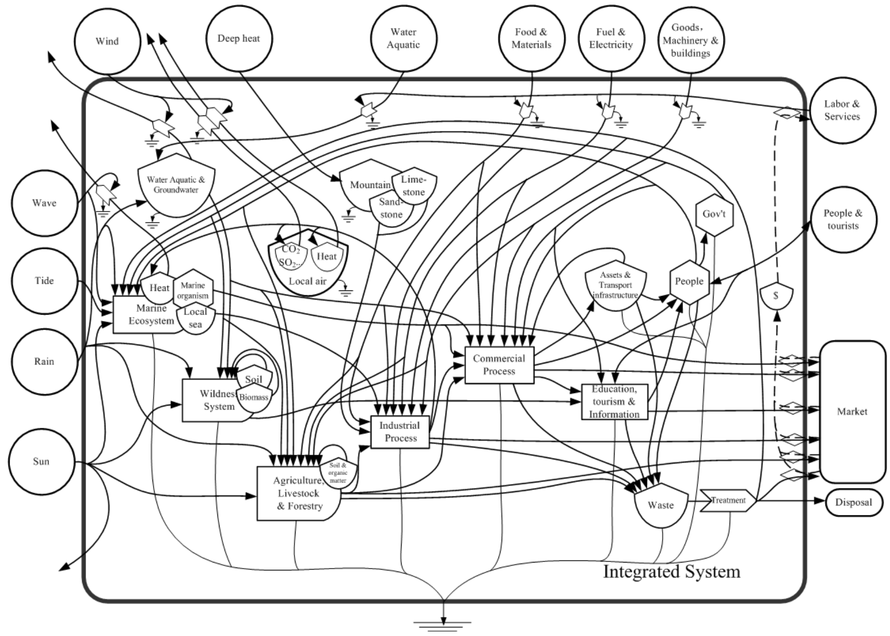

Figure 1. Country´s system diagram (courtesy of Mark T. Brown)

A set of emergy-based indicators of the investigated processes can be defined, to evaluate their performance and sustainability. Based on previous publications and reports, we selected the indicators appropriate for a discourse about policy making, within a perspective of sustainable economy, environment and resource use. The detailed formulas and meaning are shown in Table 1. The Table also includes two conventional monetary indicators (monetary value and monetary cost) which can be used to link the emergy value of a given product to its potential commercial value (selling in the market) and its monetary production cost (sum of each component´s cost).

The EMR (Emergy-to-Money Ratio, Table 1) quantifies the average emergy needed to generate one unit of currency within a given country´s economy (i.e. the ratio of the total annual emergy of used renewable and nonrenewable resources to the annual Gross Domestic Product), expressed as sej/$ (Odum, 1996). Instead, the emdollar Em$ = sej/(sej/$) expresses the emergy flow (sej) carried by a product or service in terms of its proportional GDP share, or in other words the fraction of Gross Economic Product generated by a given emergy contribution. As indicated in Table 1, this emdollar value complements the conventional *economic cost* of a product (i.e., the sum of all the costs of resources needed to produce it) and the potential *market value* (i.e., the willingness to pay for this product once it is commercially available), by integrating the environmental support required to generate a given fraction of GDP. Thus, expressing quantities in emdollars redistributes the money flow of an economy in proportion to the emergy flows that generates them, to better express their actual value in the economic and social system. In conclusion, all emergy flows (including those that are not valued economically) can be assigned a value expressed in emdollars.

Table 1. Selected emergy-based Indicators involved in Emergy Accounting (Odum, 1996; Odum et al., 2000; Ulgiati and Brown, 2004, 2014)

Indicator	Formula	Meaning
Emergy	$U= \Sigma U_i= \Sigma f_i *UEV_i$	Sum of all emergy flows supporting all systems and processes within a country´s economy. See Eqns. (1) and (2).
Emergy Yield Ratio	EYR= (R+N+F)/F	The ability of a system to exploit local renewable and nonrenewable resources
Environmental Loading Ratio	ELR= (N+F)/R	Pressure of a transformation process on the local environment pushing the system far from its natural equilibrium
Environmental Sustainability Index	ESI= EYR/ELR	The global performance of the system in using local resources compared to the environmental pressure exerted
Fraction of Renewable Emergy	%REN= R/(R+N+F)	The fraction of renewable emergy use, compared to total available resources
Emergy-to-Money Ratio	EMR=U/GDP	Average emergy supporting one unit of Gross Domestic Product
Emdollar (Em$)	Em$ = sej/(sej/$)	The fraction of Gross Economic Product due to a given emergy contribution[1]
Monetary cost (MC)	$	Sum of the economic cost of each contribution to the production of a given output
Monetary value (MV)	$	Potential commercial value of any given product
Labor and Services	L&S= L + S	Direct and Indirect Labor associated to local and imported resource processing. Points out the ability of the process to generate jobs over the production chain.
Empower Density ($sej*m^{-2}*s^{-1}$)	ED= (R+N+F)/(Area*Time)	The relation between emergy, time and land

2.2 Market value versus environmental value

As mentioned above as well as in Table 1, conventional economy values are based on resource cost in production processes and resource willingness-to-pay in commercial market dynamics. These are certainly important values at the grocery store, where focus is on production and purchasing phases, but provide no indications on sustainability and resilience of production processes and human societies. If sustainability policy making is the goal, conventional values need to be integrated by larger space and time scales assessments, to ensure future generation survival and wellbeing. This is why the emergy approach is proposed as an important component of governmental and stakeholders policy making, to provide an additional tool for deeper understanding of the role of Nature in human economies. As Odum H.T. and Odum E.P. (2000) pointed out, *"Ecosystems of the world are*

[1] Emdollar (Em$): Ratio of the emergy of a product by the emergy/$ ratio (EMR) of a country. It expresses the dollars of gross economic product corresponding to the value measured in emergy (Odum, 1996). For the sake of clarity, if a product requires 1,000,000 sej for its generation in the USA (emergy/$ ratio= 1.86E+12 sej/$), its equivalent emdollar value is 1,000,000/1.86E+12= 0.54E-6 em$

threatened because market prices are used to evaluate them." Money is only paid to people for their contributions (labor and services), and not to ecosystems (Figure 2). Market values are inverse to actual embodied contributions from Nature: "*When soils, wood, and other environmental products are abundant, they contribute the most, but market value is small. When environmental products are scarce, the market value is high.*"

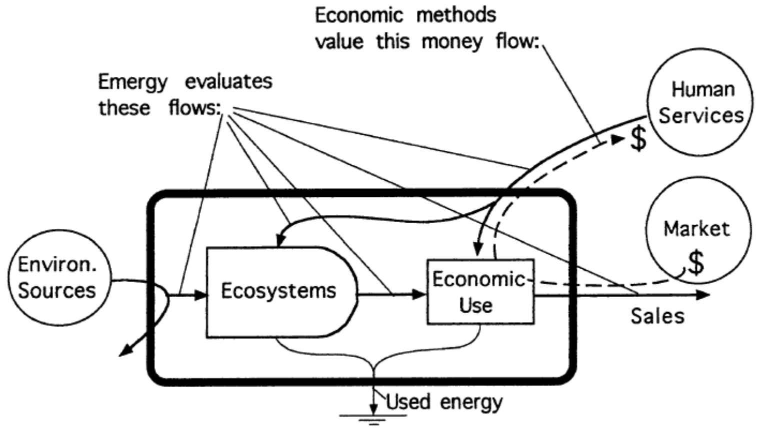

Figure 2. Contribution from humans (Labor and Services) and Biosphere and assessment methods. (Odum, H.T. and Odum, E.P., 2000)

Such reversed theory of value has not yet been understood nor accepted by stakeholders and policy-makers. Efforts by economists and others have been made in the last two decades to ''*internalize the externalities*'', namely to modify market valuations in order to assign more consideration to ecosystems. Instead, according to Odum H.T and Odum E.P., the reverse is needed: ''*externalize the internalities*'', i.e. assessing (and comparing) the contributions of the economy on the same basis and the same unit as the work of the environment.

2.3 Emergy-based policy making

By reading a large number of emergy papers, it clearly appears that the EmA approach provides a significant support to the use of resources in production and consumption processes. The usual life in cities, regions and countries faces deep and sometimes difficult debates among policy-makers, businesses, investors and stakeholders, all looking for appropriate solutions for economic processes and societal needs as well as to prevent environmental impacts of consumption and production activities. As mentioned above, a general strategy of Governments is to compare the available budget from taxes and exports with the expenses needed for societal services (health, administration, education, safety, retirement policies, among others), which is, of course, a very reasonable policy. However, while the emergy approach is unlikely to be of practical use in making decisions about the price of food at the grocery store or the way a process should be improved to maximize exergy efficiency at the local scale, its ability to link local processes to the global dynamics of the biosphere provides a valuable tool for adapting human driven processes to the oscillations and rates of natural processes, towards sustainable patterns of human economies, thus providing a comprehensive measure of cost at the scale of biosphere.

Policy making is not and cannot be a top-down process, where decisions are based on administrators´ opinions or interests. Instead, it is a clear and informed interaction among the various stakeholders, businesses, policy makers about the needed transition from a market-based to a nature-based economy and the environmental cost for this to occur. Developing and comparing emergy-based economic, environmental and social values of human-dominated and natural processes allows a comprehensive evaluation of costs, performance, resilience and sustainability of individual activities, innovative technologies, regulatory decisions, investments and equitable trade, by means of a unique and comparable currency (solar emergy, sej). In short, Odum´s emergy approach might be and should be the tool to show to policy makers and stakeholders that a new science-based and nature-based pattern is possible and show how this pattern could be (Brown and Ulgiati, 2004; Odum, H.T. and Odum, E.C., 2006; Santagata et al., 2020).

To summarize, the emergy method may help to: 1. Assess and compare the environmental and social quality of environmental systems and resources that have no market (natural capital, topsoil, fresh water, biodiversity, ecosystem services); 2. Develop a donor-side approach and innovating strategies for policy making (UEV database, valuing resources and products,…); 3. Include time and spatial scales in the assessment, in so evaluating their renewability and availability to next generations; 4. Evaluate the environmental support to human labor and services, beyond market evaluation in different countries; 5. Build an environmentally and socially just trade and labor market.

In the present study, a number of case studies are evaluated in terms of their potential application of emergy concepts and indicators to sustainability and resilience policy making.

3. Results

A large number of emergy results have been referred to in the Introduction, by summarizing the results reached by some emergy practitioners and quoting their interesting papers. Actually, the number of emergy papers has been increasing worldwide in the last years, converting the results of emergy case studies into very telling policy strategies and suggestions to overcome conventional economic evaluations and build integrated and alternative policies based on emergy accounting and the search for environmental sustainability and resilience in all economic and societal sectors. It is impossible to summarize the rich emergy literature that has been developed according to H.T. Odum´s enlightening teaching and Emergy Accounting book (1996). The rest of the present Section will limit to review and comment a small number of emergy papers that have been published as a follow up of Odum´s contribution. These papers have been selected based on their specific relation to and clear explanation of the use of the emergy approach for environmental policy making.

3.1 Urban and landscape policy-making

Odum et al. (2000) provided an interesting landscape policy making case study by applying the emergy method to the Puerto Rico regional forest system. Their focus was placed on six alternative ways of reforesting degraded lands with ages from 10 to 20 years (1. natural succession, 2. reforestation with exotic tree siris, 3. reforestation with siris and mahogany, 4. plantations unharvested, 5. planting of seedlings of many species, and 6. patches of forest by massive transfer of topsoil, seed bank and roots), in order to evaluate the contribution of environmental work and human services on a comparable basis, using emergy and its economic equivalent, emdollars (i.e., as previously mentioned, the fraction of Gross Economic Product generated by a given emergy contribution, Table 1). Odum et al compared the monetary cost for each kind of reforestation alternative and found that "*the emdollar value of a closed canopy developed in 10 to 20 years ranged from 20,000 to 48,000 em$/ha, whereas the economic costs were $1,200 to $9,700*", while the emergy yield ratios ranged from 3 to 24. This means that the contributions of environmental services provided to the society by the different kinds of forests - measured in terms of virtual, emergy related money (em$) - were always much higher than their pure management costs, thanks to the ability of the investigated forest systems to capture the environmental services and convert them into different typologies of support to the society.

In a like manner, Campbell and Brown (2007, 2012) applied the emergy accounting approach to the entire US National Forest System, a 78 million ha land managed by the US Forest Service (USFS) for different uses, among which timber extraction, water, soil preservation, biodiversity protection, public recreation and fossil fuels and mineral extraction. Campbell and Brown calculated the emergy, emdollar and economic values of provisioning, regulating, supporting and cultural services of the National Forest System, with reference to the year 2005. The goal of the study was to understand and highlight the difference, both in function and magnitude, between natural capital and economic capital, taking the US NFS as a case study. The study revealed that in 2005, the annual ecosystem services value of the National Forest System reached 197 billion emdollars, while its natural capital value was estimated at 24.3 trillion emdollars, equivalent to a total solar emergy of 46.2E+24 sej, while the economic capital (buildings, roads, knowledge, office equipment) was in the same year 5.7E+23 sej equivalent to 0.3 trillion em$, with a ratio of 81:1. If provisioning services of minerals and fossil fuels are not included (due to the high impacting factors of their extraction and use), the total emergy is 28.4E+24 sej, equivalent to 14.96 trillion em$ and the ratio to economic capital would still be as high as 50:1. In conclusion, an appropriate investment of economic capital supports the forest ecosystem to such a highly operating level that it can provide about 50 times more emergy as environmental services. Therefore, the federal government's budgetary allocation for the National Forest System was substantiated as scientifically justified through this analysis. Furthermore, the research investigated the disparity between natural and economic capital, demonstrating that natural capital components - particularly minerals, fossil fuels, and biodiversity - made substantial contributions to the total valuation. In contrast, economic capital exhibited comparatively lower value significance. These results may suggest policy makers and stakeholders the science-based validity of economic investments into the best land management strategies in terms of higher contribution of environmental services to the present and future generations.

Another interesting urban trees case study came out from the City Administration of Gainesville (FL, USA), the city where H.T. Odum lived and provided his university teaching. The case to be addressed can be found in the City´s website (https://www.gainesvillefl.gov/News-articles/Downtown-Trees-FAQ, dated March 2023) and dealt with benefits and damages provided by urban trees in downtown Gainesville, a problem shared by a large number of worldwide cities since many years ago (McPherson, Nowak and Rowntree, 1994) and most often becoming a topic of discussion among Administrators and Citizens. In short: a few, well identified trees are damaging sidewalks, curbs and roadways by expanding their roots and reducing the walking space, in particular four of them (oaks). The City Administration pointed out that the policy concerning urban forest in Gainesville would not change as a consequence of the disservices originated by these trees, according to City´s well established regulation in this matter. The first considered option, instead of removing the trees was to decrease the number of parking spaces around them and relocate the sidewalk between the new spaces and the trees, also modifying the existing storm-water system, at a final economic cost of 500,000 US$. An alternative option to modify the exterior area around some outdoor cafes where the trees were narrowing the sidewalk access was also considered, but this would have significantly altered the exterior features of some buildings included in the U.S. National Register of Historic Places since 1994. Thirdly, the option to remove at least the four, more problematic oaks, would have costed 10,000 US$ plus a smaller money amount to plant new trees, provided by the Tree Mitigation Fund. Finally, if no action were implemented (i.e., leaving the trees in place without any other mitigation work) the Administration website warned that this would "*cause future deterioration and complicate city efforts for a safer downtown sidewalk system*". The problem is still described in the City´s website, which may mean it is still under consideration due to its complex economic, social and environmental aspects. Can the emergy approach provide any additional tool to integrate and make it easier the decision making process in such environmentally and socially interesting situations? A similar case has been analysed by Shah et al. (2022) by applying the emergy approach to the Beijing street tree ecosystem (oaks and other trees), under four aspects:

1. Growing/maintenance costs (i.e., labor, fertilizers, irrigation, etc, needed to support the trees for one year)
2. Ecosystem Services provision (i.e., CO2 uptake, evapotranspiration, microclimate regulation, among other services that trees provide annually to the city)
3. Needed/to be avoided Cost for Human Health and Biodiversity Damage (i.e., toxicity of urban pollution, noise, biodiversity loss, among others)
4. Dis-services (i.e., road and sidewalk repair, street cleaning due to leaves and bird droppings, with additional demand for resources and costs).

Results are summarized in Shah et al´s paper by means of Emergy Tables and an emergy ternary diagram which allow policy makers to identify and compare the species with lowest growing/maintenance costs, highest ecosystem services provided and avoided costs for human health and biodiversity damage, and lowest ecosystem dis-services, also allowing to understand the reasons and the weight of such results (e.g., expanding roots, demand for fertilisers, etc), all expressed in one unique unit (sej) for comparison and final decision. Shah et al conclude that "*in general urban green infrastructure provides a large number of services to urban population, but it may also generate dis-services affecting human health, wellbeing and biodiversity when tree selection, location and management is not accurate*", indicate that as a result of the study oak and magnolia trees are not suitable in Beijing because of minimum value of environmental benefits compared to growing and maintenance costs and dis-services, and finally provide policy suggestions for a city to strategically and successfully maintain its urban street tree´s health and density.

A landscape related study by Brown and Ulgiati (2001) explores the use of the emergy approach to assess the carrying capacity of economic investments and, of course, suggest policies. Carrying capacity is related to the intensity of planned development, the environmental support that the investigated area is able to provide, and the appropriateness of suggested economic development considering the availability of local environmental services. In particular, Brown and Ulgiati place their focus on tourism development in Mexico and Papua New Guinea, by comparing tourist resorts in the two countries, located respectively on the Island of New Britain, PNG, and in Puerto Vallarta, Mexico. As the Authors state, the two resorts are very different as far as their structure and their functioning is concerned: "*the PNG resort was hand-built from local materials (wood and thatching), purchased fuel to generate its own electricity, burned coconut shells for hot water, and had 12 guest rooms serving an estimated 5,232 person-days per year. The Mexican hotel was built almost entirely of concrete and steel, purchased electricity, had 160 rooms and served a total of 37,584 person-days per year."* Such a difference (the Mexican resort is a "four star" hotel) is supported by very different inputs of resources, which translates into very different emergy demand and performance indicators, which might be useful to policy makers firstly to evaluate if their construction and activities fit the supporting capacity of the region, and secondly to make decisions about additional support, taxes, operating rules. The system diagram of a tourist resort, i.e. its components and their internal relations as well as inflows from and outflows to the surrounding environment, is shown in Figure 3a. The Figure also includes a symbol for the resort´s image (information), i.e. a representation of the main resort characteristics that attract the tourists. The study applies the usual emergy calculation procedures to develop and compare a set of performance indicators. In so doing, several among the indicators listed in the above Table 1 are calculated indicating for the PNG resort a higher percentage of renewable emergy resources, much lower empower density and environmental loading ratio, a much lower annual emergy use, a much lower support area needed compared to the Mexican hotel. In particular, the support area is calculated as the area needed to reach the same environmental performance of the country where the resort is located, and also including the imported emergy flows of goods, water, energy. Brown and Ulgiati note that "*Determination of support area establishes environmental carrying capacity using the ratio of support area to developed area. It is not a fixed land based ratio, but varies based on intensity of development and on the intensity of the regional economy. If the size and/or intensity of a development changes, the required support* *region will also change since its determination is based on the emergy intensity*". It clearly appears that each resort´s carrying capacity area is compared to the resources available to and used by the country´s economy, being therefore a country-related parameter. The calculated area does not need to be the area where the resort is located, but an area whose environmental integrity must be preserved in order to generate the environmental services needed by the tourist resort (Figure 3b). Once again, the emergy evaluation allows to capture data, indicators and information needed for appropriate investments policy making, if long-term sustainability and resilience is the goal.

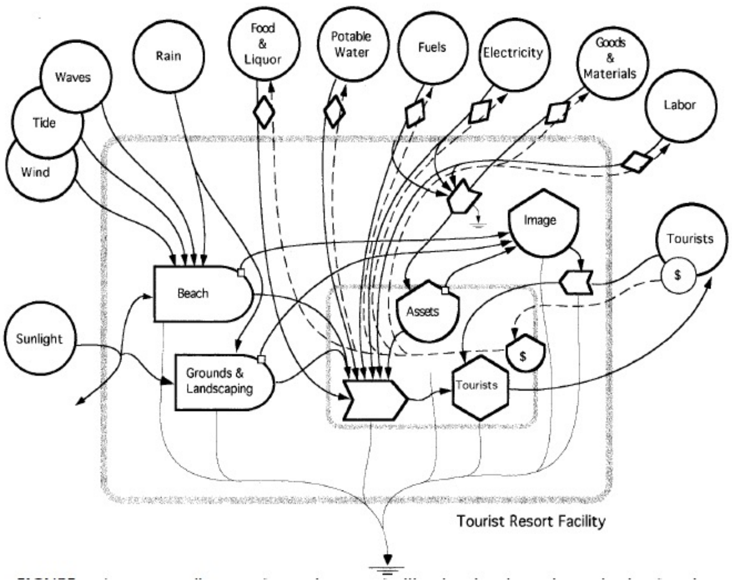

Figure 3a

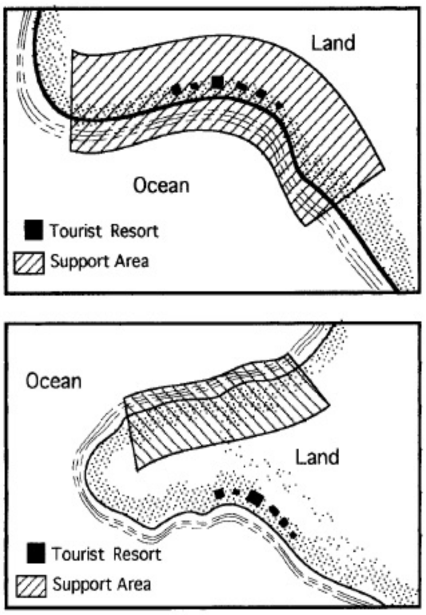

Figure 3b

Figure 3. A system diagram of a tourist resort facility (Figure 3a) and the support area needed to ensure its carrying capacity (Figure 3b). Dashed lines in Figure 3a indicate money flows while solid lines are energy and material flows. (Brown and Ulgiati, 2001)

3.2 Emergy and trade

Wealthy nations have been, are, and likely will be, those that have the power and the ability to secure through various means and political influence, raw resources to drive their economies. History is full of examples beginning with the Roman Empire and continuing till now with the invasion of Ukraine, where countries were and are invaded for resources and strategic minerals (although other non-military wars, most often even more effective, keep being fought to control markets, investments, trade and banking systems).

The importance of a peaceful and balanced exchange of resources among countries cannot be denied, if the aim is a sustainable economy. The unbalance of resource trade among countries is a real risk for environmental and political stability, as clearly pointed out by H.T. Odum (1994c): "*Trade and projects that unbalance local economies [...] they leave major sectors of the world's population in poverty, essentially outside the world economy. This pattern wastes resources into luxury and excess of the developed countries, diverting resources that used to go directly to population support (without payments). This pattern is not sustainable, does not maximize world wealth and emergy, does not reinforce world production, and will not last. These patterns will become discredited as world opinion changes, as revolutions occur, and worldwide resource depletion soon cuts off the largesse of the overdeveloped countries*." The emergy concept and calculation procedures can be used to determine international trade imbalances, if any, beyond claimed monetary terms of trade equity, highlighting the uncompensated appropriation of natural capital, generation time, ecosystem services, and technological and social information (Brown and Ulgiati, 2001, 2004). In emergy trade assessment, the EMR (Emergy-to-Money Ratio, sej/$, Table 1) is a crucial country specific parameter. Being the ratio of annual emergy, U, used within a country's economy to its annual GDP, it reflects the amount of resources needed to generate one unit of monetary outcome (Odum, 1996). In other words, it is a measure of efficiency of the economic process in converting resources into monetary wealth. In general, industrialized countries have low EMR due to high monetary circulation, while less developed countries have high EMR due to low monetary circulation. Therefore, the amount of resources needed to generate one GDP unit are different depending on the kind and level of development in each country.

Monetary flows are standard international trade accounting measures. Economically, a country benefits from trade if the monetary value of exports exceeds the monetary value of imports. A shift to biophysical flow (and benefits) accounting may provide a different perspective than just monetary flows evaluation (Ulgiati et al., 2011). Three major steps are needed to perform an emergy trade evaluation. First, an emergy system diagram must be drawn, to show components, internal exchange relations and external driving forces (e.g., Figures 1 and 3). An emergy system diagram can highlight flows of trade disparities originating from the market price of commodities and the purchasing power of a national currency between the trade partner countries. As a second step, matter, energy and money flows are determined and recorded as inventory and then multiplied by their respective UEVs for conversion to emergy amounts. Finally, emergy performance indices of trade are calculated according to Eqn. 1 and 2.

Emergy Exchange Ratio (EER) = Imported emergy/Exported emergy (1)

EER describes the general benefit within a trade relation: if the ratio is higher than one, that means the country imports more resources from its trade partner (measured in emergy units, not in monetary units) and therefore gains more work potential from resources received. In general, EER is calculated on a yearly basis.

Emergy Benefit Ratio (EBR)= Imported emergy/(Money paid x EMR of country where money comes from) (2)

EBR compares the emergy of raw and processed resources imported in a trade relationship to the emergy associated to the money paid for. Benefit largely depends on the EMR of importing country (i.e. the country where money comes from). Figure 4 shows that trade flows apparently balanced in monetary terms may have different characteristics when the embodied environmental value (emergy) is considered. The Emergy-to-Money Ratio EMR becomes a crucial parameter.

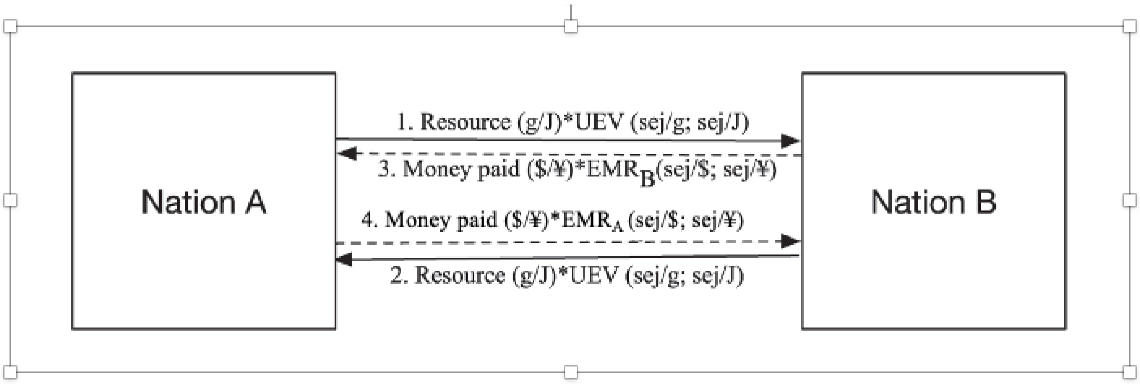

Figure 4. Diagram of trade between countries A and B: Emergy Exchange Ratio (EER_A, flow 1 versus flow 2) and of the Emergy Benefit Ratio (EBR_A, flow 2 versus flow 4). The dash arrows represent money flows paid for the traded resources.

Let´s assume that EMR_A = 9.1E13 sej/$ and EMR_B = 1.3E13 sej/$. Also assume that country A invests 10 $ to purchase corn from country B at a market price of 0.16 US$/kg (Trading Economics, 2025) and country B in turn uses the same 10 $ to purchase ammonium fertilizer from country A at a market price of 0.65 US$/kg (Trading Economics, 2025). The UEV of corn is 0.50E+12 sej/kg d.m., while the UEV of ammonium fertilizer is 5.97E+12 sej/kg (Rotolo et al., 2015). UEV values are updated to the most recent emergy baseline (Brown et al., 2016).

Therefore, with reference to Figure 4:

Flow 1: (10 US$/0.16 US$/kg) *0.50E+12 sej/kg= 31.25E+12 sej (corn, to A)

Flow 2: (10 US$/0.65 US$/kg)* 5.97E+12 sej/kg= 91.84E+12 sej (fertilizer, to B)

Flow 3: 10 US$ * 1.3E13 sej/US$= 1.3E14 sej (money paid by B)

Flow 4: 10 US$ * 9.1E*13 sej/US$= 9.1E*14 sej (money paid by A)

Results:

a) the EER of country A, Eqn. (1), is: Imported emergy to A/imported emergy to B= 31.25E+12 sej / 91.84E+12 sej= 0.34 (A imports less emergy than exported to B)

b) the EBR of country A, Eqn. (2), is: Imported emergy to A/(Money paid by A * EMR of A)=31.25E+12 sej /(10 US$ * 9.1E+13 sej/US$)= 31.25E+12 sej / 9.1E+14 sej= 0.034

On the other side:

c) The EER of country B is: 91.84E+12 sej / 31.25E+12 sej= 2.94.

d) The EBR of country B is: 91.84E+12 sej / 1.3E+14 sej= 0.70.

Interpretation:

Since A is a less developed country, as shown by its $EMR_A > EMR_B$, in this bilateral trade the same amount of money purchases more emergy when paid by country B than when paid by country A.

The above trade evaluation procedure has been applied by Huang et al. (2017) to the trade relations between China and six among the most developed African countries (South Africa, Sudan, Algeria, Nigeria, Egypt and Morocco) in the years 2001, 2004, 2008 and 2012. The EERs of Algeria, Nigeria, Egypt and Morocco were found higher than China´s, in terms of total emergy exchange, i.e. these countries received more emergy from China than vice versa over the investigated period. This seems to suggest a reversal of the typical trend in which industrialized economies exploit less developed countries, with no exchange to their economies. However, the EERs of South Africa and Sudan showed an opposite trend. China mainly imports primary resources from Africa and exports manufactured products. This composition benefits the Chinese economy (supporting resource processing and jobs) and also favoured the wealthy fractions of the African population, due to an increased access to consumery goods. Looking at the second indicator (EBR) the study indicates that China benefits more than the investigated African countries, due to its lower Emergy-to-Money Ratio (EMR) as explained above (i.e., the emergy associated to the money that China pays for imports is less than the emergy imported in terms of primary resources). This indicates that a more balanced trade is still needed: even if the African countries receive more emergy in terms of manufactured goods, the emergy associated to the money paid for is still too high.

The situation may become more complex when considering that generally trade in almost never a bilateral relation but develops among many countries at the same time. It clearly appears, however, that the emergy approach to trade relations among countries may provide useful and innovative ways to understand the trade balance and suggest improvement of benefits to all trading countries.

3.3 Human Health

Two health services (hospitals and their organization) have been investigated by Cristiano et al. (2021) in Sudan and by Alì et al. (2021) in Pakistan, by means of the emergy approach, with the aim to understand and highlight their performance in hard to face climatic and economic conditions in the Global South.

The first case study is a top-level, nonprofit specialised hospital, designed, built, and run by the Italian humanitarian NGO "*Emergency*": the *Salam* Centre for Cardiac Surgery, built between 2004 and 2007. The second one is the largest and the only public hospital of major Pakistani city Gujranwala, the District Head-Quarter (DHQ) hospital. DHQ is the only large (>100 beds) public hospital providing inexpensive treatment to the people in Gujranwala.

The design diagram of the Sudan hospital is shown in Figure 5. Given that it is managed by the Emergency NGO-Non Governative Organization, the image (i.e. the characteristics of the system to inform and attract donors) is linked to the flows of public and private donors, volunteers and free services, while no money is provided by patients. Instead, the Pakistani hospital is a governmental structure and supporting money flows only are provided by Government and patients. The diagram shows, as usually in emergy studies, renewable, nonrenewable and imported inflows interacting with inside components to yield hospital care to patients. In order to better understand the performance of these systems, not only the usual conventional indicators (energy, materials, goods, labor, etc) as well as basic emergy indicators have been calculated (e.g. the environmental loading ratio, the % of renewable input, the emergy supporting labor and services, etc), but innovative indicators have been introduced, among which the emergy per patient-day (1.85E+15 sej/p-day, with L&S), per cardiac surgical operation (5.40E+16 sej/operation, with L&S), per outpatient visit (4.50E+15 sej/visit, with L&S), per year, U (2.98E+19 sej/yr, including L&S, and 5.86E+18 sej/yr, without L&S) and a total number of pazients equal to 1.60E+04 p-days/yr. The latter values indicate the size of the hospital and the huge difference between values with and without L&S: Authors state that the "*evaluation of the hospital at hand yields the highest ratio of labour and services ever found in emergy accounting; this is related to both a specialised hospital and a cooperation project. … for it requires high-quality labour and final products to be used in industry-like processes* *delivering a service*”. Other more usual emergy indicators are the Emergy Yield Ratio (1.000, with L&S), the Environmental Loading Ratio (2524, with L&S), the indoor empower density (2.5 E+15 sej/ m^2 with L&S), among others. For comparison, the Pakistani hospital shows a total emergy U equal to 7.20E+18 sej/yr without L&S and 1.56E+19 sej/yr with L&S, an environmental Loading Ratio of 1,279 with L&S (about 50% less), a much lower emergy per pazient equal to 1.49E+14 sej/p-day compared to the Sudan hospital, and a total number of patients equal to 1.05E+05 p-days/yr. Not only these indicators can be considered a tool for performance and sustainability comparison and monitoring of systems in different locations and providing different kinds and quality of services (as the ones described above), but they certainly represent a starting point for improvement, comparison with future studies, and healthcare policy making, to face difficult climate and funding situations.

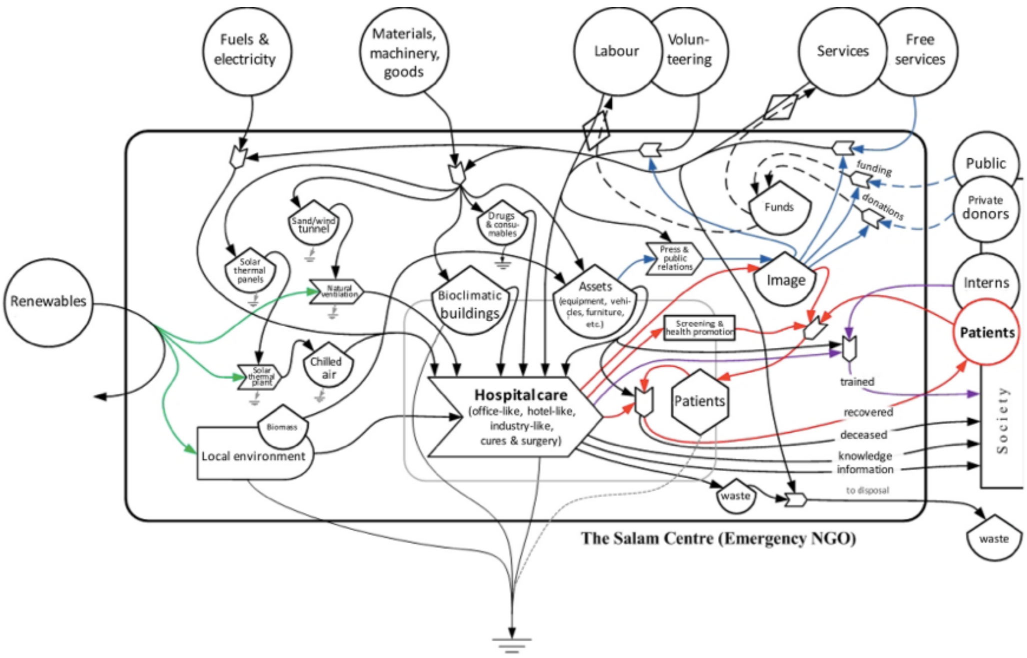

Figure 5. Systems diagram of the *Salam* Centre for Cardiac Surgery, built in Sudan by the NGO Emergency (Cristiano et al., 2021).

3.4 Facing increasing climate impacts: mitigation and adaptation

Disasters caused by pulses of energy with magnitudes and frequencies greater than normal environmental events need to be monitored and assessed in terms of their damage to human economies and costs for restoration. Evaluation of environmental energies causing disasters and monetary and material resources needed to restore the previous situation need to be calculated in comparable units. The emergy approach and its units and indicators can be adopted for the study of environmental disasters and decision making about restoration policies.

A hurricane disorders terrestrial systems (ecosystems and human-dominated systems) when its magnitude and frequency are greater than usual. Theory suggests that the best way to face these events is to build relatively inexpensive and short lifetime structures, so that their life is adjusted to the frequency of events and, when destroyed, the damage is smaller than if a more expensive structure were built and reconstruction does not require useless efforts. The interaction of hurricanes and systems (be they human-dominated or fully natural ones) was investigated by Brown et al. (1995) by assessing the annual ordering and the hurricane´s disordering energies in Dade county (Florida), based on data related to the year 1991. As the Authors point out, "*the response to the hurricane was an inflow of workers, money and resources to rebuild and repair the damage".* Important to note that the emergy concept was still at a developing stage and the research team led by H.T. Odum was using these case studies to further develop and test the approach. The calculation was based on a still developing annual emergy baseline, so that results cannot be fully compared with present values. Yet, it is very interesting to look at the development of the approach. The total annual emergy use in Dade county was calculated as equal to 66.1E+21 sej/yr (1990), while the impacted area (19%) had an emergy use around 15.4E+21 sej/yr. Only 3.4% of the total emergy use in the Dade county was locally renewable, compared to the 20.6% renewable in the impacted area. Other indicators (e.g., fraction of electric use, fuel use per person, etc) have also been calculated, to provide a clear description of energy use by both impacted and Dade county areas. The Authors also quantified in emergy units the natural and residential storages in the impacted area, as well as the damages occurred to them due to the Hurricane Andrew and the fixing costs. Important to underline that all the emergy support flows as well as costs have also been calculated in terms of emdollars, as in Section 3.1. In conclusion, calculated results have shown that the emergy value of total disordered structure (natural, agricultural and urban) amounted to 32% of the emergy budget of Dade county and 135% of the impacted area. Repair emergy costs have been respectively 34% and 147% of total available budget in the two areas. Further simulations concerning the frequency of small and major hurricanes provided a clear picture of the potential interaction between hurricane frequency, damage and repair money governmental aid, in order to help appropriate decision making. The Hurricane Andrew case study has clearly evidenced that, converting natural and economic capital, as well as environmental pulses and repair resources and investments into only one unit (emdollars) may allow assessment, comparison and decision making about needed support and better reconstruction procedures, similar to reforestation alternative and urban trees decision making in Section 3.1.

4. Discussion

The present evaluation of the ability of the emergy approach to serve as a policy making tool has been supported in the Introduction by a large number of published papers covering different economic and social sectors. Further, the Results section has deeper analysed and summarized the application of Emergy to (i) urban trees management, forests, landscape-based carrying capacity and reforestation iniziatives, (ii) balance of international trade, (iii) human health services, and (iv) climate impacts management, in order to provide a multiple and effective picture of how emergy can be used in support to policy making.

4.1 Take home lessons

A number of very telling considerations can be derived from the above diverse case studies:

1) FLEXIBILITY. The Emergy approach is very flexible and can be applied to a very large variety of cases and sectors, to increase their environmental understanding and favor the interaction and collaboration among policy makers and stakeholders. The already existing rich patrimony of published emergy documents and papers should be increasingly shared and made available.
2) VARIETY. A number of emergy parameters and indicators become available and adjusted to different situations (e.g.: comparison based on total emergy demand; decisions based on different emdollar value or different emdollar/economic cost ratio; emergy imported in trade versus emergy exported or versus emergy associated to money paid for; process improvements based on performance indicators such as ELR, %REN, or Landscape Development Intensity index-LDI, etc).
3) METHODOLOGICAL INTEGRATION. It appears evident from the evaluated cases that Emergy is not to be considered the unique evaluation method but can be and should be profitably integrated to more conventional economic (e.g.: cost-benefit analysis) and biophysical (e.g.: Life Cycle Assessment) approaches. These different evaluation methods would strengthen each other by sharing data and different time and spatial scales. Efforts are needed to make this happen.

4) WORLDWIDE APPLICABILITY. The Emergy approach has been and can be applied to environmental and social policy making worldwide, since its assessment procedure does not depend on local political, cultural, and socio-economic features and can easily integrate with them. The world, in spite of its diverse cultures and lifestyles, needs science-based and nature-based policies to ensure survival of humans and all the other species.
5) SYSTEMIC VISION. Odum´s systemic vision encompasses present and future lifestyles and wellbeing. Processes are never seen or evaluated alone, but instead they are assessed within the larger system in which they develop and where resources come from (the city, the forest, the ecosystem, the biosphere). Appropriate resource use and sharing among species may prevent injustices towards present and future generations.
6) COMMUNITY EFFORTS. The present hard-working and collaborative emergy community worldwide, partially gathered as ISAER-International Society for the Advancement of Emergy Research, may be very helpful for the improvement and sharing of the Emergy approach, in particular for the diffusion of emergy-based policy making.
7) METHODOLOGICAL SHARING. The rich and diverse Emergy results and methods developed worldwide for environmental assessments should be shared with policy makers and stakeholders through meetings and availability of specific documents, in order to facilitate discussion and application of emergy-based practices to local and larger-scale problems.

The Emergy approach is not the magic bullet that will solve any societal and economic problem. On the contrary, by focusing on larger time and spatial scales (i.e., by expanding the potential stakeholders) the approach may initially make more difficult to reach an agreement among different stakeholders, who may not be interested to far away or future users. Then, after going deeper into the emergy evaluation, the potential use of different (better, cheaper, nearer) materials and energy sources as well as circular approaches based on reuse and recycling may decrease the total emergy demand for the process under discussion and evidence the benefits also for the local users.

4.2 The Prosperous Way Down

"*Most of my high school and university education was affected by a very simple concept, namely that science would allow a continuous growth, removing all technological obstacles and solving all problems, for a prosperous life ahead*" (Ulgiati, 2004). The debate about the limits to growth gained the attention of scientists and policy makers in the 70´s, after the publication of the homonymous book, Meadows et al. (1972). H.T. Odum and his wife E.C. Odum (2001) moved a step ahead, based on nature´s behavior, i.e. the so called "pulsing paradigm". According to this concept, everything in nature (and human systems as well) grows on available resources, reaches a climax for a while and then declines due to declining resources, followed by a recovery period in which resources are regenerated, stored and made available for a new growth period. This is the behavior of trees and forests, and human civilizations and empires do the same. As the Odum´s warn in their book, "*Make no mistake, this is not a proposal for less growth. It is recognition that general systems principles of energy, matter, and information are operating to force society into a different stage in a long-range cycle*." (Odum, H.T. and Odum, E.C., 2001).

Within this pulsing paradigm, resource availability and, even more than that, the resource regeneration time assume a crucial importance, since we need to adjust our consumption patterns to the speed of resource availability´s growth and decline. Not all the resources grow and decline at the same speed: trees have an annual pulsing while many human civilizations and empires lasted hundreds of years. Therefore, whenever we are willing to match the available resources with their regeneration speed and the perspectives of the society in which we are involved, no doubt we have to account for resources by means of the Emergy concept and assessment method. This allows us to establish a policy making and lifestyle appropriate to the present and future availability of resources. If we are able to match lifestyles and resource trends, even the descent period may still appear prosperous and "*showing a good way down is a call for everyone to think ahead and plan*" (Figure 6).

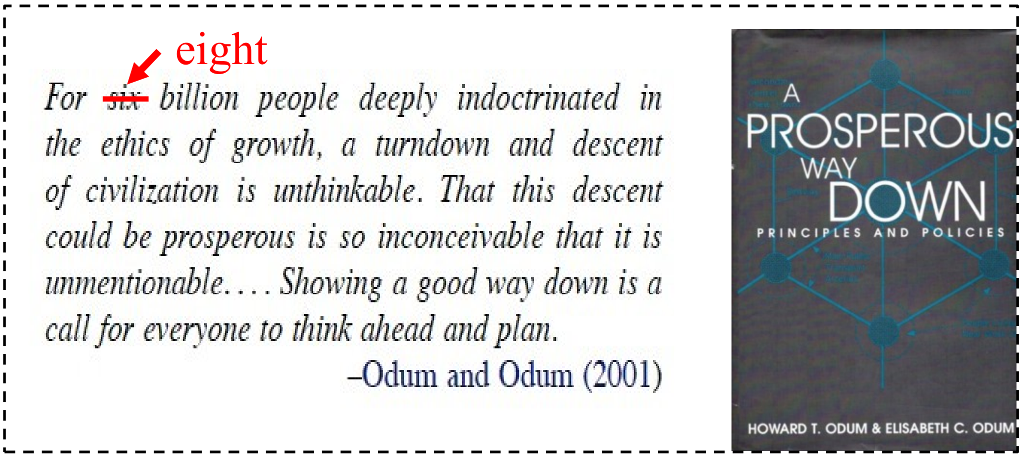

Figure 6. Odum&Odum´s sentence from "The Prosperous Way Down" book, 2001. After 24 years, May 2025, world population has reached 8 billion and 230 million people.

Conclusions

The emergy approach provides stakeholders and policy-makers with a powerful tool to understand the environmental and societal dynamics and to plan different development ways. This tool may be integrated with other economic and environmental evaluation methods, for enhanced understanding and results.

New, smooth strategies are not easy since they require education and preparation and also involve many if not all of the aspects of our daily life: money, welfare, school, housing, transport, population dynamics, international trade, religion, peace and war. Now, the question is: are the scientific, economic and social communities and their leaders ready to receive Odum´s legacy and start working on it? Considering that the dominant paradigm is still the monetary market economy and the growth perspective, much more remains to be done. The large number of published scientific results since Odum wrote his "Emergy Accounting" book evidence the interest of the scientific community for the development of a policy making tool capable to link policy choices to the biosphere dynamics. The next step is, no doubt, a deeper collaboration among the scientific community, the policy makers and stakeholders at all scales, to increase the awareness of the potential improvement of societal lifestyles and ecosystems integrity linked to a deep change of perspective: "*We expect much of the resource use, culture and public policy appropriate for the growth period to be replaced with a new set of ethics and policies affecting each scale of time and space during descent*." (Odum, H.T. and Odum, E.C., 2006)

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