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Panergy Analysis: Tool for Decision-Making in Economy, Energy, Environment and Engineering

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ABSTRACT

The PANERGY concept, presented for the first time in 2009, is taken up, revised, and better explained. Panergy is a potential belonging to any "object" having a physical entity and economic value (product, service, activity, organization, institution). It consists of the amount of energy, in any form, incorporated and/or released by the object itself during its functional life. The Panergy theory establishes the complete equivalence between economic value (in monetary currency) and embodied global energy (in units of energy) at any given moment. Based on this, economic dynamics can be described with the same tools used for thermodynamics. The report introduces a further conceptual element, the "Dark Panergy", which improves the theory and shows how the Panergy Analysis, through thermodynamic methodologies, makes available and simplifies the solutions of problems that involve decision-making choices in economics, environment, engineering and environmental policies. Examples of application in these topics are given and in many cases the results are unorthodox.

1. INTRODUCTION

The concept of Panergy was introduced for the first time in the year 2009 [1] and applied to the comparison of power generation technologies considering the energy spent for the construction of the devices. The theory was extended in 2019 [2] with application to monetary exchanges introducing the “thermodynamic currency”. In the same year [3] was presented the possibility to use the theory of Panergy to Economy processes. The present work synthesizes the already presented applications reporting examples to confirm the validity of theory. Furtherly a new application to the decision making in the field of environmental science is explored through a new considered property of Panergy: The Dark Panergy.

1.1 Panergy: Basic theory

The concept of Panergy can be understood by referring to Figure 1. If we analyze the cost (and therefore the price) of any commercial object (products, machinery, processes, or services), the value consists of three main components: Energy used directly to make it (E1), Direct labor (M1) including taxes, services and subcontracts and Supplies (S1) including materials, equipment, and services. If, on a second step, each of the components (M1) and (S1) is subjected to a similar break-down, we find out the same three sub-elements, namely energy (E2), work (M2) and supplies (S2). Pushing the reasoning to the limit, we find that the cost, and therefore also the market price, of the Object consists entirely of energy both direct and indirect. Note that the overall energy embodied in the object, according to this scheme, is more inclusive than that defined as "Emergy" or "Embodied Energy" by Odum in [4], the latter referring only to the direct energy appearing at the first level of cost allocation (E_0 in Figure 1). The current definition of "Panergy" also includes all the contributions of non-directly measurable forms of energy which are attributable to the formation of the final cost/price of the object [5-8].

From this scheme derives the *Theorem of Panergy* which establishes the equivalence between market price (commercial value) V and the total embodied energy (Panergy) P of each marketable object and is expressed by Eq. (1).

$$\boldsymbol{P} = \boldsymbol{\beta V} \tag{1}$$

$$\boldsymbol{\beta} = \lim_{n\to\infty} \frac{\sum E_n}{\sum C_n E_n} \tag{2.1}$$

where, β is the "*Specific Panergy*” converting the monetary currency into "*Thermodynamic Currency*"; it is also called “*Pantropy”* as we will see later.

It depends on the energy prices C_i charged *to the end user* of each transaction, in fact Eq. (2.1) says β is the *inverse of the average market price of energy supplied to the end user.*

Under certain conditions, such as in an economically and administratively homogeneous context, in a defined time interval, the conversion parameter β *is the ratio between the total direct and indirect energy sources introduced, and the amount of money involved.*

In these cases, another expression for β is given by Eq. (2.2)

$$\boldsymbol{\beta} = \frac{\sum E_n}{G} \tag{2.2}$$

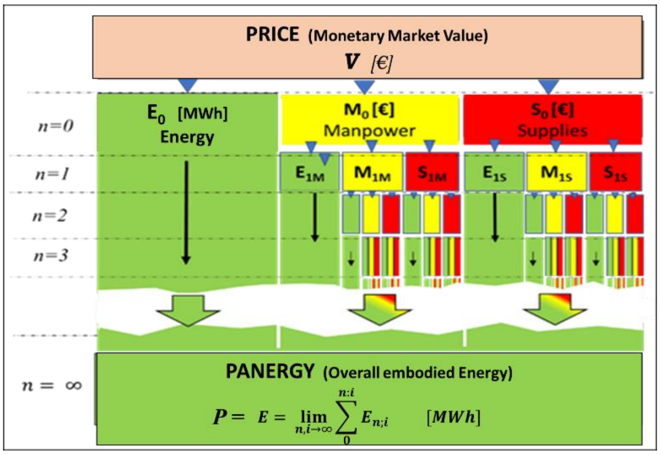


Figure 1. Equivalence between price and embodied energy

The sum in the numerator of Eq. (2.2), expressed in Energy units (TOE, MWh, GJ...), is the overall energy, upstream its transformation into a form compatible with the end-use. *G* is the gross product of the collectivity measured in monetary units (€, $...).

Some of the terms of ΣE_n inside an economic context (as a National State) are evident and measurable, as the case of the Total Primary Energy Sources *TPES*, typically classified into the following categories.

- *F:* Non-renewable fossil fuels, imported or locally produced;
- *N:* Non-fossil and non-renewable sources (e.g., nuclear electricity generation) imported or locally produced;
- *R:* Self-produced and imported renewable sources (e.g., solar PV, hydroelectric, geothermal...);
- *L:* Other non-renewable sources from internal recovery (e.g., waste).

One of the indicators considered relevant is the Primary Energy Intensity I_p. It is an item in the annual budget of any national state and is given by Eq. (3), where GDP is the Gross Domestic Product.

$$\boldsymbol{I_P} = \frac{TPES}{GDP} = \frac{F+N+R+L}{GDP} \tag{3}$$

Observing the budgets of almost all the countries of the world and combining Eq. (2.1) and Eq. (2.2), taking into account Eq. (3), it can be observed that the Specific Panergy is generated by a further Primary Source A which is not in the ability to be measured by normal economic indicators, since it is not part of the (artificial) transformation processes of Primary Sources into forms useful to the community.

$$\boldsymbol{\beta} = \frac{TPES}{GDP} + \frac{\boldsymbol{A}}{GDP} = I_P + \frac{\boldsymbol{A}}{GDP} \tag{4}$$

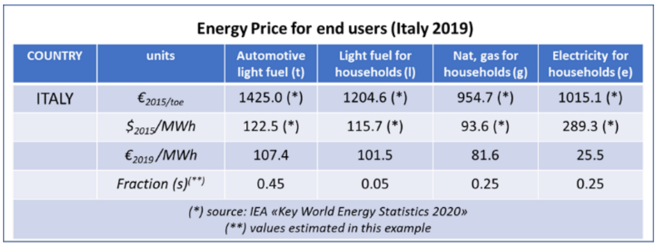
By analogy with the Dark Matter of the Cosmic Physics, ***A*** here is defined as *Dark Panergy.*

1.2 The "Dark Panergy"

Dark Panergy is the energy supplied by the primary natural resources that pervade the territory (e.g., sun, geothermal energy, hydraulics, wind...), which contributes to the subsistence of the community settled in the area (e.g., agriculture, livestock, primary food production, extraction of marketable materials...) and which is not artificially transformed into the final form of use (movement, electricity, heat...) by technological tools. The transformation for use occurs through natural processes.

A is not measurable with physical instruments (who can, for example, measure the amount of solar energy (*prime energy*) needed for wheat growth? Or the cosmic one that produced the molecules of a mineral salt (*raw material*) essential for the biological cycle of plants used for human life?). It is measured by Eq. (4).

Dark Panergy is a novelty considering the previously published works and has relevant consequences in the development of Panergy Analysis. As an example, let's analyze Italy in the year 2019, the last stable year before the subsequent upheavals. Figure 2 shows the prices of the various types of energy charged to end users taken from official statistics. Based on the above data, with the symbols of Figure 2, we obtain:



Energy Price for end users (Italy 2019)

COUNTRY	units	Automotive light fuel (t)	Light fuel for households (l)	Nat, gas for households (g)	Electricity for households (e)
ITALY	$€_{2015/toe}$	1425.0 (*)	1204.6 (*)	954.7 (*)	1015.1 (*)
	$\$_{2015}$/MWh	122.5 (*)	115.7 (*)	93.6 (*)	289.3 (*)
	$€_{2019}$/MWh	107.4	101.5	81.6	25.5
	Fraction (s)$^{(**)}$	0.45	0.05	0.25	0.25

(*) source: IEA «Key World Energy Statistics 2020»
(**) values estimated in this example

Figure 2. Energy indicators Italy 2019

$$\beta_{2019} = \frac{1}{\gamma_t t + \gamma_l l + \gamma_g g + \gamma_e e} = 0.01247\ MWh/€$$

It is interesting to note that the primary energy intensity I_P, which in official statistics is based on measurable primary sources *TPES=(F+N+R+L)*, in that year is 0.00116 MWh/€, against an *GDP* of $1{,}720\text{x}10^9$ €. (These values are based on provisional data; the final ones are slightly different). The difference between β and I_P shows that Dark Panergy *A* is $19.45\text{x}10^9$ MWh/y, then about 10 times *TPES.* Since Italy is poor in raw materials, it consists essentially in the conversion of solar raw energy into agri-food production, livestock etc., and represents only 0.0048% of that which reaches the territory ($0.42\text{x}10^{15}$ kWh/y).

A better use of Dark Panergy must be seriously addressed. The great sensitivity of β with respect to ***A***, which is valid for all modern communities in the world, highlights its importance in land use policies. Nevertheless, the importance of ***A*** is specific of each community and territory. This topic is taken up again and deepened in chapter 4.

1.3 Panergy Analysis

Panergy is a status function and is a property pertaining to all human activities. Any "Object" is a stockage pot whose content in real and virtual energy can be increased or reduced over time because of direct input (real energy) and monetary transactions (virtual energy), expressed in thermodynamic currency.

In the basic law of Panergy, Eq. (1) and Figure 3, *P* is a time-dependent function changing over time. Panergy Analysis is the methodology that analyzes all the processes having economic relevance on the variations of *P* over time including *β* variations. To perform this analysis, all economic parameters and processes must be expressed in Thermodynamic Currency.

Panergy of a marketable object (a commercial product or a Service Organization), is, for each year, the current market price multiplied by the *β* value of that year. In the example discussed in previous chapter, the value of an object placed on the market in 2019 in Italy at the price of € 1 has a Panergy content (and therefore has committed energy in all forms) of 0.01247 MWh primary. This value always remains the same over time regardless of possible subsequent monetary fluctuations. Panergy can be converted into current money later through the current value β_i.

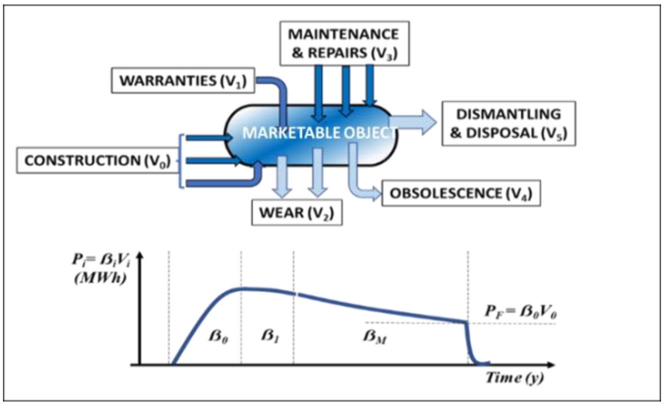


Figure 3. Panergy Analysis: Life cycle of an industrial product

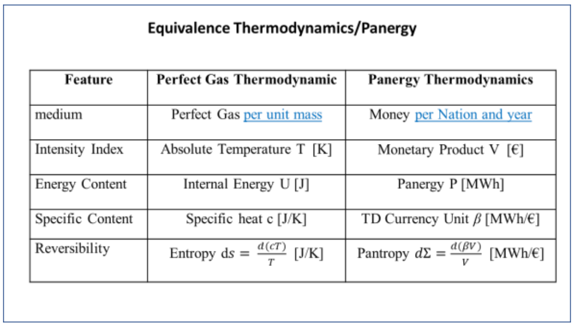
Independence from currency fluctuations is one of the peculiar properties of the thermodynamic money.

Figure 3 explains how the life cycle (market presence) of an Object (a product, in the example of Figure 3, but also a company, an institution, a community, a Nation, or the entire planet) is determined by a succession of balances between Panergy's inputs and outputs. Each instant corresponds to a *P* value resulting from all the previous economic transactions carried out and the contributions/subtractions of direct energy. Panergy, expressed in physical units (MWh, GJ, ...) is a form of energy that can be treated with methods from classical physics.

All Money spent on upgrading the Object's performance is converted into Panergy. This happens in analogy with the conversion of Work into Heat in classical Physics and therefore, obeying the *First Law of Thermodynamics*.

When one wants to monetize the Object's Panergy by transferring this into market value, it is not possible to recover some residual passive expenses (e.g., those for dismantling, decommissioning, technological decline…), therefore not all the Panergy is transformable, exactly as stated in the *Second Law of Thermodynamics*

Figure 4 shows some of the equivalences between the Gas Theory in Classical Thermodynamics and the Theorem of Panergy [3].


Equivalence Thermodynamics/Panergy

Feature	Perfect Gas Thermodynamic	Panergy Thermodynamics
medium	Perfect Gas per unit mass	Money per Nation and year
Intensity Index	Absolute Temperature T [K]	Monetary Product V [€]
Energy Content	Internal Energy U [J]	Panergy P [MWh]
Specific Content	Specific heat c [J/K]	TD Currency Unit β [MWh/€]
Reversibility	Entropy $ds = \frac{d(cT)}{T}$ [J/K]	Pantropy $d\Sigma = \frac{d(\beta V)}{V}$ [MWh/€]

Figure 4. Thermodynamics/Panergy equivalences

2. PANERGY ANALYSIS APPLIED TO MACRO-ECONOMY

As seen before, the substantial and formal equivalence between monetary value and Panergy (as form of energy energy) allows to apply the methodologies of Classical Thermodynamics to Economical Processes.

The economic governance of a community can be managed through Panergy Analysis using thermodynamic methodologies.

It is assumed that a Nation is an "Object" whose Panergy is represented by $P=\beta\bullet(GDP)$.

A positive accumulation of Panergy means improvement in the economy level of the context as the saleable store is growing. It follows that according to Panergy Analysis, the alone *GDP* increase is not enough to consider economy growing, in fact increasing *GDP* results in an equivalent decreasing of *β* so $dP=d\beta$.

In Panergy Analysis, applying the equivalences of Figure 4, $d\Sigma=d\beta$. That's the reason why *β* can be called also *Specific Pantropy*. An increase of Panergy caused by an increase of *GDP* (economy growth) corresponds to a decrease of Pantropy; the same which happens in thermodynamics for Entropy.

Panergy Analysis of an economic transformation can be assessed considering the scheme of Figure 5, which is a representation of the differential analysis of the displacements dV and $d\beta$ around a point A.

Four quadrants are identified with four combinations of the couples (dV:$d\beta$).

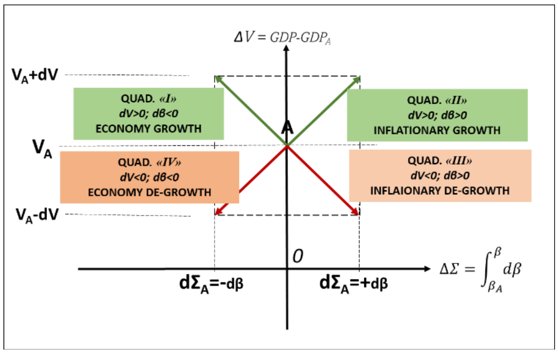


Figure 5. Assessment of economic processes

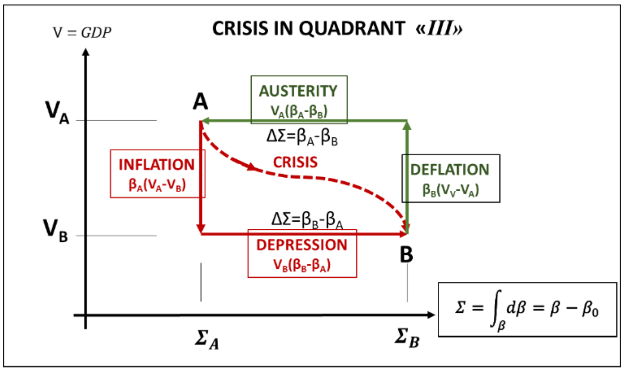


Figure 6. Closed cycle, iso-pantropic transformations and similarity to the Carnot's theorem

The diagram, in coordinates DV-$\Delta\Sigma$ (Value-Pantropy) is equivalent to the thermodynamic one DT-ΔS (Absolute Temperature - Entropy).

Reasoning in finite terms, a crisis process that makes the system pass from status A to status B, is represented in Figure 6 by the dotted red line (in the case of figure it occurs in the quadrant III). Whatever the path of the crisis, since Panergy is a status function, the result (red arrows in the diagram) corresponds to the sum of two transformations: A decreasing iso-monetary one plus an increasing iso-pantropic one.

The restoration towards the initial situation is driven through either monetary or economy-supporting interventions. The most effective intervention to an inflationary plus productive crisis is a deflationary plus austerity maneuver. In a V-ΔΣ diagram this is represented with an increasing iso-monetary and a decreasing iso-pantropic transformation (green arrows in Figure 6).

Panergy yielded by the system, due to crisis, is given by Eq. (5) while the one necessary to recover the original economic status is Eq. (6):

$$\Delta P_{AB} = V_B\Delta\beta - V_A\Delta\beta - \Delta V\beta_A \tag{5}$$

$$\Delta P_{BA} = V_A\Delta\beta - V_B\Delta\beta + \Delta V\beta_B \tag{6}$$

The algebraic sum of the two quantities is the Panergy to introduce into the system to implement the counter reaction to crisis.

$$\Delta P_{AB} + \Delta P_{BA} = \Delta V\beta_B - \Delta V\beta_A \tag{7}$$

$$\Delta P_{AA} = \Delta V(\beta_B - \beta_A) \tag{8}$$

Those who understand thermodynamics will immediately realize that this is a transposition of Carnot's Theorem to economy.

As an example, it is interesting to analyze the situation of the Italian economy in the years 2019 - 2022 where there was a fall in *GDP* with almost zero inflation in 2020, a remarkable recovery of *GDP* with low inflation in 2021 and a good recovery of *GDP* but with a burst of inflation in 2022.

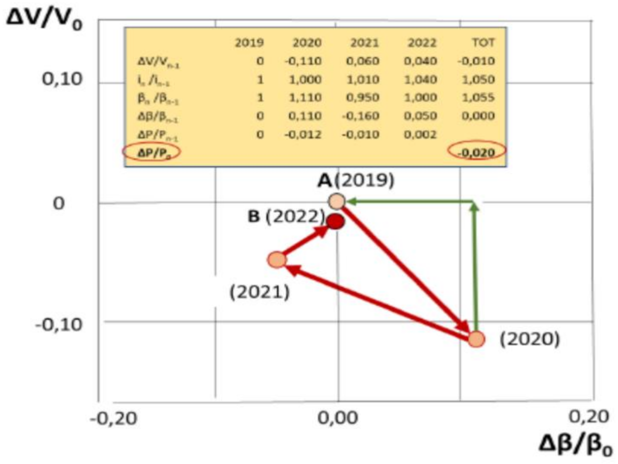
The analysis is shown in Figure 7 in a normalized variable diagram (not all the values reported are the real ones, many are provisional and others, not available, are hypotheses).

Based on a classic approach, to recover the 2020 crisis, which led to an 11% reduction in *GDP*, the EU Commission and the European Central Bank have launched a recovery plan of € 223 billion between non-repayable funds (inflation recovery) and subsidized credit (growth recovery), which is precisely about 11% of 2019 *GDP*. The Panergy Analysis, as already mentioned, assumes as a parameter of judgment the variation of the overall Panergy of the economy and not the *GDP* alone.

In relative terms, the annual change of Panergy $\Delta P_n/P_{n-1}$ is given by $\Delta V_n\ \Delta\beta_n/V_{n-1}\ \beta_{n-1}$. In this example, in the year 2020 there was a 1.2% loss of Panergy compared to 2019. In 2019 the thermodynamic currency was β_{2019}=0.01247 MWh/€, *GDP* was 1790 x10^9 € so it is P_{2019}=22.32x10^9 MWh and ΔP_{2020}=0.267x10^9 MWh which is the Panergy to introduce in the national economy, in the years after 2020 to recover the state of 2019. This recovery, limited to the 2020 crisis (green path in Figure 7) should result in a cash revaluation of 11% and a structural growth also driven by 11%. So, an injection of non-repayable cash of € 197 billion and a structural decrease of $\Delta\beta$ (overall energy consumption savings) of 2.45x10^9 MWh.

Subsequently, also because of non-repayable government interventions, but above all for the production recovery after the Pandemic, there was a growth of Panergy that dragged a *GDP* growth in 2021, attenuated with the growth of inflation due to the war events of the 2022. Overall, a loss of Panergy of 2% was observed in the three-year period and a return to the β value of 2019.

According to the Panergy Analysis, for the complete restoration, a 1% recovery of GDP_{2019} is necessary (the distance between A and B of Fig.7 can only be covered with an iso-pantropic) that is, an injection of non-repayable money into the system of about € 18 billion. This number is quite close to the figure projected in the government's 2023 budget for non-repayable aid in contrast to the 2022 rise in commodity prices. Therefore, according to the Panergy Analysis, the intervention seems adequate to achieve the objective, provided, however, that there is no further increase in inflation in 2023.



	2019	2020	2021	2022	TOT
$\Delta V/V_{n-1}$	0	-0,110	0,060	0,040	-0,010
i_n/i_{n-1}	1	1,000	1,010	1,040	1,050
β_n/β_{n-1}	1	1,110	0,950	1,000	1,055
$\Delta\beta/\beta_{n-1}$	0	0,110	-0,160	0,050	0,000
$\Delta P/P_{n-1}$	0	-0,012	-0,010	0,002	
$\Delta P/P_0$					-0,020

Figure 7. Italian economy in the years 2019-2022

3. APPLICATIONS OF PANERGY ANALYSIS IN ENGINEERING

3.1 Life cycle and residual life

3.1.1 Functional object

Functional object is one that performs, during its life cycle, an operational function within a process (e.g., a car battery, or the aircraft of an air transport company, or simply an object with an aesthetic function).

The description of the life cycle of a functional object, carried out through Panergy Analysis, has as its strong pillar the possibility of evaluating, in a simple and rapid way, at a certain moment of its life, what is the available residual time of functionality. All based on the examination of the economic transactions that have affected the object up to the year of assessment. The objective is to have a prediction of the residual life as precise as possible.

Life cycle, represented according to the Panergy Analysis, is schematized in Figure 8. It is described in terms of Panergy over time and allows final or periodical assessments regardless of monetary fluctuations often dependent on speculative causes or political tensions. The trend of Panergy over time is represented by the solid blue line in the Figure 8. The main phases are the manufacture of the Object (generally increasing), the operational or use phase (generally decreasing due to the decline or progressive physical consumption despite maintenance) and the final disposal. If there are temporal variations of the thermodynamic currency β (in green in the Figure 9), the corresponding trend of the monetary value, represented by the dashed red line, is consequently affected. Note that, since the dynamics of the currency cannot be predicted in advance, the life cycle, when evaluated in monetary terms, can lead to significant errors. By reasoning in terms of thermodynamic currency, the estimated life cycle can be evaluated with greater reliability.

The methodology applies on a case-by-case basis and depends on the data available. In the example of Figure 9 data available are the following:

1. The purchase (or offer) price of the Object in currency V_0 (€) to be transformed into Panergy P_0 (MWh);
2. The warranty period stipulated in the purchase contract t_W (years);
3. The contractual value of ordinary maintenance $P_M(t)$ (€/y) to be transformed into MWh/y with the value of β at t=0; this trend in the estimate phase is assumed to be constant over time;
4. The estimated cost of the decommissioning and disposal of the object to be incurred at the end of the life P_F (€) to be transformed into MWh with β at t=0);
5. The design lifetime of the Object t_F (in the absence of such datum, the amortization time established by law can be used);
6. The initial cost of the vital component of the object, i.e., the one essential for the functioning of the system P_{CR} (MWh).

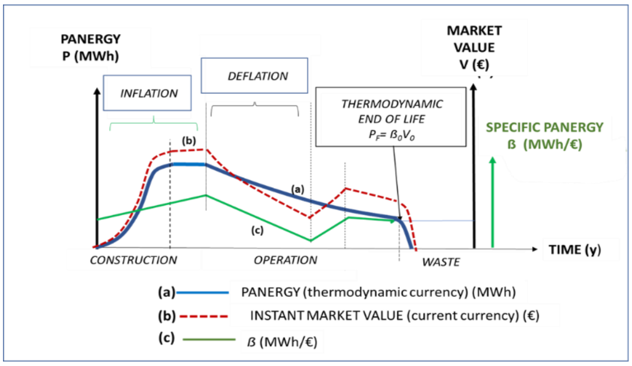


Figure 8. Panergy Analysis: Description of the life cycle in terms of Panergy

The end of operating life happens on the first occurrence of one of the following events:

A- Achievement of the financing period envisaged by the planning.

B- Routine maintenance cost that exceeds the residual market value.

C- Cost of the extraordinary maintenance necessary to replace the vital component is higher than the current value of the object.

D- Current value of the object which becomes lower than the costs of dismantling and disposal.

The most critical element to define is the trend $P_D(t)$ namely the natural degradation of the object. In absence of statistical data, one can assume Eq. (9) which is valid for all physical processes.

$$\frac{dP_D}{dt} = -kP_D \tag{9}$$

The trend of the Panergy of the object is expressed by Eq. (10)

$$P(t) = P_M(t) + P_D(t) \tag{10}$$

The degradation curve is uniquely determined with the system of Eqs. (10)-(14)

$$P_D(t) = P_1 e^{-k(t+t_2)} + P_3 \tag{11}$$

$$P(t_W) = P_0 \tag{12}$$

$$P_D(t_F) = 0 \tag{13}$$

$$P_D(0) = P_0 \tag{14}$$

Figure 10 shows, in an intuitive way, how any extraordinary maintenance interventions consequent to severe failures involving the interruption of operation, produce the extension of the system's life from t_F to t_R.

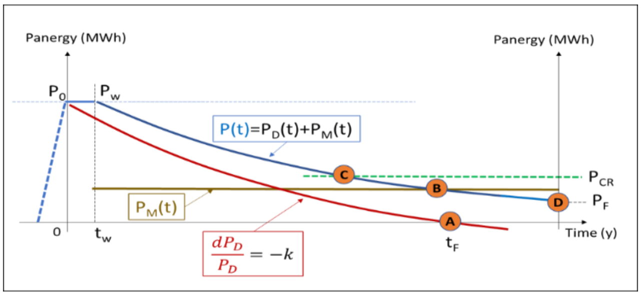


Figure 9. Life cycle analysis of an object

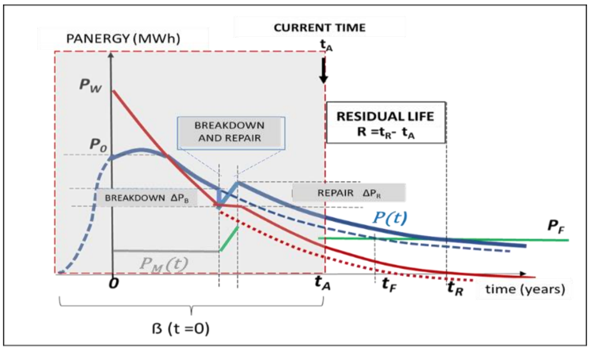


Figure 10. Determination of residual life with Panergy Analysis

3.1.2 Productive object (cash flow and cost/benefit assessment)

A productive object is one whose mission is to produce money (for example, a company that carries out any material or immaterial production process or, more simply, an energy production plant).

In the case of a trading company, it trades Panergy with the market (in), with partners (out) and with suppliers (out) which are each a Sub Object. The Company's cash flow, expressed in current currency (€), is convertible into Panergy (MWh) whose profitability is measured in units of energy. The company's turnover is, in essence, an exchange of energy. A measure of the company's effectiveness is the payback time.

In Panergy Analysis the index used is ERoEI (Energy Return on Energy Investment). The return time is the one in which ERoEI=1. If the problem is analyzed using the classic cash flow method, the index used is RoI (Return of Investment). The difference between the results of the two methods can be considerable because, due to the variability of β, they evolve at differently. In practice, EROEI provides predictable information while RoI provides unreliable results due to the unpredictable currency variability.

Figure 11 is an example of this situation. If the expected cash flow is constructed in terms of Panergy, reference must be made to a constant β_0 equal to the initial production value. The useful functions of time, expressed in thermodynamic currency, are based on the expenses incurred for the construction of the Object and of the maintenance contracts available at t=0. The invested capital in terms of Panergy decreases over time due to wear and degradation that routine maintenance cannot compensate for. Conversely, if one operates in monetary terms, the invested capital is revalued based on current interest rates (and possibly inflation) and then grows over time. The crossings that determine ERoEI=1 and RoI=1 occur at different times. A particular case is that of the economic management of an energy generation plant by a company that intends to buy it and wants to evaluate its profitability in advance. If the plant is complex, the value of the investment in energy to calculate the EROEI is almost impossible with the traditional Life Cycle Assessment while it is immediate with the Panergy Analysis: $P_0 = \beta_0 V_0$.

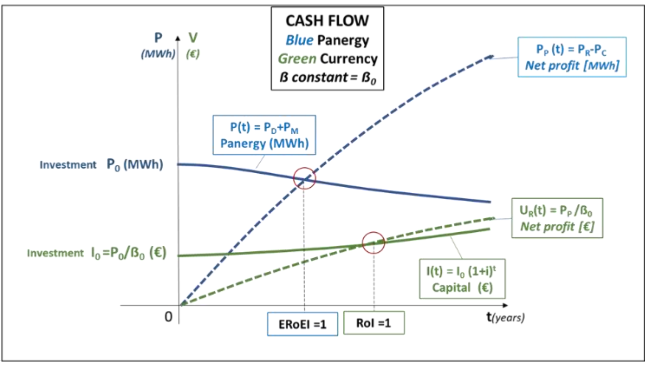


Figure 11. Trends in Panergy and monetary value in a cash flow

With reference to Figure 12, one observes that the investment P_0 and the yearly sale of energy W_u consist of incoming Panergy while the expenditure for purchasing the primary fuel W_i and the business management costs (losses of Panergy in the life cycle) P_D consist of Panergy Outgoing. The business profit at the end of life is $(W_u - W_i)t_F$ where W_u and W_i are saleable energy and are considered constant in life (MWh/y); their difference ($W_u - W_i$) represents the average production capacity of the plant W_N (MWh/y).

The value of ERoEI is given by Eq. (15)

$$ERoEI = \frac{(W_u - W_i)t_F}{P_F} \tag{15}$$

As it is a forecast, all quantities must be calculated with β at t=0 including the prices of fuels purchased, as required by the Panergy Analysis. If it is a final balance, all the values are transformed into Panergy at the time of exchange with the related β.

The payback time t_{PB} is determined by the value ERoEI=1, then by Eq. (15) where P_{PB} is the value of Panergy at $t = t_{PB}$. If t_{PB} is assumed $<< t_F$ as it should be for a profitable firm, one can assume P_{PB} approximately equal to P_0.

$$t_{PB} = \frac{P_{PB}}{W_u - W_i} \sim \frac{P_o}{W_N} \tag{16}$$

Eq. (16) in the approximate formulation is the so called simple ERoEI. The RoI calculation in monetary terms is more complicated and must consider *the interest rate* at which the capital is purchased and the inflation rate (not easy to predict). One way is Eq. (17). The wording is irrational and must be resolved numerically.

$$t_{PB} = \frac{V_0 (1+i)^{t_{PI}}}{(V_u - V_i)} \approx \frac{V_0}{V_N} \tag{17}$$

V_N is the average business capacity of the plant expressed in terms of money (€/y). Simple return time (simple RoI) does not consider any interest rate and no inflation to achieve the result. Simple RoI and simple ERoEI, in Panergy Analysis, coincide but are different when calculated in their complex form and ERoEI is Panergy return on Panergy investment, as shown in Figure 11. *The reason of the difference is Dark Panergy*.

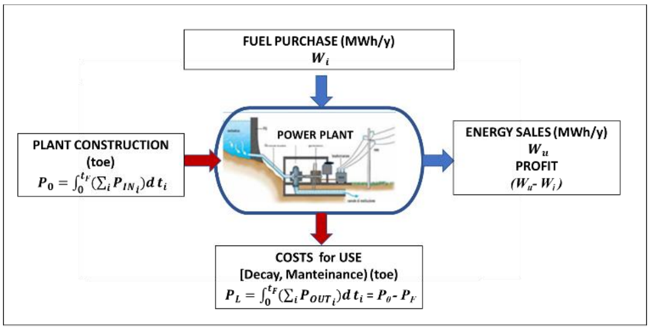


Figure 12. Panergy exchanges in a power plant

3.2 Energy technology assessment

3.2.1 Effectiveness of energy production systems

Panergy Analysis makes possible, quickly, and directly, to evaluate the effectiveness of an energy production device. Significant indexes are ERoEI in Panergy Analysis and RoI in Cost Benefit Analysis

ERoEI is calculated at the end of the productive life and therefore is a simple fraction. A system of production and sale of energy is even more efficient the more ERoEI is greater than one.

Eq. (18) is a more complete description of EroEI. W_{N0} is the gross annual profit for energy sold in thermodynamic currency, t_F the expected life in years and V_M the annual cost for maintenance in constant current currency. It allows to evaluate the Energy profitability.

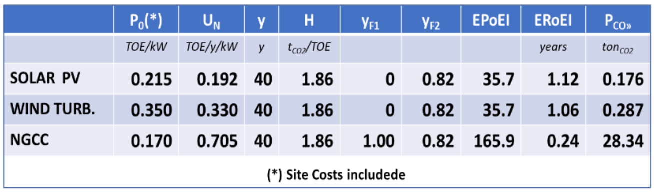
$$ERoEI = \frac{W_N t_F}{P_0} = \frac{(W_{N0} - \beta_0 V_M) t_F}{P_0} \tag{18}$$

Another sensitive factor to consider in the comparison is the environmental impact in terms of global warming which is calculated through Eq. (19).

$$P_{CO2} = H(\gamma_{F1} W_N t_F + \gamma_{F2} P_0) \quad [ton_{CO2}] \tag{19}$$

where, γ_{F1} is the fossil fraction of the fuel used for production, γ_{F2} is the fossil fraction inside the mix of primary sources consumed by the context that is, in first approximation, but will be better seen in Chapter 4, $(F+L)/(F+N+R+L+A)$; H is the conversion factor of energy to ton CO_2; W_N is the same as in Eq. (18), which can also be interpreted as the installed power.

Figure 13 analyzes, in a defined context (the one taken as an example does not differ much from that of Italy in the year 2020) the comparison between various production technologies for industrial sized plants (≈10 MWe).



	P_0(*)	U_N	y	H	γ_{F1}	γ_{F2}	EPoEI	ERoEI	$P_{CO»}$
	TOE/kW	*TOE/y/kW*	*y*	*t_{CO2}/TOE*				*years*	*ton_{CO2}*
SOLAR PV	**0.215**	**0.192**	**40**	**1.86**	**0**	**0.82**	**35.7**	**1.12**	**0.176**
WIND TURB.	**0.350**	**0.330**	**40**	**1.86**	**0**	**0.82**	**35.7**	**1.06**	**0.287**
NGCC	**0.170**	**0.705**	**40**	**1.86**	**1.00**	**0.82**	**165.9**	**0.24**	**28.34**

(*) Site Costs includede

Figure 13. Numerical example of comparisons between energy production technologies

One can deduce that, at least for the context of the example, from the point of view of the energy profit, Natural Gas Combined Cycle is extremely more effective of the renewable technologies examined. From an environmental point of view, however, the judgment is exactly the opposite.

3.2.2 Effectiveness of raw materials and fuels

Raw materials lying in the territory take on value, and therefore Panergy, after being extracted and transformed to be usable. Their transformation (search for deposits, extraction and processing plants, transport...) determines their commercial value and therefore the saleable Panergy.

When not yet extracted they have a potential value derived from Dark Panergy (in this case the cosmic energy to produce their growth). Once extracted, they acquire an initial value that decreases over time with use and degrade, as described in Section 3.1.2. Fuels, when in mine, possess an original Panergy content P_0 consisting of the calorific value, measurable in units of energy (MWh).

Fuels, on the contrary, possess Panergy when in mines; it is the calorific value. The cycle that brings the fuel from mine to end user involves a continuous descent of Panergy correlated to the price paid for the various processing steps attributed pro rata to the fuel reference unit. In the end, the content of Panergy P_U is significantly reduced and the unit price (€/MWh) increased accordingly. Figure 14 is illustrative of this process.

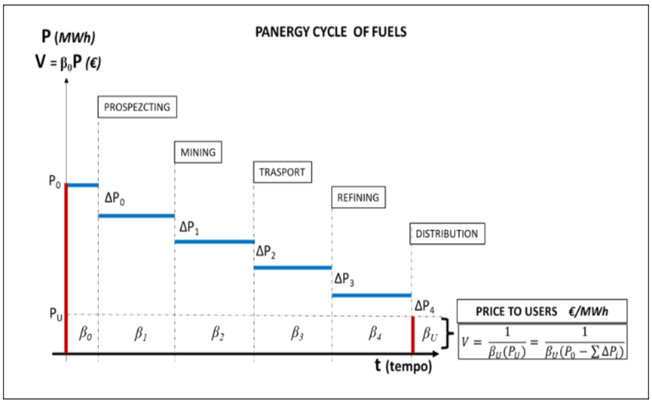


Figure 14. Panergy cycle of fuels

4. PANERGY ANALYSIS IN ENVIRONMENTAL AND SOCIAL SCIENCES

4.1 Environment and Quality of Life

Quality of Life is a very poorly defined feature, it can be associated with the average feeling of well-being perceived by a population and therefore it is very dependent on the predominant culture in the community of reference.

Each analysis, therefore, must be made considering the context and the interpretative model of the indicators. In most of the countries, the conditions taken are social situations, such as *housing, health, training, reconciliation of work and private life, and so on,* and environmental situations such as *environmental quality and safety*.

To improve these situations, the communities include in their budgets an item of expenditure referred as *welfare*; this expenditure is a part of the Gross Domestic Product (GDP), i.e., the denominator of Eq. (3) and Eq. (4). Without changing the primary energy engaged, if one increases the socio-environmental expenditure, β decreases and, with it, the Panergy of the system, i.e., one moves to quadrants I and IV of the diagrams in Figure 6.

This means that the improvement in well-being ($\Delta\beta<0$) comes at the expense of economic growth ($\Delta P>0$ as stated in chapter 2), someone is in favor of this perspective which is called "happy degrowth". However, almost all economic communities consider the growth of the economy as a positive category for the improvement of the Quality of Life. The choices in development policies, in this framework, generate conflicts between analysts. Panergy Analysis can simplify the problem; to see how, we circumscribe the field of the various socio-environmental categories by dealing only with the reduction of CO_2 emissions, to be balanced with the decrease in Pantropy $\Delta\beta$ required by growth. The simplest intervention is to replace fossil fuels with equivalent quantities of zero-emission sources while maintaining the same level of social spending. In the commonly taken approach, in dealing with these dynamics, the reference indicator is, generally, the primary energy intensity I_P which, with the notations of Eq. (3), is rewritten in Eq. (20); in this form it allows to discriminate between polluting technologies (noZE) and beneficial ones (ZE).

$$I_P = \frac{(F+L)_{noZE} + (N+R)_{ZE}}{GDP} \tag{20}$$

Reasoning in terms of Panergy we realize that I_P of Eq. (20) is an inadequate indicator as (N + R) is not completely ZE (Zero Emission) and, above all, neglects the contribution of Dark Panergy *A* which is predominant, and therefore essential, in designing an environmental strategy. A more appropriate methodology is to consider the indicator β instead of I_P. Eq. (20) can be transcribed, from an environmental point of view, in Eq. (21)

$$\boldsymbol{\beta} = \frac{(F + L)_{noZE} + (N + R)_{nearZE} + A_{ZE}}{GDP} \tag{21}$$

where, all quantities are expressed in thermodynamic currency. In Eq. (21) the term A_{ZE} considers that *A* is a source of essentially solar primary origin. Subscript *near ZE* means that zero combustion sources, if looked with Panergy Glasses, contain *noZE* constituents embodied during construction and maintenance.

4.2 Strategies for the ecological transition

If we apply the Panergy Analysis (β instead of I_P as key parameter), the consequent strategy to reduce emissions is the following:

1. Increase Community Panergy $\Delta P=\Delta(\beta \cdot GDP)$ with contemporary $\Delta\beta < 0$ (2nd Law of thermodynamics)-this can be obtained by:
2. Reduce *noZE* sources (F, L, A_{noZE});
3. Increase the A_{ZE} source to compensate for the reduction of *noZE* sources (F+L);
4. Do not increase non-combustible sources *near ZE* (N, R).

Translated into political terms, this means that a community (or the entire planet) should organize itself and its territory by decreasing the consumption of fossil fuels, compensating it with a more efficient use of the Dark Panergy *A*. Since *A* is essentially agriculture, breeding, reforestation and hydrology, the territory devoted to these activities should not be reduced.

(These indications are valid for geographic areas with dark Panergy contribution like the Italy’s one, if a territory is essentially desertic the conclusions are different).

Figure 15 is a transposition of the diagram of Figure 6 in terms of possible strategies for replacing combustion technologies with *ZE* technologies. Four Quadrants are individuated corresponding to the four combinations of the couples $\Delta\beta - \Delta A$, where ΔA is the amount of recourse to Dark Panergy.

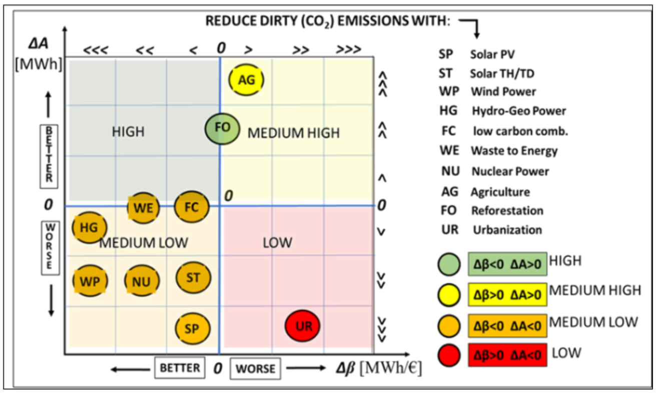


Figure 15. Hierarchy of technologies in ecological transition

The most striking result is the placement of Solar Photovoltaic (SP) at the bottom of Quad. IV. This is because the expansion of photovoltaic leads to the reduction of the of Dark Panergy productive area (ΔA<0). Another criticality is the position of the Urbanization interventions (UR) found in Quad.III due to the conflict with the use of the territory.

The reduction in the surface of the urban area promises its vertical development. This would also reduce pollution from urban traffic.

As one can see, the application of the Panergy Analysis to Ecological Transition carries to unorthodox strategies.

5. CONCLUSIONS

Panergy Analysis represents a powerful planning and decision-making tool in economy, in production processes, in the choice of technologies, in the prediction of the residual life of plants and artefacts and in collective environmental and social policies. The use of this methodology can be of considerable help to decision makers working on various topics.

The examples reported, in the various applications, confirm the reliability of the methodology also considering the innovations introduced in the development of the theory (Dark Panergy).

It is interesting to note that in some cases the methodology suggests results that contrast with those of current decision-making processes (Figure 16).

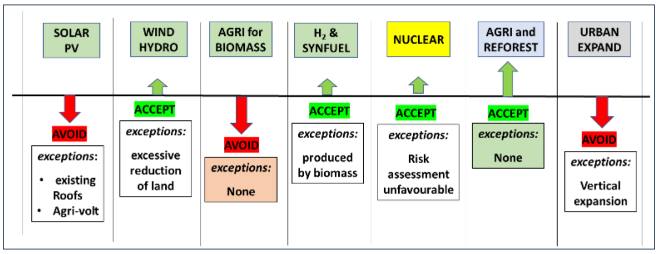


Figure 16. Indications on policy of replacement of fossil fuels consequent to Panergy Analysis

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NOMENCLATURE

A	Dark Panergy, MWh/y
C	Cost/Price of Energy, €/MWh
c	Specific heat J K^{-1}
E	Energy direct, MWh
F	Fossil primary supply, MWh/y
G	Wealth production, €/y
GDP	Gross Domestic Product, €/y
H	Conversion factor, MWh/ton$_{CO2}$
I	Energy Intensity, MWh/€
k	Decay constant, y^{-1}
L	Energy recovery, MWh/y
M	Manpower, €
N	Nuclear Supply, MWh/y
NDP	Net Domestic Product, €/y
P	Panergy, MWh
R	Renewable Primary Supply, MWh/y
S	Supplies, €
s	Entropy J K^{-1}
T	Absolute Temperature, K
t	Time, y
$TPES$	Total Primary Energy Supply, MWh/y
U	Internal Energy, J
V	Market price, €
W	Panergy Production, MWh/y

Greek symbols

β	Specific Panergy, MWh/€
γ	Fraction
Σ	Pantropy, MWh/€

Subscripts

0	Initial
i	Inlet
n	Generical item
p	primary
u	Outlet
CR	Critical item
F	Final
D	Decay, degradation
M	Maintenance
N	Average
PB	Pay back
noZE	Bad emissions
ZE	Zero emissions