# How close are Macro-Economics/ Macro-Thermodynamics? The Knowledge & Energy Pair Economies in the Net Zero Era

*The paper has two academics parts; the first addresses several common features that relate to the theoretical bases of the two disciplines, the second part is underlining the paradigm that the author proposed in 2022 (the knowledge-energy "KE" pair) that is present in all activities encountered in any enterprise. In part 1, the author elaborates on two new terms in Macro Economics; Income Potential Function "IPF", Labor Effort "LE", that were introduced in 2002 through his work with Dr. Professor Ibrahim Oweiss. Innovations represent a key factor in deriving the developments of both nation's economies and electrical power systems. Part I opens new areas for generalizations of theories in MacroEconomics based on established theoretical treatments in MacroThermodymamics. In parts I&II, many applications from Economics and Thermodynamics that exhibit similar trends are noted supporting the close relation of the first part of the Paper's title. The novel concept of the KE pair in part II could lead to a knowledge measurement scale. In part IV, with the ideas and thinking behind the contents of parts I&II, factoring his expertise in energy the author summarizes important considerations for economists dealing with nation's economies to meet the big challenges facing countries in the energy transition/decarbonization/Net Zero Era by 2030 and 2050. Relatively short times to transform the energy infrastructure that was built over more than a century (for most countries).*

**Keywords:** *Macro Economics/Thermodynamics commonalities, Innovations, Knowledge & Energy Optimization, Net Zero Era*



## Background/Introduction

In 1987 the author took an economics course as part of the MBA program he was following; he recognized some similarities between some aspects with some of what he knew from thermodynamics that he studied in his under-graduate and graduate courses in mechanical engineering. In 1988, he discussed these initial ideas with Professor Dr. Ibrahim Oweiss – Economics Professor at Georgetown University who saw merits in these initial ideas and they agreed to jointly investigate the subject. They started collaboration but because of the author's continuous travels for his job, the progress of the joint investigation was slow. In 2002 they published **Book** 1 which established analogies between terms Macro-Economic and Macro-Thermodynamics. In **Book** 1, the used thermodynamics practices to simulate some applications of economic theories. This approach did not gain much acceptance among economists as the thermodynamics was not easy to comprehend to without spending some time to grasp its fundamentals. The author was discouraged except for one positive rection to **Book** 1 that Dr. Oweiss and the author received from Nobel Economics Price recipient Dr. John Nash in 2005. Dr. Nash's comments were very complementary, but he warned us that it would not be easy to get this novel approach through the economics community. The author recognizes that perhaps because Dr. Nash was a mathematician, he could easily grasp the essence of what was included in **Book** 1.

The author put aside undertaking further research on the subject as he was quite busy working at a senior position at Consolidated Contractors Group Offshore – in Greece. When he retired in September 2020, he embarked on a second journey building on what was reached in **Book** 1. Unfortunately, Professor Oweiss was not available to collaborate on this second phase. The author decided to stay away from the equations of Thermodynamics in this second endeavor. He produced **Book** 2 published in 2022.

In this paper, some key information from **Book** 1 is summarized related to the first part of the title of this paper "How close is Macro-Economics / Macro-Thermodynamics?' – under Part I. Then building on the concepts introduced in **Book** 2, the fundamental pillars for all activities within an enterprise "the pair of the Knowledge & Energy" is discussed under Part II.

In parts I and II, the author attempted to simplify the thermodynamics information as much as he could to have the economics reader get over what could be initial comprehension difficulties. The reader can refer to the references for further details. Takeaways from Parts I & II are summarized in Part III.

In part IV, the author presents some ideas for economists dealing with or exposed to national economies planning as they tackle the challenges of the Net Zero Era, based on his long experiences in energy and factoring the concepts of Parts 1-III. Lastly, Part V contains some concluding remarks.



## Macro-Economics and Macro-Thermodynamics

⇒ Macro-Economics

In Macro-Economics generally one is dealing with results of the activities of the workforce in a country or a region – e.g. a state within a country or a group of countries. For example, a country with defined boundaries has a population and the working workforce of this population produces the products and services that make up the Gross Domestic Product (GDP) – as measured in money. Generally, beside the work force in the private industries, government agencies contribute to the GDP. Across the boundaries of the country there could be imports and/or exports. One may refer to the dynamics of what the overall workforce (in private and government agencies) produces and consumes. When it is services there is no material in the deliverables. The consumption includes that of the dependents. For products there is a combination of services and material. Note, in some services, there may be some material in the delivery of the services e.g. in a restaurant.

⇒ Macro-Thermodynamics

In Macro-Thermodynamics, the engineer or the thermodynamics analyst defines a system with hypothetical boundaries. Interior to the boundaries is referred to as a system and outside the boundaries are the surroundings. Macro-Thermodynamics is concerned with the energy and mass changes of the system.

- ❖ Enterprises Operation / The functioning of the enterprise

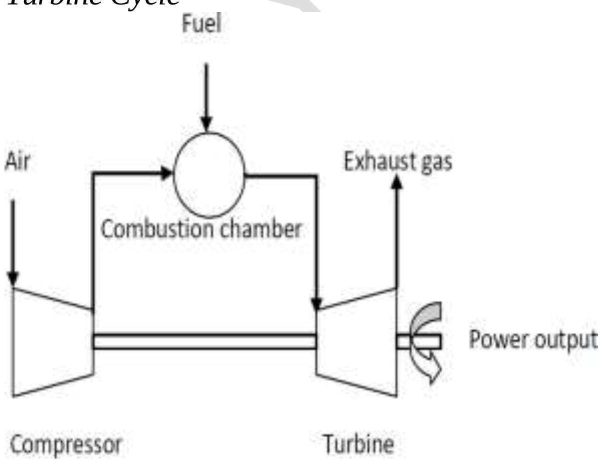
Enterprises form the foundations of the economy of a country. In an enterprise, through capital investment in a plant or a service center (equipment and facilities). These are installed and built prior to start of operations. In the productive (operational) phase, the workforce through variety of processes complete deliveries of products or services. Through the repetition of the sequence of the processes the production over a period (say annually) is measured. The workforce takes the central role. We also observe that the processes utilize inputs and those end up as useful deliverables products but also in the output there is rejection/waste. For the workforce, in recent years the human knowledge is the predominant contribution rather than the handwork in previous times. Further elaboration of this point is discussed in Part II.

⇒ Heat Engines -Thermodynamic Cycles / Power Plants

Based on two laws of Macro-Thermodynamics (please refer to later section below), thermodynamic cycles under different names such as Rankine, Brayton, Otto, Diesel. Ericson, others have been introduced by pioneers as early as in the 18th century (generally referred to Heat Engines). A cycle consists of sequence of processes that start from one thermodynamic state and ends at same state. In Thermodynamic terminology, a state of a medium is defined by two independent properties such as temperature, pressure, or specific volume (volume per unit mass/the reciprocal of density).

Figure 1 shows as an example a schematic of the Brayton Cycle that is the basis of the operation of gas turbines.

**Figure 1.** *Schematic of the Brayton Cycle – Basis for the Operation of the Gas Turbine Cycle*




⇒ <u>Closed System and Open System & Steady Flow Open System</u>

A closed system is defined as a system for which there is no mass transfer across its boundaries i.e. from within the system or from the surroundings.

An Open system is a system where there is mass flow across the boundaries.
A Steady Flow Open System is an open system that there is no accumulation of mass or energy within the system, further the conditions of the incoming and outgoing states are constant with time.

⇒ Fundamental Laws in. Macro-Thermodynamics

1st Law: mass and energy are conserved. For a system, between two sates i and ii, the net mass and net energy coming into and out of the system (in -out) is equal to the stored within the system.

2nd Law: for a heat engine operating in a cycle between two high and low temperatures where heat addition takes place at the high temperature, inherently there will be rejected heat at the low temperature. The essence of this law simply is "in a thermodynamic cycle there is always an efficiency in converting heat to work". Work being in a cycle is the difference between heat added minus heat rejected. An ideal cycle referred to as Carnot cycle, that has constant temperature heat addition and constant temperature heat rejection processes separated by two; constant entropy processes (isentropic processes). For thermal cycles with maximum temperature and minimum temperature but not at constant values for the heat addition and rejection that cycle will have a lower efficiency than the Carnot operating at the constant maximum and constant minimum temperature. A corollary result from the Carnot cycle, the higher the temperature of the heat addition the higher the thermal efficiency, and the lower temperature of the heat rejection the higher the thermal efficiency.

❖ ORIGIONS OF KNOWLEDGE & ENERGY

Knowledge originates from humans and energy originates from nature.

It is interesting to briefly highlight the working of the human body systems, with various body systems, e.g., circulatory, digestive, respiratory, and nervous systems with the brain prime role in dealing with knowledge storage and the control of the functioning of the various body parts plus the retention of information, please refer to **Book** 2 for further details.

❖ Premium Contents in products and services

Consumers have different appreciation (valuation) for the products and services, the appreciation reflects perceptions of the utility and the sophistication of the knowhow that went into the preparation of the product or service.

⇒ Categories of Energies

With reference to Table 1 below, energy transfers to use, are what we are after in Macro-Thermodynamics, heat is the energy associated with temperature difference. Mechanical energy generally referred to as work and in dynamics terms it is (integral F.dx), Force "F" over distance "x". This is the most desirable form of energy as it has versatile utilization, in simple form moving a weight over a distance, and in more handy way electricity that can be transmitted across long distances. As noted above to produce work according to the second law of Thermodynamics in a thermal cycle from a heat there will be inherently heat rejection, thus the work will be only a fraction of the added heat (efficiency). Please refer to discussions covering heating value and electrical output from fossil fuels and the CO2 emissions Table 2 in Part IV.

*Power Plants*

- Fossil and Nuclear Plants (based on Thermodynamic cycles)
- Renewable Energy
  - Hydro – (Transformation of Potential Energy to mechanical/ electrical energy).
  - Solar – (Transformation of Radiation Energy into electrical energy).
  - Wind (Transformation of kinetic energy to mechanical/electrical energy).
- Fuel Cells (Transformation of chemical energy to electrical energy).
- Electrical Energy Storage "EES"
  - Battery
  - Hydro pump storage
  - Compressed air storage

**Analogous Terms Macroeconomics & Macrothermodynamics**

**Table 1.** *Macro-Economics Terminology versus Macro-Thermodynamic Terms (**Book**1)*

| # | **Economics Term[E,1,3]** | **Corresponding Thermodynamics Term[2]** |
|---|---|---|
| 1 | Capabilities[E] [A] represent internal or latent attributes that a human being possesses, which enables this person to undertake an activity *or complete a part of an activity*[2]. It is a generalized of what we frequently refer to as "Knowledge [K]" | Energy "E" |
| 2 | Services[E] [SV] come about resulting from changes of Capabilities. /Knowledge Transfer. | Changes in Energy / Heat [Q] |
| 3 | Utility[E] [U] is the total satisfaction derived from the consumption of goods or Capabilities changes as could be manifested through services. | Work [W] |
| 4 | Capital[E] [***K***] consists of the durable | Same – Capital [***K***] required to set |

| | | |
|---|---|---|
| | produced goods that are in turn used in production. The major components of capital are Equipment, Structures/Facilities and Inventory. In accounting and finance, "capital" means the total amount of money deployed by the shareholders in the corporation (equity & debt). | up the power plant. |
| 5 | Convertibility$^E$ Services/Utility; money is the term that resembles the convertibility. | kCal /Joule for conversion between heat and work or vice versa |
| 6 | **Income Potential Function** $^E$ (IPF), while income is the flow of wages, interest payments, dividends, and other receipts to an individual or a nation during typically one year, the **Income$^E$ Potential Function** is a measure of usefulness. The higher the level of technology the higher the **IPF**. | Temperature "T" |
| 7 | Marginal Utility$^E$ [$M_u$] the additional utility arising from consumption of an additional unit of the commodity. | Pressure "P" |
| 8 | Quantity [N] is the repeat of a commodity. The specific quantity is number of units per person. | Volume "V"<br>Specific Volume "v" (volume per unit mass) |
| 9 | Labor is generally defined by the group of people of age of 16 and older who are either employed or unemployed. However, a more representative term that was introduced by the authors of **Book 1**, is **LABOR EFFORT$^E$** [LE] which depicts the effort exerted by humans.<br>Specific Labor effort is [le] Labor effort per person. | Entropy "S"<br>Specific entropy "s" (entropy per unit mass) |

*1) Superscript "E" designates an Economic term*
*2) Thermodynamics Term.*
*3) Bold terms were newly introduced by the authors of **Book 1**.*

From the Table 1 of the analogous economic and thermodynamic terms are listed below:

1) Capabilities [A] – Energy [E]
2) Capabilities Change / Services [△A/SV] –Energy Change / Heat [△E/Q] Services [ △A/SV]– Heat [△E /Q]
3) Utility [U]– Work [W]

4) Capital is really behind what is set to have production under economics or setting the power plant in thermodynamics. The Capital [$\boldsymbol{K}$] (measured in money) used in setting the production facility or the power plant.
5) Convertibility: Money / Kcal/Joule
6) Marginal Utility [MU]- Pressure [P]
7) **Income Potential Function** [IPF] – Temperature [T]
8) Quantity Number of commodities [N] – Volume [V] specific quantity is a commodity unit [le] – specific volume per unit mass [v].
9) **Labor Effort** [LE] – Entropy [S] specific labor effort per commodity [l] - specific entropy per unit mass [s]

It is noted that in thermodynamics the medium is generally the fluid that is in the system under consideration or used in the thermodynamic cycle. For economics the equivalent is an ensemble of commodities with the specific quantity being one unit of the commodities.

The two terms IPF and LE may be difficult at first for an economist, but they were reached after extensive debates between the author and Professor Dr. Oweiss.

To supplement the above definitions, the following key equations are noted:

Economics: $dSV = IPF\ dLE$ analogous to Thermodynamics
$dQ = T\ dS$ Eq. 1

Economics $dU = M_u\ dN$ analogous to Thermodynamics
$dW = P\ dV$ Eq. 2.

In **Book 1**, a **Capital Engine**[E] was introduced analogous to the heat engine. In **Book 1** borrowing on known well established practice in thermodynamics two charts were devised IPF-LE analogous to T-S, and $M_u$ – N analogous to P-V, respectively. For the idealized Capital Engine equivalent to the Carnot cycle (based on the second law of thermodynamics), led to equivalent conclusions:

>>>> The higher IPF the higher the efficiency in the convertibility of services– (knowledge level under which technology falls).

From Eq. 1. in the economics terms of Table 1, and introducing the term Ecapby (E- capability), one gets Eq.3 and Eq, 4 for the Ecapby1 and Ecapby2 , corresponding to the two IPF's; the higher IPF at 2 and a lower one 2'. In both cases the $IPF_{ref}$ corresponds to the IPF of the surroundings.

The added Ecapby is

Ecapby = $\triangle$LE . (IPF ). Eq. 3.

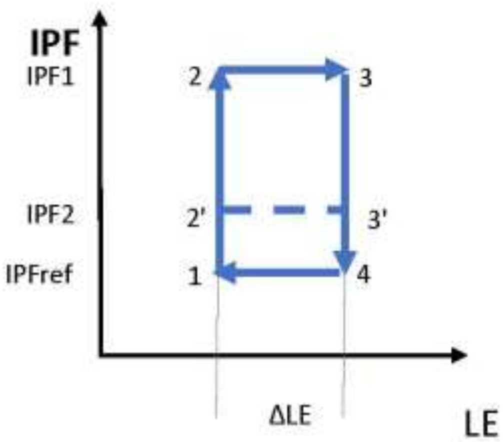
ECapby1 = $\triangle$LE . (IPF1 ). Eq. 4
ECapby2 = $\triangle$LE . (IPF2 )

The disposed (rejected) Ecapby is

$ECapby_{ref}$ = $\triangle$LE . ($IPF_{ref}$ ). Eq. 5

The term Ecapby (E-capability) is simply conveying that the economic system having a higher Income Potential function IPF1 that is higher than that of IPF2 (will yield larger utility compared to the system at a lower IPF2. IPFref is the lowest IPF that corresponds to the surroundings. A starting guess could be the IPF corresponding to the minimum wage, or somewhat lower value. Figure 2 depicts the above statements.

**Figure 2.** *Ecapaly for Two Cycles IPF1 Higher than IPF2 – The Two Cycles (1234) and (12'3'4) use the same IPFref*




Focusing on an economic system; we define humans in a certain location with a refence conditions outside the system that is the surroundings at that location the lowest Income Potential Function is $IPF_{ref}$. To bring this term closer to what we generally we see in different countries, that is what drives the minimum wage. The term Ecapby is showing the effect of the level of knowledge as represented by the higher IPF.

If one considers a workforce economic cycle (WFEC), the workforce is repeating sequence of processes "a cycle). The efficiency of the idealized WFEC "η" can be written as the ratio of:

$$\eta = (ECapby1 - Ecapby_{ref}) / ECapby1 \qquad \text{Eq. 6}$$

Substituting from Eq. 4 &5 we obtain:

$$\eta_1 = (IPF_1 - IPF_{ref})/IPF_{1.}$$

& Eq. 7

$$\eta_2 = (IPF_2 - IPF_{ref})/IPF_2$$

Please refer to further information under the demonstrative examples later.

**Parallelism of Products & Services Markets and Electricity Systems**

In **Books** 1 & 2, Professor Oweiss and the author argued that since bartering started the two persons that were exchanging say cotton versus wheat. The two were trading the value perceived by the two for the worthiness of the knowledge of planting the two crops, and the utility of the two items. This premise has dominated the trade ever since, the value of knowledge that goes in the making the product or the service provided is the major determinant of the traded item. We turn to examining markets and electric systems.

Figure 3 Shows the simplified presentation of markets of products and services.

Figure 4 depicts a simplified electrical system that evolved in recent years to include generation in some consumers, that was not the case before, as the electrical system was subdivided to three subsystems: generation, transmission, and distribution.

**Figure 3.** *Schematic of the Markets of Products and Services (Ref.3)*

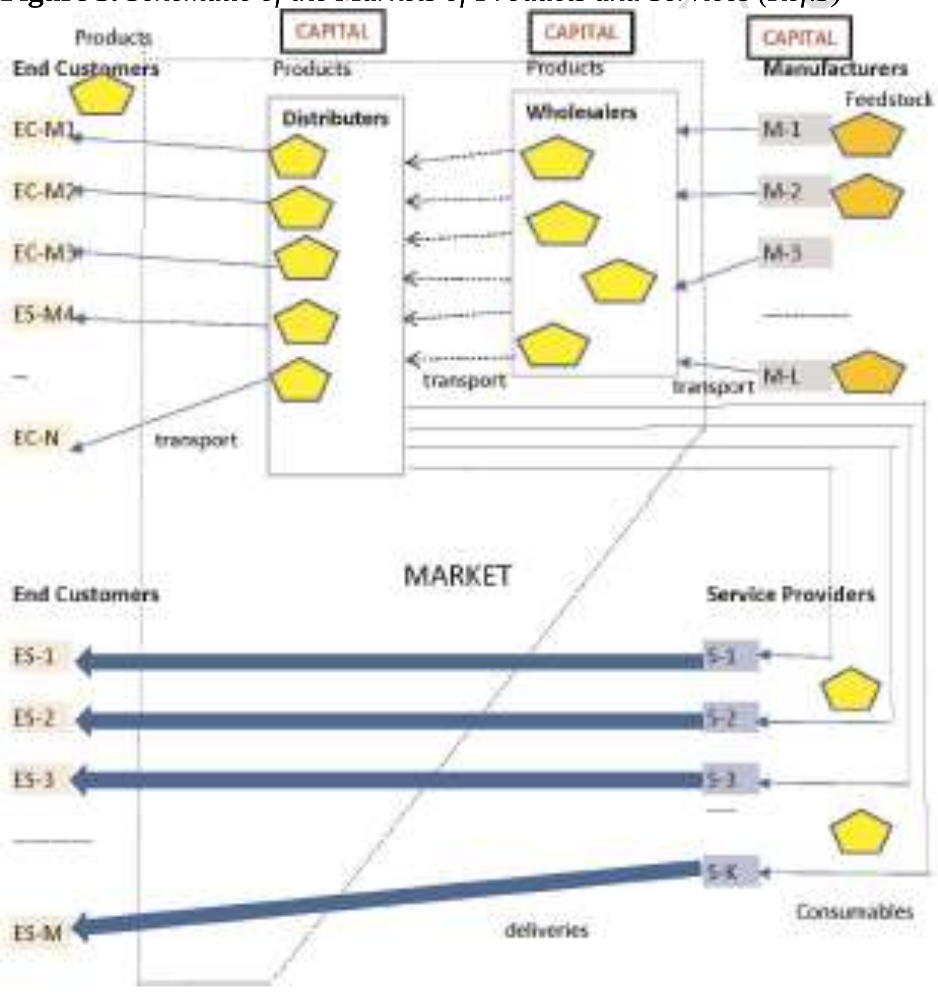
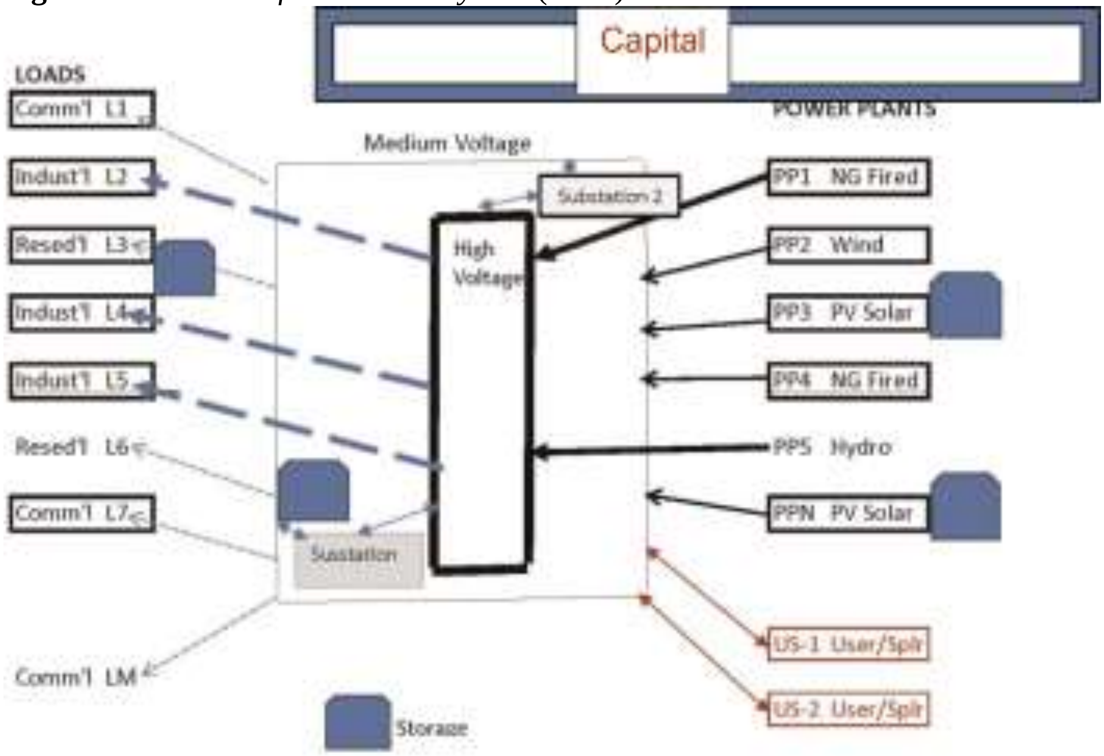


**Figure 4.** *Schematic of the Electric System* (Ref.3)




Note that in markets we deal with different commodities and products / services each could have its own market characteristics, while in the electrical system we primarily are dealing with electricity. Further, one notes the well-known fact that for countries GDP and electricity growth trends are quite similar.

In Ref. 3, a comparison of the characteristics of both the GDP changes and those of the electric system and the control of both can be found (inflation – interest rate and Voltage & Frequency, respectively. Ref. 2 and Ref.3 also discuss Money, Capital/Investments.

## Demand & Supply

Referring to the comparison of the products and services markets and the electrical system schematics in Figures 3 and 4 above, one sees the two are set to deal with supply commensurate with the demand – that is the underlining common structure for both.

## The Convergence of the Electricity Market to Commodity Markets

With privatization that started and grew from the late part of the last century, the vertical integrated electrical system was unbundled in many countries, and the generation and distribution were privatized in most countries while the transmission subsystem remained public. With privatization electricity markets were introduced and now we see merchant electricity markets in many countries, where the buyers of electricity make price bids for future electricity deliveries in a stock type market. Another trend found its way to the electricity when the users were enabled to generate renewable energy electricity, use it for their own and sell to others surplus through the grid. The old electrical system generation, transmission, and distribution had one direction, now has possibility for electricity to flow from nodes in the network, and the nodes could have both generation and consumption. Now one can see that the electrical system has a lot of similarities to the market of commodities.

## Demonstrative Examples

To demonstrate what messages could be obtained from the theoretical treatment discussed in part I, as an example we refer to Figure 2 and its related discussions, specifically Eq. 7. If one perceives for the workforce of a nation as an ensemble working between the low $IPF_{ref}$ and either the high $IPF_1$ or $IPF_2$, the efficiency of the workforce economic cycle (WFEC) would be $\eta_1$ and $\eta_2$, respectively. $\eta_1$ will be greater than $\eta_2$ As noted earlier, what is $IPF_{ref}$ ?, it corresponds to the lowest wage, let us say the minimum wages in the country. If one uses the simplified hypothetical Idealized WFEC. the author chose to use the term (workforce economic cycle) to differentiate it from the economic cycle generally used in economics when the economy goes between two successive of depressions with a recovery period in between. While an idealized WFEC is hypothetical, that cannot be realized it still gives indicators that can help in understanding causes and effects. For instance, the economy of nation with a high technological advanced work force (e.g., a developed country) could be corresponding to $IPF_1$ versus in a developing country with $IPF_2$ (if one keeps $IPF_{ref}$ the same).

Another situation that one can see from Eq. 7, is that if a country is considering the increase of the minimum wage, it should realize an advancement in the higher IPF to sustain a growth, represented by the WFEC's efficiency.

Further, a plausible cause of what we have been dealing with the phenomenon of inflation in a country, recognizing that the waste or the rejected Ecapby at the ref. continues to cause the $IPF_{ref}$ increase because of the limited size of the surrounding. The moves by central banks to curb inflation by slowing the economy, indirectly start to slow the increase in $IPF_{ref}$.

## The Knowledge & Energy Pair

Knowledge is a produced by humans an entail accumulation of observations and practices as well as human creativity in devising new ideas. Knowledge covers wide spectrum, it spans many life fields and industries etc. Under knowledge, comes education, training, information, data, technologies, knowhow, propitiatory information, patents. digital technologies have had a profound impact on many fields, advanced computing, communications, internet, artificial Intelligence, robotics, etc.

Innovation relates to knowledge, humans come up with ideas that improve or introduce new practices. Research and Development “R&D” in private entities and governmental agencies is vital for growing the economies as well the boosting the competitiveness of an enterprise.

Energy is not a substance, but it is starts from nature. Over the years, historically, man was able to find and harness different sources for energy; fossil fuels, nuclear energy renewable energy (solar and wind), etc. In the case of fossil fuels (coal, oil, and natural gas), when the energy contained in the fuel is released through chemical reaction of burning due to oxidation from the Oxygen of air, in the form of heat, the liberated heat can be used in variety of ways in many applications. In the case of nuclear fuel, heat is liberated due to atomic splitting of nuclear fuel mostly from Uranium. Through Macro-Thermodynamics, heat cycles were adopted to convert the heat to mechanical work and electricity. The mechanical work and electricity provided more versatile energy that can be utilized in many applications. That was behind the growth of the electric industry in the 20$^{th}$ century. Electricity use evolved through domestic (home), commercial and industrial sectors of the economy.

Historically, wind turbines, water wheels were built to replace animals in movements that is harnessing kinetic and potential energy. In the last two decades a significant trend to use renewable energy from solar and wind has swept the world to avoid and combat the Carbon dioxide emission associated with the massive use of fossil fuels in industrial and electricity generation.

Electricity is a form of energy beside being versatile, can be transferred in effective ways, that led to the evolution to the electric systems consisting of the generation, transmission (High Voltage), and distribution subsystems. The electric systems were interconnected and the power plants capacities under generation grew, and generation became centralized in relation to the areas being served by the electric system. The centralized power generation approach started to change towards a distributed direction in recent years.

*The Knowledge & Energy Pair*

When one examines all processes/tasks in an enterprise, always the two inputs are present; a knowledge component and an energy component, the weight of one could be bigger than the other. This paradigm was introduced in **Book** 2 and can be easily understood, for instance in the case of mining, if one realizes that material is only a conveyance means of whatever utility is desired, the material extraction and hence its use is only possible because of the knowledge and the energy expended in the extraction otherwise the material will be still in the ground. The value added by the labor is the result of the accumulation of the knowledge by the individual and applying that knowledge in the task he/she is engaged in. The energy utilized in the task could be the energy to run the computer (electricity) the individual is using in the performance of the task. Further, one can envisage the knowledge and the energy pairs in the engineering, manufacturing processes of equipment and the construction of facilities. Tasks in different fields e.g. accounting, health care etc. use processes that has the knowledge and energy together the KE pair.

In the process the energy could be heat (low category) or electricity (high category).

Improvements of for a product or a delivered service come about through **Innovations** meaning reduction of the input combination of the KE and or the reduction of the rejected waste of the KE combination. Mostly a quality enhancement in the knowledge leads to lowering of the energy input.

**Book** 2 has examples of initial applications for K&E in quantitively prepared estimates.

## Optimization of Inputs to Attain a Target Quantity of Useful Output

In **Book** 2, the author proposed a model for the knowledge & energy pair forming the basis of all activities in an enterprise, business economics as appearing in the title of the **Book 2**. The author further proposed in **Book** 2 representing knowledge in the same units of energy i.e., Joules. The premise behind this proposition is that for an enterprise, it is to aim at optimizing the inputs of both knowledge and knowledge to reach the desired output, to be eventually measured in currency.

In **Book** 2 for some examples, data for compensation of the labor and the prices of electricity in currency (from USA data) was used to calculate the Joules for knowledge (equivalent to energy). In the examples the energy was electricity, however the knowledge was from different categories (levels). **Book** 2 recommended investigating the levels of knowledge including the possibility of examining a comparable term to exergy (Thermodynamic Term which was not included in Table 1 to avoid some difficulties in explanation of this term at this point.

The term ECapby (appearing in Table 1) reflects the knowledge innovation. It is through multitude of factors the knowledge level of the individual (person) is boosted. The most important one is innovation.

While the theoretical ideas and proposed concepts shed insights that are useful as they are quite general and have wide applicability. However, for a practitioner they are not ready for use. In the author's opinion the search for the scale of the Income Potential Function that is equivalent to the Temperature scale in Thermodynamics is the key to raise the confidence of the treatise covered in part I to wide application.

Ref. 3 elaborated on the estimation of capital required for investments by addressing the processes of the project development phases starting from the initial feasibility study, project planning and implementation (EPC) – Engineering, Procurement and Construction leading to the commissioning of the plant or service center to start the operational phase, please refer to Ref. 3 for more details. During the operational phase one deals with direct and indirect processes and with sourced out activities. The sourced-out activities means that the sub-supplier or subcontractor is dealing with the pertinent processes still the KE pair is present in all the processes. Further as noted earlier the markets form the channel through which the products and services are delivered from producers to consumers. Still the processes in the transport involve the KE pair.

*Demonstrative Example*

If one refers to Ref. 5, according to Gobb & Douglas (1928) the "Theory of Production" commonly accepted in economics. Gobb & Douglas related production to two factors; Labor and Capital. They put forward this hypothesis almost a century ago. In today's conventions this amounts to a correlation rather than a theory. This does not take anything of Cobb & Douglas who made their contribution in 1928. They used a formula of the product of the two factors each with an exponent that they introduced and verified. But as economists realized the two factors may be oversimplifying the topic, they started adding factors, yet in most cases the related work amounted to correlations for limited application range. The author based on his extensive work in construction, can say that this approach is a top-down approach which in practice is used for a quick price estimate but with realization of the limitations of the data it is based on. The other approach is a bottom-up which is generally more time consuming, requires detailed data base but yields accurate estimate. Advancement of the quantification of the knowledge as suggested in Part. II and the proposition of the KEC model Ref.'s 2&3 provide an alternative "two factors <u>Knowledge</u> and <u>Energy</u>" that can produce dependable results that have true generalizations.

**Takeways from Parts I & Ii**

From Part I, many aspects that have common meaning or essence in both Macro-Economics and Maceo-Thermodynamics have been noted:

1. Table 1 shows analogies between the terminologies of MacroEconomics & MacroThermodynamics. It opens good opportunities under fresh thinking. The two new terms "Income Potential Function & Labor Effort" are two terms that can be quite useful in new endeavors in economic theories.
2. The realization of the thermal power generation plants is built on the theoretical MacroThermodynamics / heat engines. Whether this can have a parallel relation in MacroEconomics is worth exploration. The similarity aspects between markets and power systems that are included in Part I, is an example of possible studies based on this premise.
3. All applications in MacroThermodynamics are governed by the two laws that form cornerstones for all their theoretical bases. The author believes counterparts to these laws exist and establishing such laws will render a distinctive new advantage to MacroEconomic theories.
4. Innovations are key to improvements. Innovations lead to increasing the Income Potential function.

5. The demonstrative examples though hypothetical they indicate that there are merits behind the treatment used.

From Part II,

6. The importance of knowledge is underlined. The presence of knowledge and energy together the KE pair in all tasks and processes in enterprises represents a key fact that should be realized by businesses and more generally in MacroEconomics.
7. The notion of optimization of the inputs of knowledge and energy is a very useful tool in search of more competitive products and services.
8. The possibility of measuring knowledge in the units of energy warrants further investigation.
9. The level of knowledge is of utmost importance and hence for MacroEconomics policies it deserves the appropriate priority.
10. The simultaneous presence of knowledge and energy in all tasks, underlines the importance of attending to growing knowledge and energy resources in any nation to sustain desirable economic growth. The last two items form key drivers for a country in the transformation related to Energy Transition Net Zero Era discussed in section IV below. Before leaving this part, we must underline the impact of rejected knowledge & energy rejections /waste and the environmental effects associated with the economic activities, and the energy uses.

**Relevance for Econmies in the Net Zero Era**

Just a short simple note about a plausible explanation for the global warming in light of part I, the surrounding on the global scale is the environment of the earth, if the surrounding is unrestricted then it is unlimited – infinitely large, but if it is limited because of the buildup of the CO2 layer in the outsider strata above the earth, then we have a limited reservoir though large, when we burn enormous amounts of fossil fuel per day as we are doing the rejected heat builds up leading to the increased the temperature in the earth.

Another point that warrants noting is what are the CO2 emissions from fossil fuels. Please refer to Table 2 showing representative emissions CO2 from burning 1 kg from different fuels, and assuming a typical engine of power plant efficiency the electrical kWhe/kg and the CO2 per kWhe.

**Table 2.** *Showing representative emissions from different fossil fuels that have been used in transport and power generation*

| | | kWh/kg fuel[1] | BTU/lb fuel[1] | Kg CO2 /Kg fuel[1] | Thermal Eff. | kWhe/kg fuel | kgCO2/kWhe |
|---|---|---|---|---|---|---|---|
| Methane (natural gas) | EG Electrical Generation | 15.4 | 23,900.00 | 2.75 | 60% | 9.24 | 0.3 |
| Gasoline | Transport | 12.9 | 19,900.00 | 3.3 | 45% | 5.81 | 0.57 |
| Kerosene (Jet) | Aviation | 12 | 18,500.00 | 3 | 45% | 5.4 | 0.56 |
| Diesel | Transport | 12.7 | 19,605.00 | 3.15 | 50% | 6 | 0.5 |
| Heavy fuel oil (No.6/Bunker C) | EG Electrical Generation | 11.6 | 18,000.00 | 3.11 | 33% | 3.83 | 0.81 |
| Coal Bituminous | EG | 8.4 | 13,000.00 | 2.38 | 35% | 2.94 | 0.81 |
| Coal Lignite | EG | 3.9 | 6,000.00 | 1.1 | 35% | 1.365 | 0.81 |

*1 Ref.5.*

Please refer to Ref. 5 for the data foot noted in Table 2. The thermal efficiency are typical values that the author introduced. Note the earlier note in part I, about the premium level for the $kWh_e$ (Kilowatt-hour electrical) versus the kWh in the fuel as heat. Further please refer to Ref. 6 for trends of CO2 emissions of in the USA from various sectors, electrical generation, transport, industrial. The values in the last column gives the reason for the preference of Natural Gas.

Referring to the emissions in Table 2, one notes the following the emissions noted does not include emissions in the extraction and preparation of the fuel $\delta$ at the source, transport onshorew at the country of origin $\delta_{OO}$ and marine transport to country of use $\delta_M$ and lastly transport on-shore at the country of use $\delta_{OU}$. Referring to the discussions of manufacturing in part II, one notes that for products the energy that enters in the intermediate steps / outsourced is associated with emissions and the transports have also δs. More complexities particularly when there is a significant outsourcing in different countries for the product.

Since the Paris Accord in 2015 Ref. 7, a lot of activities have taken place to combat the global warming on an international scale. The IPCC has issued several reports documenting the warming up and the negative effects that have been observed in many parts of the world, refer to the latest report 2023 Ref. 8. The IPCC has advocated a scenario for the world to keep the temperature rise to 1.5 C. In 2017, The UN issued the sustainability principles Ref. 7, having 17 goals that are generally interrelated or interdependent. The 7th goal is "affordable and clean energy". Adopting appropriate sustainability program is now part of the culture of companies and governments.

Further, under the auspices of the UN several COP xx have been held. The latest were in COP26 -Glasgow UK (2021), COP27-Sharm ElSheikh Egypt (2022) and the most recent was in COP28-Dubai UAE (2023) Ref. 8. Refs. 7-8, reflect the wide concern of the global warming, and the emerging consensus among the almost 200 countries to accelerate steps to reduce Carbon Dioxide CO2 before it is too late. Ref.11 shows, initiative in the USA to support the Renewable Energy through tax incentive. Further, Ref. 12 shows a multibillion support announced in Oct. 2023 for major projects in the USA. Similarly, you find announcement from the European Commission supporting significant projects in Europe Ref.13. 2023 saw significant movements in the USA (Department of Energy "DOE" and Europe "European Commission "EU" in formulating guidance for energy transmission policies.

The world has a major challenge to curb Carbon Oxide "CO2" emissions. COP conferences over the years saw differences in the approaches between developed countries and developing & the less fortunate countries in Africa and islands. COVID 19 -2020 amplified the need for countries to cooperate on global crisis's, thus from 2021 there emerged a thrust towards shifting to Renewable Energy and avoiding fossil fuels. Countries started making national commitments to limit CO2 emissions. With the huge installed capacity of fossil power plants, worldwide and because of significant levels of CO2 emissions from coal, and oil-fired power plants, the consensus now is for all countries to retire the coal and oil-fired plants. Now there is still debate whether it will be possible to eliminate natural gas fueled power plants (emitting less CO2 per kWh of generated electricity, compared to coal and oil-fired plants). Initially there was a direction to eliminate fossil fuels completely the world began to realize that to achieve "eliminate totally" by years 2030 and 2050 may not be realizable. the approach was modified to keep using Natural Gas to a minimum and the targets of the Energy Transition was aligned to a Net Zero Era for 2030 and 2050. Realizing that from 2024 to 2030, we have only 6 years, and what is the overall objective of all countries of the world "is to change their energy supply infrastructures that took more than 100 years for many countries to a new drastically different form in relatively short time". This is a huge task. It is vital that the transformation takes place without negatively affecting the country's annual growth rates. This is what nations economists would help planners to maintain. This is quite demanding; the author is including his notes on various considerations based on his extensive experiences and his follow up of recent evolution of various issues / topics under the Net Zero Activities below. The list is not all inclusive/complete but is a good starting point. The user needs to engage or consult with specialists as he/she needs in-depth information. The reader will find in Table 2 a list of the main candidate strategies being followed in search of set of suitable strategies for the time-scenarios to be selected and adjusted as needed for the country.

**For a country, energy uses are primarily through the electrical systems (end users; residential. commercial and, industrial, trains), transport (onshore; vehicles, buses, trucks, aviation), and industrial plants that burn fossil fuels (heavy industries e.g. steel, cement, fertilizers, medium or light industries e.g. food industries). If one takes the electrical system, it generally took the country many years (could be more than hundred) to build and grow its infrastructure, now to cope with the targets of the Net Zero Era, the country has a much shorter time 2024-2030/2050 to substantially transform it, to different sets of operation regimes while adopting technologies that in many cases are still in early development and are not quite ready for large**

**scale commercial use. This is amid the usual constraints on fundings. Handling these tough challenges while keeping competitiveness requirements for enterprises and the nation put a lot of pressures. The stake holders include governments, regulators, communities, off-takers, private investors, financing institutions, equipment suppliers, contractors, labor, others. Planning the path forward in each country under this background requires in-depth consideration of many interrelated /interacting aspects. Economists that are interested or would be involved in assessments, to support country's action plans would be called upon to make estimations for various scenarios and evaluate sensitivities to inputs.**

*Strategies*

**Table 3.** *List of main candidate strategies for adoption in the Net Zero Era*

| # | Target Sector(s) | Strategy | Notes |
|---|---|---|---|
| A | All sectors | Energy Savings | Encourage this low hanging fruit. |
| EG.1 | Electrical Generation "E" | Retire immediately Coal & Oil Fired | Take action to stop using coal plants. Move to stop operation of oil fire plants. |
| EG.2 | Electrical Generation "E" | Convert if possible, to Natural Gas for finite time | Depending on the investment's costs convert Oil fired plants to natural gas. |
| EG.3 | Electrical Generation "E" | Use **Hydrogen** "**H2**"- &Natural Gas mix with aim to go to 100% Hydrogen | Encourage the development of Fuel mix Natural Gas & H2 firing capability in Gas Turbines. |
| EG.4 | Electrical Generation "E" | Expand Renewable Energy"RE" (Solar / Wind. Onshore & offshore / Hydro, other) | Encourage and facilitate; locating and licensing of RE plants. |
| EG.5 | Electrical Generation "E" | Adopt Electric Storage Systems "EES' | Encourage EES and support effort to reduce their costs. |
| EG.6 | Electrical Generation "E" | Use as much as possible curtailable power | Adjust PPAs to |
| EG.6 | Electrical Generation "E" | Encourage RE generation at Consumers | Like rooftop applications |
| EG.7 | Electrical Generation "E" | Deploy Nuclear Power Plants | Nuclear plants are not popular with the public for concerns about safety and long-term nuclear waste. |
| ET.1 | Electrical Grid | Reinforce and expand Grid | High priority to minimize curtailment and insure robust and high quality. |

| | | | |
|---|---|---|---|
| ET.2 | Electrical Grid | Modernize and introduce digitalization | Allow fine resolution monitoring |
| CC.1 | Electrical "E" - Natural Gas Fired | **Carbon Capture Storage** and Use | Reduce costs and identify cabdidate scavern for storage. |
| CC.2 | Heavy / Chemical Industries | **Carbon Capture Storag**e and Use | |
| CC.3 | for clusters | $CO_2$ Storage & Transport | Build $CO_2$ piping infrastructure |
| T.1.1 | Transport Onshore | Electrical Vehicles & Charging Stations | Discourage use of Diesel and petrol fuel vehicles , possibly put time limit . |
| T.1.2 | | **H2** Vehicles & filling stations. | |
| T.2 | Transport Marine | LNG early later **H2** | Discourage Diesel and fuel , possibly put time limits . |
| T.3 | Transport Aviation | Hydrogen Derivatives - SAF Sustainable Aviation Fuel | Discourage Jet fuel, possibly put time limit, |
| H.1 | *To provide fuel to; EG.3,T1.2 and T.2* | Green **Hydrogen** Production | Need to connect to RE for electrical input. Need to overcome intermittent RE. Large scale plants need to be proven. Equipment cost need to improve. Electrical specific consumption "ESC" per Kg of $H_2$ need to be reduced. An invention that reduces the ESC by 50% would be a great news. |

*Considerations*

1) Setting targets for frames 2030 and 2050. Because of complexities and uncertainties, the targets must be flexible yet doable and subject to new alignments.
2) Establishing policies to support plans to achieve the targets under 1 above.
3) Factoring international cooperation, including balancing imports versus security concerns.
4) Preparation of emergency plans for potential severe environmental occurrences.
5) Helping other courtiers particularly poor ones and those severely hurt/ affected from global warming.
6) Prompt and permanent shutdown of coal and oil in industrial and power plants, in the meantime include some flexibility for natural gas use in the short term to make up for the intermittent nature of solar and wind.

7) Energy conservation – this entails publicizing and introduction of incentives. This should encourage replacing old equipment and appliances by newer more efficient ones among all users including domestic users.
8) Encouragement of Electrical Storage Systems “ESS”. Required materials – e.g., Lithium.
9) Speedy adoption for Pricing of CO2 emissions.
10) Participation of Private/Private Public.
11) Appropriate public funding expenditures among competing directions, support to manufacturers of new technologies, financial support to developers/investors, support to infrastructures enhancements and new ones, tax incentives for the users to alleviate higher prices.
12) Monitoring of the execution of adopted programs.
13) Boosting Knowledge/Technology. This should encompass all aspects that advances the capabilities of the workforce.

Among the emerging thinking of locating new private plants that receive public funding/subsidies in regions of less fortunate populations, the boosting of the knowledge level is far demanding.

14) Incentives for Innovations. This is very important to secure in-country-created technologies and knowhow. This will also foster capacity building when acquiring imported technologies.
15) Training/particularly new disciplines/traits/skills. This is vital to enable the workforce with regards to 13-14 above.
16) Project financing with uncertainties of new technologies. For financial institutions to take risks for large projects with 20 -25 years performance of technologies that are relatively new, requires engaging dependable independent technical advisors.
17) Standardization of Offtake agreements. Term acceptable to Offtaker depending on its products market.
18) Permitting/environmental approvals for Renewable Plants (Renewable Solar/Wind). Recognizing that these plants require large areas there should be enough thrust to weigh the environmental negatives versus the positives of these plants. Onshore/Offshore.
19) Electrical Systems reconfiguration and adoption of Digitization to cope with the large RE fluctuations and or resolve congestions - Funding
20) Heavy Industries/Commercial Offtakers adoption of Carbon Capture (short medium term); reconfiguring existing plant for H2 – Costs.
21) Transport
    - Land – Penalize Diesel and Petrol vehicles to discourage continued (e.g. extra taxes on the fuel prices), removal of fuel subsidies or adding taxes must be over some time and in increments to avoid possible discontent among the public.
    - Support electric vehicles “EVs” in the short term and fuel cells and hydrogen engines in the midterm.
    - Charging stations for Electrical and filling stations for hydrogen.
    - Priorities for trucks, buses, cars depending on the local circumstances.

- Facilitating locating charging stations and H2 filling stations
- Offering tax credits for EVs and Green Hydrogen cars
- Marine – Replace Oil engines by LNG and natural gas in the short term.
- Aviation – CO2 emissions at airports & SAF Sustainable Aviation Fuel for Planes.

22) Hydrogen

Note that unlike fossil fuel Green Hydrogen starts from premium electrical energy which is used as input to the electrolyzers to produce an extra grade energy in H2 because it can be stored.

**Two factors come to play to reduce the price of Green Hydrogen, i) use low-cost Renewable Energy, ii) find a solution for covering the electrical energy required to run the eelectrolyzers at high load (base load operation) when the RE is not available or at low level.**

- Green Hydrogen Technologies (electrolyzers splitting water into Hydrogen & Oxygen) – Alkaline, PEM, proton exchange membrane (PEM), and solid oxide (SO) – the core of the electrolyzer plant is the stacks modules.
- Other equipment electrical and mechanical and control complete the plant, they add to the cost of the plant, and these also deserve improvements to reduce costs.
- Co-location/integration – (meaning locating together renewable park with electrolyzer plant close to the offtake location).
- Use of noble/scarce materials – cost.
- Supply chain concerns.
- Hydrogen Transport & Storage.
- Safety Concerns.
- Colored Hydrogen – in the short term.
- Hydrogen derivatives – e.g. SAF (Safe Aviation Fuel).
- Incentives/Tax credit for Green Hydrogen.

23) Carbon Capture Technologies (Storage/Use)
- Carbon Capture technologies (precombustion / post combustion – Open capture)
- Supply chain concerns
- Corridors and hubs for CO2
- Incentives / Tax credits for Carbon Capture.

24) Consider grants to assist manufacturers for Hydrogen and Carbon capture to innovate and reduce costs.

25) Dependence on importation of Natural Gas/LNG in the short term, RE in the medium term and long term and or Color Hydrogen, Green Hydrogen, and its derivatives in the long term. Balancing security, infrastructure e.g. ports and transport storage facilities versus the low importation price.

26) Dealing with the certificates of CO2 avoidance based on the imports under 25) above.

## Concluding Remarks

The paper contents underline the interdependence of the national economies to knowledge resources and the energy supplies. The technology role in the various sectors of the economy as well as the energy is vital, this underlines the importance of innovations.

For Accademia's professionals and researchers many topics for new research have been identified from the closeness of the Mactro-Economics/ Thermodynamics.

Dealing with knowledge measurement in Joules could open a wide area for research could lead significant results.

The author invites economists that would like to collaborate with him in further investigations on related to part I and/or II to get in touch with him.

Part IV is meant to summarize a list of considerations in dealing with the Energy Transition that entails fast changing and interdependent factors which require balancing risks and rewards among stake holders for long term commitments 20- 25 years. This is amid dealing with applying technologies that need significant funding for further development to gain reliable performance for the large-scale plants at desired price levels to meet 2030 and 2050 ambitious targets for Net Zero.

## References


1) **Edited Book 1**, Safwat, H.H and Oweiss, I.M, "Economics: New Horizons, Shifting the Paradigm", ISBN: 1-891231-71-5, published by Word Association, 2002.
2) **Edited Book 2**, Safwat, H.H., "Business Economics – Knowledge and Energy", ISBN: 978-1-63385-444-4, published by Word Association, 2022.
3) Paper Safwat, H.H., "BUSINESS ECONOMICS: KNOWLEDGE & ENERGY – CAPITAL KEC", "Business and Management Annual Volume 2023," 978-0-85014-523-6, visit the book page for details here: http://www.intechopen.com/books/business-and-management-annual-volume-2023.
4) *Cobb, C. W.; Douglas, P. H. (1928). "A Theory of Production" (PDF). American Economic Review. 18 (Supplement): 139–165. JSTOR 1811556. Retrieved 26 September 2016*
5) https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html
6) https://www.eia.gov/environment/emissions/carbon/index.php U.S. Energy-Related Carbon Dioxide Emissions, 2022
7) https://unfccc.int/most-requested/key-aspects-of-the-paris-agreement#:~:text=The%20Paris%20Agreement%27s%20central%20aim,further%20to%201.5%20degrees%20Celsius. United Nations Framework Convention on Climate Change, Paris, Dec. 2015, signed by 165 nations. The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.
8) https://www.un.org/sustainabledevelopment/development-agenda/ World leaders came together in 2015 and made a historic promise to secure the rights and well-

being of everyone on a healthy, thriving planet when they adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs).

9) https://www.ipcc.ch/report/sixth-assessment-report-cycle/ Intergovernmental Panel on Climate Change, AR6 Synthesis Report: Climate Change 2023.

10) COP28: Roadmap to Net Zero - COP28: Tackle Climate Change UAE, Dubai, Nov.-Dec. 2023.

11) https://www.epa.gov/green-power-markets/summary-inflation-reduction-act-provisions-related-renewable-energy The inflation Reduction Act of 2022.

12) https://www.modernpowersystems.com/news/news7-billion-dollars-for-usas-first-clean-hydrogen-hubs-11228215.7 billion dollars for USA's first clean hydrogen hubs

13) https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6047 Commission proposes 166 cross-border energy projects for EU support to help deliver the Green Deal, Nov. 28, 2023.Commission proposes 166 cross-border energy projects for EU support to help deliver