Moulay El Mehdi Falloul

Energy and environmental economics

Edilivre

Introduction

Energy economics is a broad scientific subject area which includes topics related to supply and use of energy in societies. Due to diversity of issues and methods applied and shared with a number of academic disciplines, energy economics does not present itself as a self-contained academic discipline, but it is an applied subdiscipline of economics. From the list of main topics of economics, some relate strongly to energy economics: econometrics, environmental economics, finance, industrial organization, microeconomics, macroeconomics, resource economics. Energy economics also draws heavily on results of energy engineering, geology, political sciences, ecology etc. Recent focus of energy economics includes the following issues: Climate change and climate policy risk analysis and security of supply sustainability, energy markets and electricity markets, demand response, energy and economic growth, economics of energy infrastructure environmental policy, Energy derivatives, forecasting energy demand.

Environmental Economics is a sub-field of economics that is concerned with environmental issues. Quoting from the National Bureau of Economic Research Environmental Economics program. According to the National Bureau of Economic Research: ”Environmental Economics undertakes theoretical or empirical studies of the economic effects of national or local environmental policies around the world”. Particular issues include the costs and benefits of alternative environmental policies to deal with air pollution, water quality, toxic substances, solid waste, and global warming.

This text provides an overview and a clear introduction to the fields of energy and environmental economics. The volume's audience is broad-gauged, academics and students seeking foundations for learning and research, and practitioners seeking guidance for informing their critical decisions in energy and environmental economics. Both newcomers to study of the field and those with a deeper knowledge base will find the material informative and stimulating.

In order to establish boundaries and facilitate learning, I have divided this book into two parts: the first part deal with energy economics and the second part deal with environmental economics.

Part I

Energy Economics

Chapter 1
Introduction to Energy Economics and its related fields

1. Introduction

Energy economics or more precisely the economics of energy is a branch of applied economics where economic principles and tools are applied to "ask the right questions", and to analyse them logically and systematically to develop a well-informed understanding of the issues.

The energy sector is complex because of a number of factors:

- The constituent industries tend to be highly technical in nature, requiring some understanding of the underlying processes and techniques for a good grasp o the economic issues.
- Each industry of the sector has its own specific features which require special attention.
- Energy being an ingredient for any economic activity, its availability or lack of it affects the society and consequently, there are greater societal concerns and influences affecting the sector.
- The sector is influenced by interactions at different levels (international, regional, national and even local), most of which go beyond the subject of one discipline.

Consequently, analyses of energy problems have attracted inter-disciplinary interests and researchers from various fields have left their impressions on these studies. The influence of engineering, operations research and other decision support systems in the field of energy economics has been profound.

Energy issues have been analysed from an economic perspective for more than a century now. But energy economics did not develop as a specialised branch until the first oil shock in the 1970s. The dramatic increase in oil prices in the 1973–1974 highlighted the importance of energy in economic development of countries. Since then, researchers, academics and even policymakers have taken a keen interest in energy studies and today energy economics has emerged as a recognised branch on its own.

Like any branch of economics, energy economics is concerned with the basic economic issue of allocating scarce resources in the economy. Thus the microeconomic concerns of energy supply and demand and the macro-economic concerns of investment, financing and economic linkages with the rest of the economy form an essential part of the subject. However, the issues facing the energy industry change, bringing new issues to the fore. For example, in the 1970s, the focus was on understanding the energy industry (especially the oil industry), energy substitution and to some extent on renewable energies. Moreover, there was some focus on integrated planning for energy systems with a major emphasis on developing countries.

The scope of the work expanded in the 1980s. Environmental concerns of energy use and economic development became a major concern and the environmental dimension dominated the policy debate. This brought a major shift in the focus of energy studies as well-the issue of local, regional and global environmental effects of energy use became an integral part of the analysis.

In the 1990s, liberalisation of energy markets and restructuring swept through the entire world although climate change and other global and local environmental issues also continued. These changes brought new issues and challenges to the limelight and by the end of the decade, it became evident that unless the fundamental design is not well thought through, reforms cannot succeed.

In recent years, the focus has shifted to high oil prices, energy scarcity and the debate over state intervention as opposed to market-led energy supply. This swing of the pendulum in the policy debate is attributed to the concerns about security of supply in a carbon-constrained world.

Accordingly, the objective of this book is to present in a single volume basic economic tools and concepts that can be used to understand and analyse the issues facing the energy sector. The aim is to provide an overall understanding of the energy sector and to equip readers with the analytical tools that can be used to understand demand, supply, investments, energy-economy interactions and relate policy aspects.

2. Energy and Multidimensional Interactions

The multidimensional nature of the energy-related interactions is indicated in Figure 1. At the global level, three influences can be easily identified:

(a) Energy trade-All transactions involving energy commodities (especially that of oil and to a lesser extent that of coal and gas) are due to the differences in the natural endowments of energy resources across countries and the gaps in domestic supply and demands; similarly flow of technologies, human resources, financial and other resources as well as pollutants generated from energy and other material use can also be considered at this level.

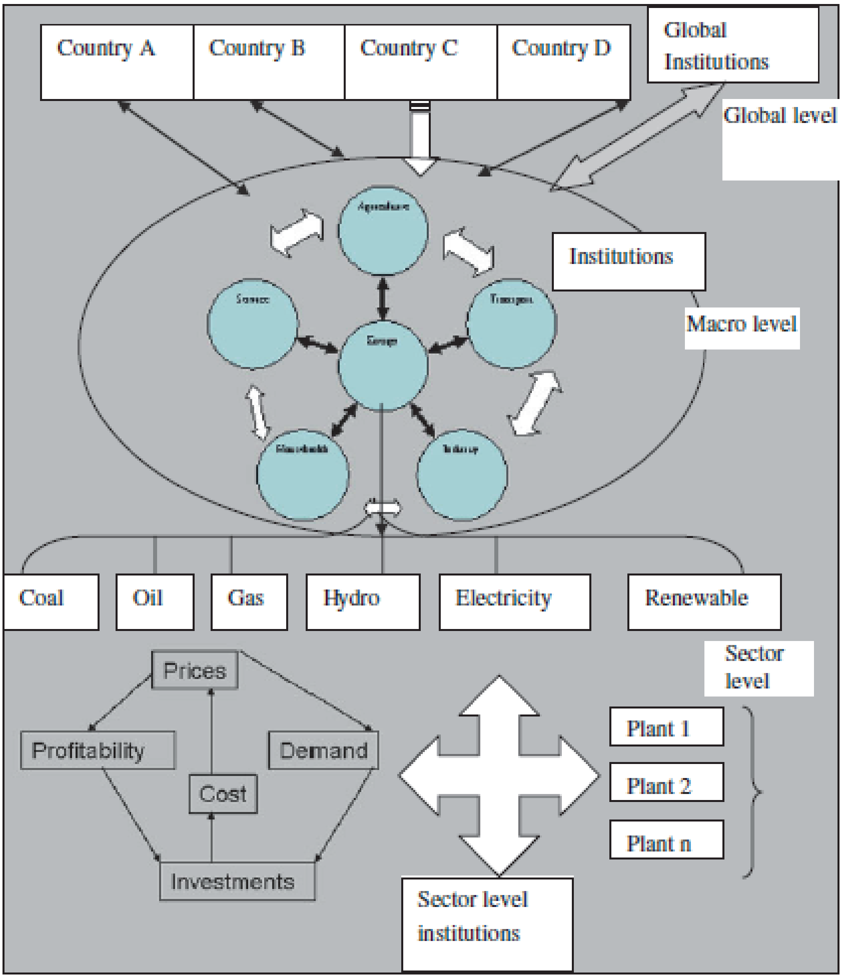
(b) International institutional influences-Various influences through international institutions affect interactions among countries and govern transactions. These include the legal frameworks, treaties and conventions, international organisations such as the United Nations (UN), the World Bank and the International Monetary Fund (IMF), the judicial system and the like.

(c) Other interaction-Other interactions among countries (co-operation, competition and conflicts) involving their governments or other entities (such as the firms) also influence the energy sector.

These influences are neither mutually exclusive nor static in nature. Consequently, the relative importance of one or more of these influences on a particular country would vary and changes in the importance of one or the other over time could modify the relationships extensively.

The key role of the energy sector in the economic activities of any economy arises because of the mutual interdependence between economic activities and energy. For example, the energy sector uses inputs from various other sectors (industry, transport, households, etc.) and is also a key input for most of the sectors. These interrelations influence the demand for energy, possibilities of substitution within the energy and with other resources (capital, land, labour and material), supply of energy and other goods and services, investment decisions, and the macro-economic variables of a country (economic output, balance of payment situations, foreign trade, inflation, interest rate, etc.). Once again, the national level institutions (including the rules and organisations like government, judiciary, etc.) both influence and get influenced by these interactions.

Figure1 Multidimensional interaction of the energy sector



Thus the macro-level influences arise broadly from:

(a) The level of economic activities and its evolution over time;
(b) Interdependence of energy and other economic activities as well as interactions among economic activities;
(c) The structure of each activity and its evolution over time;
(d) The technical composition and characteristics of the economic activities and its evolution over time;
(e) The institutional arrangement that provides the enabling environment for different activities to flourish and its evolution;
(f) Macro-management of the economy and its interaction with the institutional arrangement.

Finally, the energy sector itself is composed of different industries (or subsectors), each of which has different technical and economic characteristics. They are also interdependent to some extent and each industry attempts to achieve a balanced operation considering demand, investment, prices, supply and the institutional environment. The operating decisions are highly influenced by the objectives and goals of the operators and the operating constraints faced by them (including the resource related and socio-political constraints). The ownership pattern as well as institutional factors also influences the decisions.

Thus the sector faces both micro-level operating issues which are short-term in nature as well as those involving the medium and long-term future. Because of specific characteristics of the energy sector such as reliance on non-renewable energies, capital intensiveness of investments, discrete plant sizes, long gestation period, scale economies, tradability of certain goods leading to high revenue generation potential compared to other economic activities, and the boom-bust cycle phenomenon, the decisions need to be taken well in advance for the future and the present greatly shapes the future outcomes, although with a greater level of uncertainty. While the above outline of interaction is generic, the specifics vary depending on the circumstances (e.g. resource rich or resource poor country), economic conditions (developed or developing country), time dimension, and the like.

Various chapters of this book focus on the above aspects. The book is organized into six parts each covering a specific theme.

(1) Part 1 presents the topics related to energy demand analysis and forecasting.

This part covers energy statistics, concepts about energy demand and presents simple methods for demand forecasting. It also covers the ideas related to demand-side management.

(2) Part 2 is devoted to the economics of energy supply. It starts with the concepts of economic evaluation of projects and uses this framework to understand the economics of fossil fuel, renewable energy and electricity supply.

(3) Part 3 is concerned with energy markets. An introductory chapter provides the basic ideas of markets and extends this to include the specific features of the energy sector. This is followed by an analysis of energy pricing, taxation and subsidies. Subsequent chapters present the specific aspects of oil, gas and coal markets. Finally, a chapter is devoted to an integrated analysis of energy systems.

(4) Part 4 deals with important issues and challenges facing the energy industries. Although the issues vary from one country to another, this section picks up a few common issues such as energy security, effects of high oil prices on the economy, energy investments and energy access that are widely analysed and discussed in the current policy debate. (5) Part 5 introduces the concepts of environmental economics as applied to the energy sector. It covers the mitigation options for pollution from stationary and mobile sources, and introduces the issues of climate change from an economic perspective. It also touches on the Clean Development Mechanism. (6) Finally, Part 6 considers the regulatory and governance issues related to the energy sector. The regulatory options commonly used in the network industries and the approaches to reform and restructuring of the sector are presented in this part.

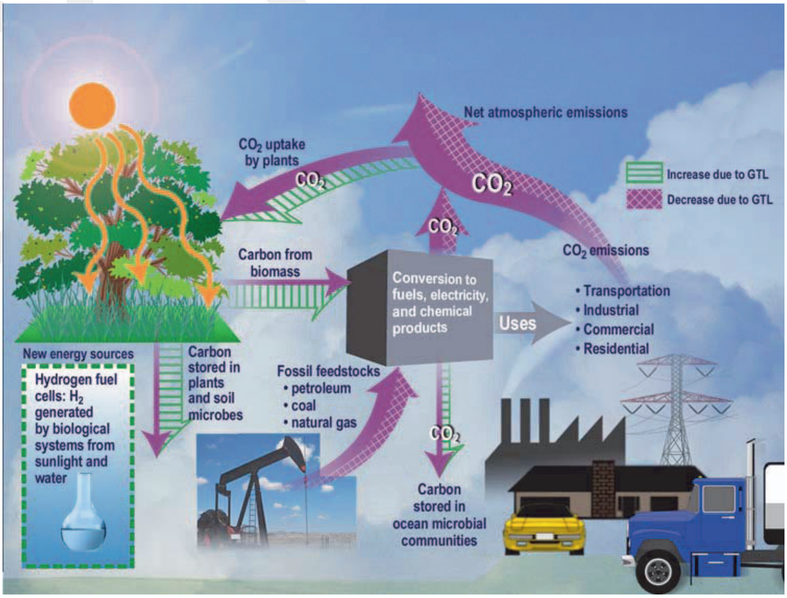
3. Energetics

Energetics is the scientific study of energy under transformation. Because energy flows at all scales, from the quantum level to the biosphere and cosmos, energetics is a very broad discipline, encompassing for example thermodynamics, chemistry, biological energetics, biochemistry and ecological energetics. Where each branch of energetics begins and ends is a topic of constant debate. For example, Lehninger (1973, p. 21) contended that when the science of thermodynamics deals with energy exchanges of all types, it can be called energetics.

Aims

In general, energetics is concerned with seeking principles that accurately describe the useful and non-useful tendencies of energy flows and storages under transformation. "Principles" are understood here as phenomena which behave like historical invariants under multiple observations. When some critical number of people have observed such invariance, such a principle is usually then given the status of a "fundamental law" of science. Like in all science, whether or not a theorem or principle is considered a fundamental law appears to depend on how many people agree to such a proposition. The ultimate aim of energetics therefore is the description of fundamental laws. Philosophers of science have held that the fundamental laws of thermodynamics can be treated as the laws of energetics. Through the clarification of these laws energetics aims to produce reliable predictions about energy flow and storage transformations at any scale; nano to macro.

3.1 Principles of energetics



As a general statement of energy flows under transformation, the principles of energetics include the first four laws of thermodynamics which seek a rigorous description. However the precise place of the laws of thermodynamics within the principles of energetics is a topic currently under debate. If the ecologist Howard T. Odum was right, then the principles of energetics take into consideration a hierarchical ordering of energy forms, which aims to account for the concept of energy quality, and the evolution of the universe. Odum proposed 3 further energetic principles and one corollary that take energy hierarchy into account. The first four principles of energetics are related to the same numbered laws of thermodynamics, and are expanded upon in that article. The final four principles are taken from the ecological energetics of H.T. Odum.

- ***Zeroth principle of energetics***

If two thermodynamic systems A and B are in thermal equilibrium, and B and C are also in thermal equilibrium, then A and C are in thermal equilibrium.

- ***First principle of energetics***

The increase in the internal energy of a system is equal to the amount of energy added to the system by heating, minus the amount lost in the form of work done by the system on its surroundings.

- ***Second principle of energetics***

The total entropy of any isolated thermodynamic system tends to increase over time, approaching a maximum value.

- ***Third principle of energetics***

As a system approaches absolute zero of temperature all processes cease and the entropy of the system approaches a minimum value or zero for the case of a perfect crystalline substance.

- ***Fourth principle of energetics***

There seem to be two opinions on the fourth principle of energetics:

- The Onsager reciprocal relations are sometimes called the fourth law of thermodynamics. As the fourth law of thermodynamics Onsager reciprocal relations would constitute the fourth principle of energetics.

• In the field of ecological energetics H.T. Odum considered maximum power, the fourth principle of energetics. Odum also proposed the Maximum empower principle as a corollary of the maximum power principle, and considered it to describe the propensities of evolutionary self-organization.

• ***Fifth principle of energetics***

The energy quality factor increases hierarchically. From studies of ecological food chains, Odum proposed that energy transformations form a hierarchical series measured by Transformity increase. Flows of energy develop hierarchical webs in which inflowing energies interact and are transformed by work processes into energy forms of higher quality that feedback amplifier actions, helping to maximise the power of the system".

• ***Sixth principle of energetics***

Material cycles have hierarchical patterns measured by the emergy/mass ratio that determines its zone and pulse frequency in the energy hierarchy. (Odum 2000, p. 246). M.T. Brown and V. Buranakarn write, "Generally, emergy per mass is a good indicator of recycle-ability, where materials with high emergy per mass are more recyclable".

4. ERŒI & Thermo economics

4.1 ERŒI

In physics, energy economics and ecological energetics, **ERŒI** (energy returned on energy invested), **ERœi**, or **EROI** (energy return on investment), is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource. When the ERŒI of a resource is equal to or lower than 1, that energy source becomes an "energy sink", and can no longer be used as a primary source of energy.

$$EROEI = \frac{\text{Usable Acquired Energy}}{\text{Energy Expended}}$$

Non-manmade energy inputs

The natural or original sources of energy are not usually included in the calculation of energy invested, only the human-applied sources. For example in the case of biofuels the solar insolation driving photosynthesis is not included, and the energy used in the stellar synthesis of fissile elements is not included for nuclear fission. The energy returned includes usable energy and not wastes such as heat.

Relationship to net energy gain

ERŒI and *Net energy (gain)* measure the same quality of an energy source or sink in numerically different ways. Net energy describes the amounts, while ERŒI measures the ratio or efficiency of the process. They are related simply by

$$(\mathrm{NetEnergy} + \mathrm{EnergyExpended}) \div \mathrm{EnergyExpended} = EROEI$$

Or

$$(\mathrm{NetEnergy} \div \mathrm{EnergyExpended}) + 1 = EROEI$$

For example given a process with an ERŒI of 5, expending 1 unit of energy yields a net energy gain of 4 units. The break-even point happens with an ERŒI of 1 or a net energy gain of 0.

The economic influence of ERŒI

High per-capita energy use has been considered desirable as it is associated with a high standard of living based on energy-intensive machines. A society will generally exploit the highest available ERŒI energy sources first, as these provide the most energy for the least effort. With non-renewable sources, progressively lower ERŒI sources are then used as the higher-quality ones are exhausted.

For example, when oil was originally discovered, it took on average one barrel of oil to find, extract, and process about 100 barrels of oil. That ratio has declined steadily over the last century to about three barrels gained for one barrel used up in the U.S. (and about ten for one in Saudi Arabia). Currently (2006) the ERŒI of wind energy in North America and Europe is about 20: 1 which has driven its adoption.

Although many qualities of an energy source matter (for example oil is energy-dense and transportable, while wind is variable), when the ERŒI of the main sources of energy for an economy fall energy becomes more difficult to obtain and its value rises relative to other resources and goods. Therefore the ERŒI gains importance when comparing energy alternatives. Since expenditure of energy to obtain energy requires productive effort, as the ERŒI falls an increasing proportion of the economy has to be devoted to obtaining the same amount of net energy.

Since the discovery of fire, humans have increasingly used exogenous sources of energy to multiply human muscle-power and improve living standards. Some historians have attributed our improved quality of life since then largely to more easily exploited (i.e. higher ERŒI) energy sources, which is related to the concept of energy slaves. Thomas Homer-Dixon demonstrates that a falling ERŒI in the Later Roman Empire was one of the reasons for the collapse of the Western Empire in the fifth century CE. In "The Upside of Down" he suggests that ERŒI analysis provides a basis for the analysis of the rise and fall of civilisations. Looking at the maximum extent of the Roman Empire, (6 million) and its technological base the agrarian base of Rome was about 1: 12 per hectare for wheat and 1: 27 for alfalfa (giving a 1: 2.7 production for oxen). One can then use this to calculate the population of the Roman Empire required at its height, on the basis of about 2,500-3,000 calories per day per person. It comes out roughly equal to the area of food production at its height. But ecological damage (deforestation, soil fertility loss particularly in southern Spain, southern Italy, Sicily and especially north Africa) saw a collapse in the system beginning in the 2nd century, as ERŒI began to fall. It bottome in 1084 when Rome's population, which had peaked under Trajan at 1.5 million, was only 15,000. Evidence also fits the cycle of Mayan and Cambodian collapse too. Joseph Tainter suggests that diminishing returns of the ERŒI is a chief cause of the collapse of complex societies. Falling ERŒI due to depletion of non-renewable resources also poses a difficult challenge for industrial economies.

4.2 Criticism of ERŒI

Measuring the ERŒI of a single physical process is unambiguous, but there is no agreed standard on which activities should be included in measuring the ERŒI of an economic process. In addition, the form of energy of the input can be completely different from the output. For example, energy in the form of coal could be used in the production of ethanol. This might have an ERŒI of less than one, but could still be desirable due to the benefits of liquid fuels.

How deep should the probing in the supply chain of the tools being used to generate energy go? For example, if steel is being used to drill for oil or construct a nuclear power plant, should the energy input of the steel be taken into account, should the energy input into building the factory being used to construct the steel be taken into account and amortized? Should the energy input of the roads which are used to ferry the goods be taken into account? What about the energy used to cook the steelworker's breakfasts?

These are complex questions evading simple answers. A full accounting would require considerations of opportunity costs and comparing total energy expenditures in the presence and absence of this economic activity.

However, when comparing two energy sources a standard practice for the supply chain energy input can be adopted. For example, consider the steel, but don't consider the energy invested in factories deeper than the first level in the supply chain.

Energy return on energy invested does not take into account the factor of time. Energy invested in creating a solar panel may have consumed energy from a high power source like coal, but the return happens very slowly, i.e. over many years. If energy is increasing in relative value this should favour delayed returns. Some believe this means the ERŒI measure should be refined further.

Conventional economic analysis has no formal accounting rules for the consideration of waste products that are created in the production of the ultimate output. For example, differing economic and energy values placed on the waste products generated in the production of ethanol makes the calculation of this fuel's true ERŒI extremely difficult. ERŒI is only one consideration and may not be the most important one in energy policy. Energy independence (reducing international competition for limited natural resources), freedom from pollution (including carbon dioxide and other green house gases), and affordability could be more important, particularly when considering secondary energy sources. While a nation's primary energy source is not sustainable unless it has a use rate less than or equal to its replacement rate, the same is not true for secondary energy supplies. Some of the energy surplus from the primary energy source can be used to create the fuel for secondary energy sources, such as for transportation.

4.3 ERŒI under rapid growth

A related recent concern is energy cannibalism where energy technologies can have a limited growth rate if climate neutrality is demanded. Many energy technologies are capable of replacing significant volumes of fossil fuels and concomitant green house gas emissions. Unfortunately, neither the enormous scale of the current fossil fuel energy system nor the necessary growth rate of these technologies is well understood within th limits imposed by the net energy produced for a growing industry. This technical limitation is known as energy cannibalism and refers to an effect where rapid growth of an entire energy producing or energy efficiency industry creates a need for energy that uses (or cannibalizes) the energy of existing power plants or production plants. The solar breeder overcomes some of these problems. A solar breeder is a photovoltaic panel manufacturing plant which can be made energy-independent by using energy derived from its own roof using its own panels. Such a plant becomes not only energy selfsufficient but a major supplier of new energy, hence the name solar breeder. Research on the concept was conducted by Centre for Photovoltaic Engineering, University of New South Wales, Australia. The reported investigation establishes certain mathematical relationships for the solar breeder which clearly indicate that a vast amount of net energy is available from such a plant for the indefinite future. BP Solar originally intended its plant in Frederick, Maryland to be such a Solar Breeder, but the project did not develop. Theoretically breeders of any kind can be developed.

5. Thermo economics

Thermo economics, also referred to as **biophysical economics**, is a school of heterodox economics that applies the laws of thermodynamics to economic theory. The "thermo economics" was coined in 1962 by American engineer Myron Tribus, and developed by the statistician and economist Nicholas Georgescu-Roegen.

Thermo economics can be thought of as the statistical physics of economic value. Thermo economics is based on the proposition that the role of energy in biological evolution should be defined and understood through the second law of thermodynamics but in terms of such economic criteria as productivity, efficiency, and especially the cost and benefits (or profitability) of the various mechanisms for capturing and utilizing available energy to build biomass and do work. Thermo economists claim that human economic systems can be modeled as thermodynamic systems. Then, based on this premise, they attempt to develop theoretical economic analogs of the first and second laws of thermodynamics. In addition, the thermodynamic quantity exergy, i.e. measure of the useful work energy of a system, is one measure of value. In thermodynamics, thermal systems exchange heat, work, and or mass with their surroundings; in this direction, relations between the energy associated with the production, distribution, and consumption of goods and services can be determined.

Thermoe conomists argue that economic systems always involve matter, energy, entropy, and information. Moreover, the aim of many economic activities is to achieve a certain structure. In this manner, thermo economics attempts to apply the theories in non equilibrium thermodynamics, in which structure formations called dissipative structures form, and information theory, in which information entropy is a central construct, to the modeling of economic activities in which the natural flows of energy and materials function to create scarce resources. In thermodynamic terminology, human economic activity may be described as a dissipative system, which flourishes by consuming free energy in transformations and exchange of resources, goods, and services.