Sustainable Assessment Method for Energy Systems

Indicators, Criteria and Decision Making Procedure

by

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PREFACE

The idea for this book was born during our work on The Encyclopaedia of Life Support Systems, which was developed with a group of scientists willing to share their expertise in the promotion of sustainability development on a global scale. It was determined that the complexity of the problem requires a specialised approach and that energy is of paramount importance for the development of the sustainability concept. The multidimensionality of the energy issue has imposed the need for a new approach to the energy strategy concept. In particular, it was recognised that future energy strategy will have to deal with energy as a complex issue encompassing economic, environmental, social, cultural, educational, and resources aspects. This implies that the energy system concept has to be an interactive and proactive, correlating human needs and future developments.

The term sustainability has been "reinvented" in political discourse as a key word to describe quality of life issues, limitation of natural resources and a sense of commitment to our future generations. Other definitions of sustainability have been used in religious, environmental and political contexts in the course of history, each giving specific emphasis to the relevant issues of the time.

The discussion of "limits of growth" focuses on the issue of resource limitations and their potential implications on the future of Western industrial society. While this issue has triggered some positive economic responses in developed parts of the world, it has not yet addressed the growing problems of modern society on a global scale. In an attempt to foster sustainable development, political and normative bodies have focused on the concept of globalisation.

It has become obvious that the inherent complexity of these problems requires researchers and policy makers to enhance and deepen their understanding of the different aspects of present day sustainability. While the economy and the environment are often cited as key issues affecting the quality of life on our planet, emphasis also needs to be placed on the fundamental importance of social aspects in the understanding of sustainable development. As such, attention is now being focused on the links between social processes and other aspects of the modern development strategy.

It is critical to use a reliable methodology for the analysis of a complex system and its behaviour. But before we can do that, it is necessary to define the system, taking into a consideration its complexity. As for any system, this has to be determined by relevant intensive and extensive parameters. This requires a sound knowledge of the internal processes in the system. However, only a system with a known structure can be described with the appropriate number of parameters, thus leading to the description of the internal interaction among the elements of the system. The complexity of the system can not be defined without knowing its structure.

Engineering science has been based on the canonical laws of physics and its derivatives in other branches of science. As such, close links among these fields have been highlighted in a number cases. To a lesser extent, engineering science has been integrated into the social aspects of these issues. The sustainability concept requires a multidisciplinary approach in order to address its full complexity. It is essential to have an understanding of the interactions among the different processes in the system, as a single discipline cannot solely cope with the complexity of these problems.

This book addresses the issue of sustainability by offering a new methodology based on multi-criteria indicators for the evaluation of energy as a system. Since energy plays a critical role in human life, it is imperative to investigate new methods for energy system evaluation. Consequently, the organisation of the book highlights the different indicators for the evaluation of energy systems.

Sustainable Assessment Method for Energy Systems: Indicators, Criteria, and Decision Making Procedure is composed of seven chapters including: Chapter 1- Introduction; Chapter 2 – Sustainability; Chapter 3 – Sustainable Energy Development; Chapter 4- Sustainability and Energy Education; Chapter 5 – Energy System Assessment with Sustainability Indicators: Chapter 6, Sustainability Assessment of Heat Exchanger Design; Chapter 7 – Water and Energy Co-Generation Assessment.

Every human endeavour, including writing a book, requires a supportive environment from those associated with the authors in the process of preparing a book. With the UNESCO Chair on Sustainable Energy Management at the Instituto Superior Tecnico, the Institute was a natural environment for this effort. The authors would like to express their high regard to Prof. B.Berkovski, Director of Engineering and Technology Division of UNESCO and Prof. Dimantino Durão, President of Instituto Superior Tecnico, for their support and vision in the development of this work. The Authors would also like to express high appreciation to Dr. Darwish Al Gobaisi, Editor-in-Chief of the Encyclopaedia for Life Support System, for his encouragement and support. In particular, the authors are indebted to Prof. M.Cumo, University of Rome " La Sapienza", for his suggestions and contribution to formulating the nuclear issues expressed in the book. Also, our great appreciation is devoted to Prof. Mohammad Darvish from Kuwait University for his contribution in presenting material related to the water desalination problem. Prof. N.Hovanov developed some of the decision-making procedures presented in this book and the authors would like to thank him for his co-operation in the preparation of the material for this book.

Every book strongly depends on the support of the people associated with the preparation of the manuscript. The authors would like to express their sincere gratitude to Ms. Rita Maia for her services in editing and typesetting the text and to Mr. Jorge Coelho for his contributions to the graphics and table organisation.

CONTENTS

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Energy resources have always played an important role in the development of the human society [1]. Since the industrial revolution the energy has been a driving force for the modern civilization development. Technological development and consumption of energy, along with the increase in the world population, are interdependent. The Industrial Revolution, especially to the momentum created by the change from reciprocal engines to the great horsepower of steam engines in the late nineteenth century, which brought about a revolution in dynamics - began a drastic increase both in consumption and population of the world [2].

The history of life on the Earth is based on the history of photosynthesis and energy availability [3]. The history of such a planet lies on the capture of the solar energy and its conversion by photosynthesis in plants and phytoplankton as organic molecules of high energy content. The plants convert this energy into other organic compounds and work by biochemical processes. Photosynthesis counteracts entropy increase and degradation since it tends to put disordered material in order. By capturing the solar energy and decreasing the planetary entropy, photosynthesis paves the way for biological evolution.

Boltzman [4], one of the Fathers of modern physical chemistry, wrote, in 1886, that the struggle for life is not a struggle for basic elements or energy, but a struggle for the availability of negative entropy in energy transfer from the hot Sun to the cold Earth. In fact, life on the Earth requires a continuous flux of negative entropy as the result of the solar energy captured by photosynthesis. The Sun is an enormous machine that produces energy by nuclear fusion and offers planet Earth the possibility of receiving large quantities of negative entropy. Every year the Sun sends 5.6×10^{24} joules of energy to the Earth and produces 2×10^{11} tons of organic material by photosyntesis. This is equivalent to 3×10^{21} joules/ year. Through the billions of years since the creation of the planet Earth this process has led to the accumulation of an enormous energy in form of different hydrocarbons. Most of the fossil fuels belong to the type of material where molecular binding is due to Van der Waals potential between every two molecules of the same material. Mankind's energy resources rely heavily on the chemical energy stored in the fossil fuel. Table 1 shows assessed energy resources [5].

Energy and matter constitute the earth's natural capital that is essential for human activities such as industry, amenities and services in our natural capital as the inhabitants of the planet earth may be classified as:

- Solar capital (provides 99% of the energy used on the Earth)
- Earth capital (life support resources and processes including human resources)

These, and other, natural resources and processes comprise what has become known as 'natural capital' and it is this natural capital that many suggest is being rapidly degraded at this time. Many also suggest that contemporary economic theory does not appreciate the significance of natural capital in techno-economic production.

2. ENERGY RESOURCES

All natural resources are, in theory, renewable but over widely different time scales. If the time period for renewal is small, they are said to be renewable. If the renewal takes place over a somewhat longer period of time that falls within the time frame of our lives, they are said to be potentially renewable. Since renewal of certain natural resources is only possible due to geological processes which take place on such a long time scale that for all our practical purposes, we should regard them as non-renewable. Our use of natural material resources is associated with no loss of matter as such. Basically all earth matter remains with the earth but in a form in which it can not be used easily. The quality or useful part of a given amount of energy is degraded invariably due to use and we say that entropy is increased.

There are number of sources for the date on energy resources and reserves. There are two factors effecting the reliability of date. Time the data are produced is one of the substantial factor which reflects the amount of capital invested in the investigation of new resources. The second factor which may be linked to the time is the technology available for the discovery of new resources. With these two constrains, the data presented in Table 1, are taken from WEC sources.

Table 1. Fossil Fuel and Uranium Reserves at the end of 1993[4]

	Proven Reserves[1] Gtoe[5]	Resources[2] Gtoe	Resource Base[3] Gtoe
Oil	343	477	820
Natural Gas	141	279	420
Coal & Lignite	606	2,794	3,400
Total Fossil Fuel	1,090	3,550	4,640
Uranium	In Thermal Reactors	In fast Reactors	

	Proven Reserves[1] Gtoe[5]	Resources[2] Gtoe	Resource Base[3] Gtoe
	3,390	15,540	

1 Proven Reserves are those that can be produced with existing technologies under present market conditions.
2 Resources are those which with technical progress could become economically attractive to produce.
3 Resource Base is Proven Reserves plus Resources.
4 Source:'Global Energy Perspectives to 2050 and Beyond', WEC/IIASA, 1995.
5 Gtoe: Giga tonnes of oil equivalent

Use of the energy resources is subject to the technologies for their transformation. In this respect Table 2 gives schematic presentation of the technologies needed to convert the energy resources in the form adapted for its use.

Table 2. Schematic presentation of the energy resource technologies.

Resources	**Coal**	**Gas**	**Oil**	**Nuclear**	**Waste**	**Solar**	
Extraction	Coal mine	Gas well	Oil well	Nuclear processing	Agro-forestry	Collector	
Primary sources	Coal	Gas	Oil	Nuclear fuel	Bio-mass	Heat	Electricity
Conversion Technology	Power plant	Gas distribution		Refinery	Methanol Plant		
Distribution Technology	Electric grid	Gas grid	Oil transport system				
Final Energy	Electricity	Gas	Kerosene				
End use technology	Engine	Furnace	Light	Oven	Automobile		
Energy service	Power	Space heating	Illumination	Cooking	Transport	Space heating	Illumination

Adapted from N.Nakicenovic at al [5].

3. ENERGY CONSUMPTION - PAST, PRESENT AND FUTURE

The abundant energy resources at the early days of the industrial development of the modern society have imposed the development strategy of our civilization to be based on the anticipated thinking that energy resources are unlimited and there is no other limitations which might affect human welfare development. It has been recognized that the pattern of the energy resource use has been strongly dependent on the technology development. In this respect it is instructive to observe [6,7] the change in the consumption of different resources through the history of energy consumption.

Worldwide use of primary energy sources since 1850 is shown in Figure 1 [6]. F is the fraction of the market taken by each primary-energy source at a given time. It could be noticed that two factors are affecting the energy pattern in the history.

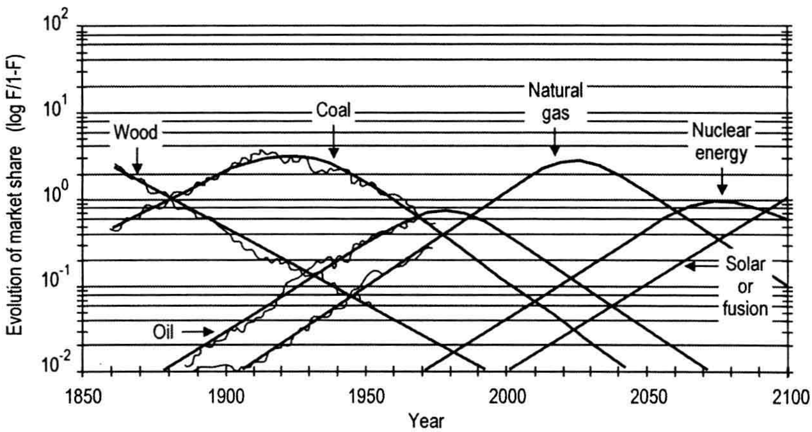

Figure 1. Primary energy sources.

The first is related to the technology development and, the second, to availability of the respective energy resources. Obviously, this pattern of energy source use is developed under constraint immanent to the total level of energy resources consumption and reflects the existing social structure both in numbers and diversity [8,9,10]. The world energy consumption is shown in Figure 2. [11].

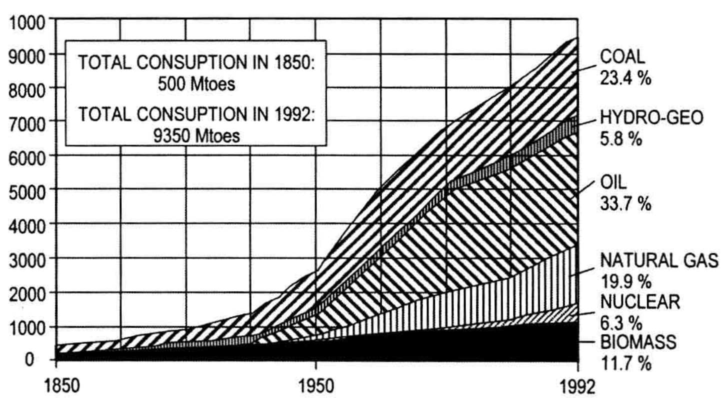

Figure 2. World energy consumption.

Looking at the present energy sources consumption pattern, it can be noticed that oil is a major contender, supplying about 40% of energy. Next, coal supply is around 30%, natural gas 20% and nuclear energy 6.5%. This means that current fossil fuel supply is 90 % of the present energy use. In the last several decades our civilization has witnessed changes which are questioning our long-term prospect. Fossil fuel, non-recyclable is an exhaustible natural resource that will be no more available one day. In this respect it is of common interest to learn how long fossil fuel resources will be available, as they are the main source of energy for our civilization. This question has attracted the attention of a number of distinguished authorities, trying to forecast the energy future of our planet. The Report of the Club of Rome " Limits to Growth", published in 1972 [12], was among the first ones which pointed to the finite nature of fossil fuel. After the first and second energy crisis the community at large has become aware of the possible the physical exhaustion of fossil fuels. The amount of fuel available is dependent on the cost involved. For oil it was estimated that proved amount of reserves has, over past twenty years, leveled off at 2.2 trillion of barrels produced under $ 20 per barrel. Over the last 150 years we have already used up one-third of that amount, or about 700 billion of barrels which leaves only a remaining of 1.5 trillion of barrels. If compared with the present consumption, it means that oil is available only for the next 40 years. Figure 3 shows the ratio of the discovered resources to the yearly consumption for the fossil fuels [11].

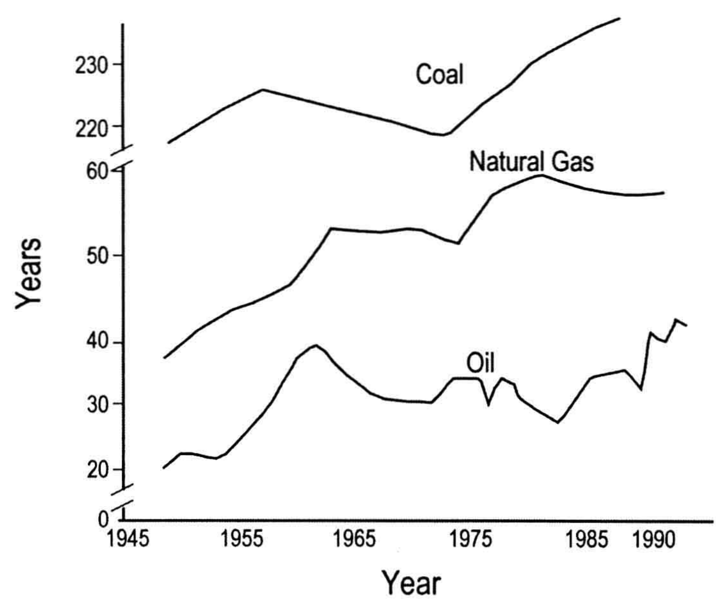

Figure 3. The ratio of the discovered resources to the yearly consumption for the fossil fuels.

From this figure it can be noticed that coal is available for the next 250 years and gas for the next 50 years. Also, it is evident that as much as the fuel consumption is increasing, new technologies aimed to the discovery of new resources are becoming available, leading to a slow increase of the time period for the exhausting of the available energy sources.

It is known that the energy consumption is dependent on two main parameters. Namely, the amount of energy consumed per capita and the growth of population. It has been proved that there is a strong correlation between the Gross Domestic Product and Energy consumption per capita. Figure 4 shows the economic growth and energy consumption for a number of countries, in 1990 [12].

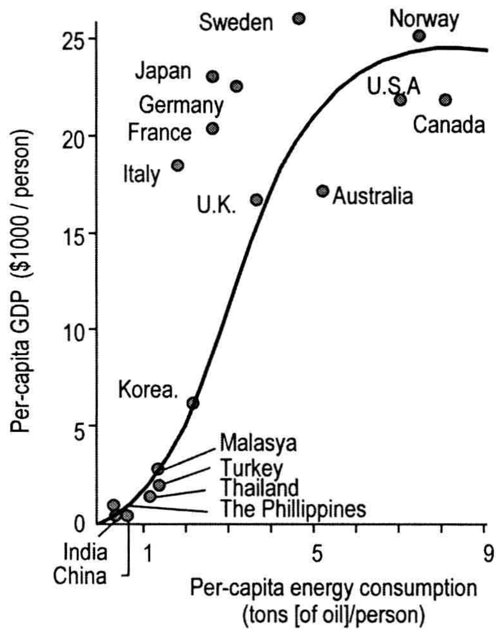

Figure 4. Economic growth and energy consumption for a number of countries, in 1990.

There is a number of scenarios which are used for the forecast of the world economic development. With the assumption that the recent trend in the economic development will be conserved in the next 50 years and considering the demographic forecast in the increase of human population, as shown in Figure 5 [13] the future energy consumption could be calculated, as shown in Figure 6 [14].

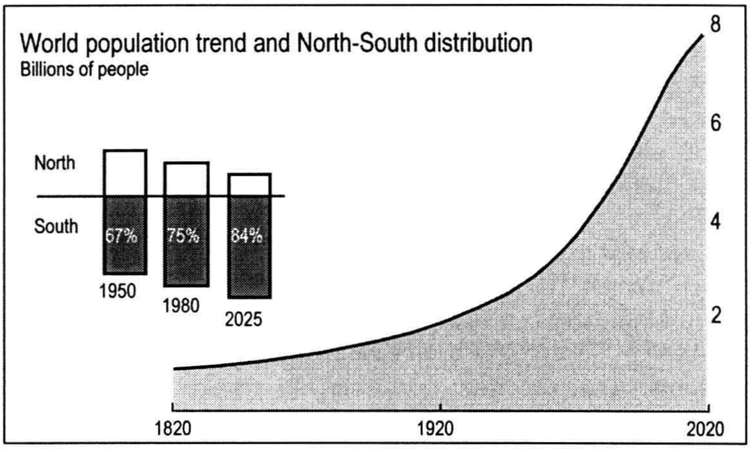

Figure 5. Demographic forecast in the increase of human population.

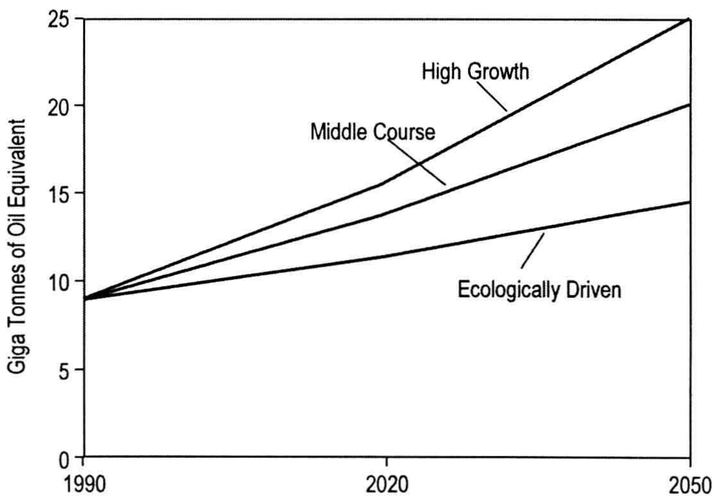

Figure 6. Future energy consumption.

Compared with the available resources it is easily foreseen that the depletion of the energy resources is an immanent process which our civilization will face in the near future. Nevertheless, whatever is the accuracy of our prediction methods and models, it is obvious that any inaccuracy in our calculation may affect only the time scale but not the essential understanding that the energy resources depletion process has begun and requires the human action before adverse effects may irreversibly enforce.

Natural resources scarcity and economic growth are in fundamental opposition to each other. The study of the contemporary and historical beliefs showed [15], that: (1) natural resources are economically scarce, and become increasingly so with the passage of time; (2) the scarcity of resources opposes economic growth. There are two basic versions of this doctrine. The first, the Malthusian, rests on the assumption that there are absolutely limits; once these limits are reached the continuing population growth requires an increasing intensity of cultivation and, consequently, brings about diminishing returns per capita. The second, or Ricardian version, viewed the diminishing returns as current phenomena reflecting the decline in the quality of resources brought within the margin of a profitable cultivation. Besides these two models, there is also the so called "Utopian case' where there is no resources scarcity. There have been several attempts to apply these models to the energy resources in order to define the correlation between specific energy resources and economic growth.

The substantial questions related to the scarcity, its measurement and growth are: (1) whether the scarcity of energy resources has been and/or will continue to be mitigated and (2) whether the scarcity has "de facto" impacted the economic growth. An analysis based on the relative energy prices and unit costs has been applied to natural gas, bitumen coal, anthracite coal and crude oil. The USA analysis in this respect can serve as the indication for the future trend in a world scale. Using two measures of scarcity - unit cost and relative resource price change in the trend of resource scarcity for natural gas, bitumen coal, anthracite coal and crude oil, over three decades are shown in Figure 7 [16].

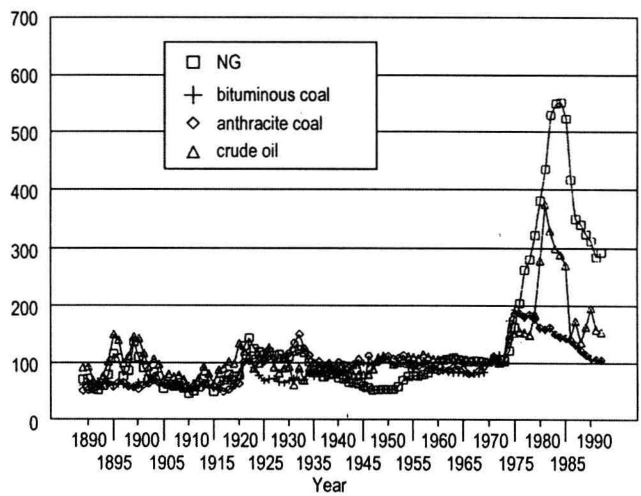

Figure 7. Resource scarcity for natural gas, bitumen coal, anthracite coal and crude oil.

It can be noticed that each one of the energy resources has become significantly more scarce during the decade of the 1970s. The situation reversed itself during the 1980s. The change, that took place, has implications for the future economic growth to the extent resources scarcity and economic growth are interrelated, even if it was not proved that short term energy resources scarcity fluctuation has substantial implication on the long term economic growth. It has become obvious the need for an active involvement in allocating scarce, non-renewable energy resources and its potential effect on the economic growth.

4. ENVIRONMENT CAPACITY CONSUMPTION - PAST, PRESENT AND FUTURE

Primary energy resources use is a major source of emissions [17,18,19,20]. Since fossil fuels have demonstrated their economic superiority, more than 88 % of primary energy in the world in recent years has been generated from fossil fuels. However, the exhaust gases from combusted fuels have accumulated to an extent where a serious damage is being done to the world global environment. CO_2 is the mostly debated one of the greenhouse gases. Its global warming potential is compared to the other greenhouse gases is lower but its emission are higher and are directly related to a daily need of humankind, namely energy supply. It is therefore very important that its sources and sinks are well understood and investigated. The balance and the assessment of implications of changes of CO_2 is of great importance. The quantification of how much is taken up by each CO_2 sink is complicated and cause to numerous re-evaluations. The recent estimations suggested that about 2 Gt C/yr is taken up by ocean, about 3.2 Gt C/yr by atmosphere and about 1.4 Gt C/yr is assimilated up by terrestrial ecosystem. The accumulated amount of CO_2 in atmosphere is estimated at about 2.75×10^{12} t. The global warming trend from 1900 - 1990 is shown in Figure 8 [21].

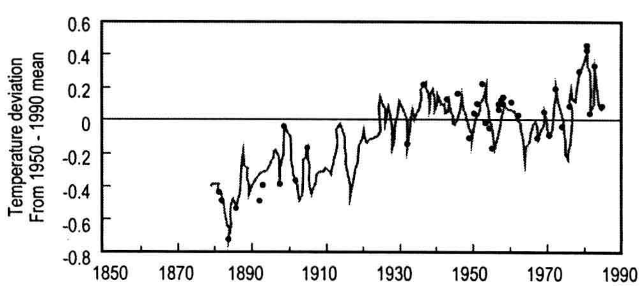

Figure 8. Global warming trend from 1900 – 1990.