'Energy for energy' concept or total energy rationality

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REVIEW

By analyzing different concepts dealing with rational use of energy, the issue that becomes growingly important for the world economy, the paper analyzes global energy economics, i.e. energy balance of energy production, or the energy cost of producing energy. This analytical direction started in the 1970s with The Limits to Growth: a report to the Club of Rome. It reappeared many times again in various concepts, from sustainable development theory and call for preservation of resources to Peak Oil theory and 'net energy cliff' concept, which prove that overall hydrocarbons production becomes less and less rational when we consider the energy needed to produce them. Analyses of the energy cost of producing energy will become an important issue of energy considerations and energy policies of the future.

Key words: Energy, "energy cliff "concept, "energy for energy"concept, total energy rationality

1. Introduction

We distinguish several forms of energy: primary energy, energy transformations and useful energy. Primary energy is used in the form in which it appears; energy can be transformed into another energy form, while useful energy refers to energy form convenient for use, which buyers can buy on energy markets. Fuel wood, coal or natural gas can be used in their primary form, while crude oil generally gets transformed into more usable forms like gasoline, diesel or fuel oil. Also, energy is sometimes transformed into another form because of easier transportation.[1]

Systematization of energy forms is presented in Figure 1.

Primary energy is used in the form it is found in nature, such as fuel wood, coal or natural gas. Some authors call it also natural energy form.[2] However, only some energy sources can be used in the form found in nature. Among the most important ones are main traditional resources such as fuel wood and coal, with the growing share of natural gas.

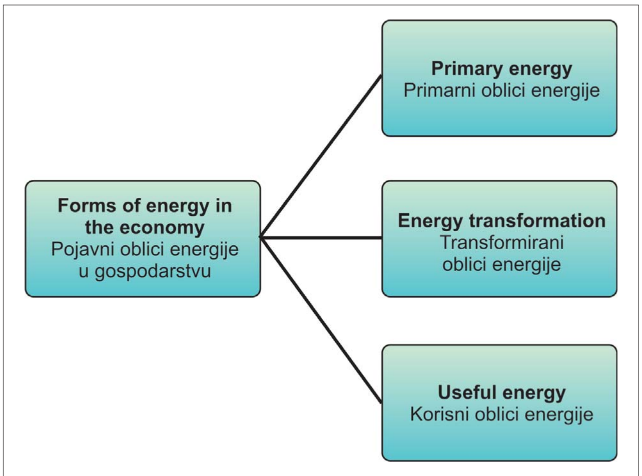

Fig. 1. Basic concepts of energy systematization
Sl. 1. Osnovni pojmovi sistematizacije energije

Other energy sources cannot be used in the form found in nature, but have to be converted into another energy form which is technologically more suitable for use, safer or economically viable. Common feature of processes and plants for energy transformation is their task to convert primary energy sources into more usable form needed for meeting specific needs.

As a pattern, "more developed communities have higher share of energy transformations in their energy production and consumption than primary sources."[3] However, all energy transformations result in energy efficiency lower than 1, the sum of energy obtained by transformation process to be used for transport, industry or households, is always lower than primary energy quantity. Therefore energy efficiency becomes one of the key factors of sustainable economic development.

In all processes of energy use it is very important to measure energy and use standardised measuring units. This equally applies to technology systems for producing energy and for energy consuming appliances, for energy economics and for recording of energy use in industrial plants or transport.

Therefore, energy measuring units and relationships among them in different metric systems are crucial for calculations, comparisons and energy economics. Professor I. Kolin from Mining, Geology and Petroleum Engineering Faculty, University of Zagreb, designed a witty illustration presenting 1 kWh = 860 kcal which, according to his formula, represents the energy 10 men need to lift 36.72 kg burden to 1000m elevation (reference to Dante Alighieri's La Divina Comedia). Amazingly, this quantity of energy can be released from only 86 g of diesel fuel. The copy of the original drawing is presented in Figure 2.

Measuring and exact calculation of consumed energy are cruical for economic analyses and energy economics

Fig. 2. Professor I. Kolin's illustration of 1 kWh
Sl. 2. Ilustracija I. Kolina za 1 kWh
Source / Izvor: Kolin, I.: kWh (posveta Danteu). Interna dokumentacija RGN fakulteta u Zagrebu.

in general. It is impossible to imagine any serious energy efficiency analysis without exact measurement readings, calculations and interpretations of obtained results.

2. Energy use and growth of energy demand

During the previous one and a half century energy consumption increased continuously, but in the second half of the 20th century this growth accelerated. World energy consumption tripled in the first half, and quadrupled in the second half of the 20th century, but then it slowed down at the turn of the century and in the first decade of the 21st century. As energy is crucial for further development, projections of future production and consumption are very much in demand, along with various energy scenarios.

It is expected that energy consumption will keep growing, despite higher energy costs and global economic crisis, because it is unlikely that developing countries will give up further industrial development. In circumstances where globalisation processes and transfer of technologies, goods and services stimulate new industrial development, economic relations enable expansion of markets and consumption. In such conditions the only way out from the current recession for the developed countries of Europe and North America is to increase export of their industrial products and technologies. This is why we can expect further growth of energy consumption.

Most projections and forecasts indicate that global energy consumption will continue to grow in the coming decades, particularly after economic recovery. Majority of the future energy consumption growth will take place in the developing countries, i.e. outside OECD countries (North America, Western Europe and Eastern Asia). In other countries of Asia, Central and South America, energy consumption will grow at accelerated rate in the next two decades, and will account for more than a half of total world growth. According to projections, the energy consumption of the industrialised countries will stagnate or moderately grow.[4,5,6]

In 2010 total world consumption of primary energy was around 12 billion toe. In this total consumption the share of crude oil was 34%, natural gas 24%, coal 30%, electricity generated in hydro plants and renewable sources 7% and electricity generated in nuclear plants (fission) 5%. After considerable decline in consumption in 2009 following the recession and economic crisis in the developed countries, in 2010 energy consumption resumed growth and increased to around 12.5 billion toe.[7,8]

The structure of global energy consumption in 2012 is presented in Figure 3.

The analysis of efficiency rate of energy transformations and the use of transformed energy in energy consuming appliances, represents the essence of economization of total energy use and includes analyses of all processes from primary energy production, transformations to final use, i.e. the use of energy in economic sense in appliances and machinery. The calculations of energy efficiency for different energy sources and total efficiency of substitute energy are very complex and for now they are mainly done by comparison of production and other costs of alternative fuels.

Hence, the analysis of energy efficiency of individual sectors of economy or entire economy is in the early stage of its wider universal use in economic planning. Cur-

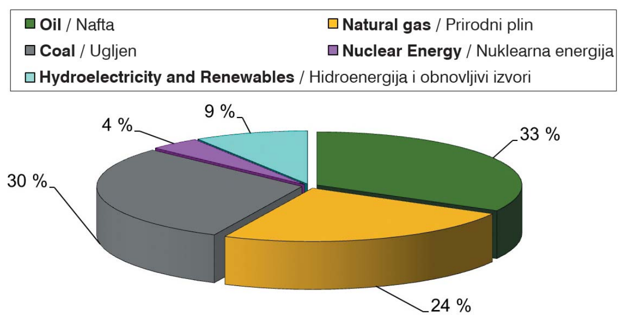

Fig. 3. Structure of global energy consumption in 2012
Sl. 3. Globalna struktura potrošnje energije 2012. godine
Source / Izvor: Hubbert, M. King. Energy Resources. National Research Council, Committee on Resources and Man, Resources and Man. San Francisco: 1969. W. H. Freeman.

rently, such analyses are carried out by comparing efficiency of substitute energy forms or comparable energy use. The assessment of energy efficiency of the entire economy is usually done by comparison of energy consumption and created value or GDP. Such analyses can be performed for different sectors of economy or entire economy, usually by comparing growth of energy consumption with GDP growth.

3. Depletion of fossil energy sources

The problem of depletion of the best coal mines is long as the mining itself. Professor A. Zambelli formulated the view on depletion of mineral resources based on experiences gathered in the 1950s in the following way: "All mines have their life cycle; the deposits contain certain limited exploitable mineral resources. ... When exploitation of a mine starts, mineral substance decreases and becomes lower and lower up to final depletion".[9]

The problem of depletion of natural resources became more prominent with intensive industrialisation and extensive exploitation of fossil energy sources, particularly hydrocarbon fluids during the last one and a half century. Throughout the largest part of the 20th century economic growth was unbiased. It was believed that the development of science and technology will remove all obstacles on this growth path. However, when energy crises emerged during the 20th century, scientists and leaders started to question unprecedented growth, put forth theories on limitation of natural resources and posed serious questions about ecological capacity of the planet Earth and abundance of energy sources.

The first scientist who became widely known for his predictions on future decline of hydrocarbons production was American geologist and geophysicist Marion K. Hubbert. In 1956 he put forth a thesis stating that the total US and world oil production can be described by a bell shaped curve similar to normal distribution curve, and published his predictions on the US and world oil production. According to his calculations, US oil production would peak around 1970 and after that it would start to decline, while world oil production would peak at the beginning of the 21st century, after which total world oil production will start to decline. The curve presenting rising and then falling oil production over the years has been called after him the Hubbert's curve, and maximum oil production Hubbert's peak oil.[10]

Hubbert's curve of world oil production is presented in Figure 4.

The challenge of limited capacity of the planet and scarcity of natural resources arouse global interest after the report prepared by the research group from Massachusetts Institute of Technology for the Club of Rome which highlighted the key challenges of mankind. It was published in 1972 in the book The Limits of Growth.[11] The report analyzed the expected exponential economic growth and compared it with the projections of available natural resources. Limitations in possible food production and other natural resources pointed to constraints in predictions on sustainable longterm growth. These studies and research became very popular in the 1970s and 1980s, but with sharp decline of crude oil prices in 1986 and seemingly abundant cheap energy, they were forgotten. It continued so till the beginning of the 21st century when the challenges of scarce resources instigated the renewal of global interest for sustainable development.

Already in 1997 British geologist Colin J. Campbell published the study 'The Coming Oil Crisis' in which he reaffirmed Hubbert's predictions on imminent peak oil and aftermath decline and gradual depletion of oil reserves. (12) In 2001 Campbell established the Association for the Study of Peak Oil & Gas. In the same year American geologist Kenneth S. Deffeyes published the book "Hubbert's Peak: The Impeding World Oil Shortage".[13]

Soon after that the challenges of the modern world became frequent topic in various studies and the media: depletion of energy resources, global warming and constraints stemming from the need of environment protection, including other natural, technological and energy balance limitations resulting from intensive use of fossil energy resources. Increased energy consumption and more intensive negative effects of industrialisation, contributed to reaffirmation of sustainable development principles, which were formulated in the 1980s but then pushed back in the 1990s. Concerns of energy sources depletion and the discussions on peak oil represent one of the key controversies of the today's energy paradigm.

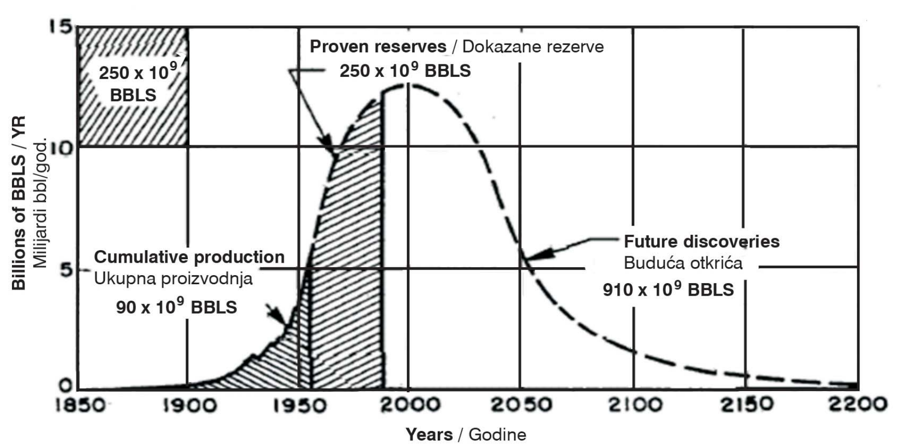

Fig. 4. Hubbert's curve peak world oil production
Sl. 4. Hubbertova krivulja za proizvodnju nafte u svijetu

4. "Energy Cliff" theory and "energy for energy" concept

During the last decade, global energy determinants changed assumptions for future energy policies. The US gas revolution, i.e. sharp increase of natural gas production from unconventional resources brought the United States at the forefront of the world natural gas production and created conditions for reindustrialisation based on cheap energy. Europe developed technologies and manufacturing of equipment for production of electricity from renewable sources. At the same time China, India and some other countries expanded production and use of coal and caused uncontrolled emissions of CO_2 and other greenhouse gases. In this context, the efforts of the developed countries to reduce emissions, which consume lower share of total energy anyway, make little sense in the global balance of pollution of the planet's ecosystems.

In addition, the discussions on peak oil, that revive Hubbert's theory, start questioning energy balance of individual energy sources. Concerns about climate change and negative effects caused by it, are frequently related to the use of fossil energy resources. Also, many authors mention direct correlation between peak oil theory and global resource depletion theory. These considerations are formulated in the energy cliff theory.

It started with the energy return on investment - EROI concept that was drawn up some ten years ago by ecologist Charles A. S. Hall.14 The theory investigates the ratio of energy returned from an energy gathering activity compared to the energy invested in that process.

Charles Hall's EROI concept is presented in figure 5.

It is worth mentioning that the EROI concept is very close to the ideas included in the concept 'energy for energy' put forth by the Croatian energy scientist Hrvoje Požar. His concept was designed and discussed in the late 1980s, but due to some circumstances professor H. Požar and other energy experts from the Zagreb energy group did not publish any systematic report at the time.

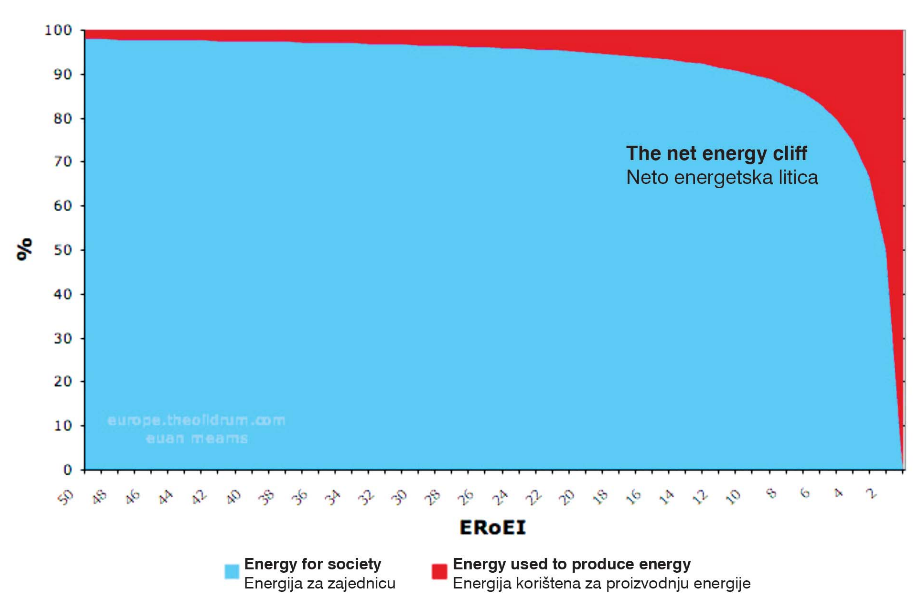

Fig. 5. Energy return on energy invested (EROI)
Sl. 5. Energetski povrat investicija u energetiku (EROI)
Source / Izvor:
http://2.bp.blogspot.com/uualVqzFPk/SM1tsPPuH3I/AAAAAAAAAGQ/BvdMe1fC4lg/s1600-h/euan_eroi.png

Calculation of net invested energy for obtaining energy (EROI) assumes a macroeconomic analysis of total energy balance according to the following equation:

Net obtained energy $E\ net = E\ obtained - E\ invested;$

in which energy return on investment is equal to ratio of energy returned from energy invested in its generation.

Energy cliff concept for production of energy from different types of fossil fuels is presented in figure 6. The figure indicates that the quantity of obtained energy compared to invested energy becomes smaller and smaller as hydrocarbons production becomes deeper (both onshore and offshore) or more complex with growing exploration, development and production costs. The curve presents also the ratio of invested and obtained energy in electricity generation from the two main sources of renewable energy: wind and solar.

Similar methods can be used for analyzing energy return on investment for all types of energy sources used in today's energy industry. Number of energy transformations in technology processes such as exploration, development, production, transport, distribution and final use of energy will certainly decrease total ratio of obtained and invested energy because each transformation has efficiency rate lower than 1. Technical background of the relation between material resources and energy was explained by professor H. Požar as follows: "In principle, all basic chemical substances can be used in a closed cycle process, but in each preparation stage for their reuse we need energy."[1]

The question is which segment of preparation technology and equipment manufacturing should be included in energy for energy analysis. Is it necessary to include energy for obtaining aluminium for manufacturing wind turbine rotor blades? Is it necessary to factor in energy used for production of thin film coatings for photovoltaic cells? These are the dilemmas that have not been resolved yet.

When we compare global energy balances for energy used in the previous 4 decades from the analyses published by IEA, some very interesting facts start to emerge. The relationships between use of primary energy sources and final consumption do not indicate any advancement in energy return from energy invested.

Energy consumption in OECD countries had moderate increase from 1973 to 2010 and was accompanied by considerable technology development, creation of new value, improvements in energy equipment manufacturing and increase of energy transformations (in electricity generation two and a half times). Significant progress has been achieved in enhancing energy efficiency in final consumption as for example in more efficient car engines, aircraft engines or electrical appliances.

Balance of final energy consumption compared to primary energy consumption does not show any significant improvement of efficiency in final energy use. According to the data published by IEA, the share of final energy consumption in OECD countries in 2010 compared to primary energy input was around 68% (3.666 billion toe compared to primary energy input of 5.392 billion toe); while in 1973 the same percentage was 75% (2.817 billion toe in final consumption compared to 3.75 billion toe of primary energy input).[4]

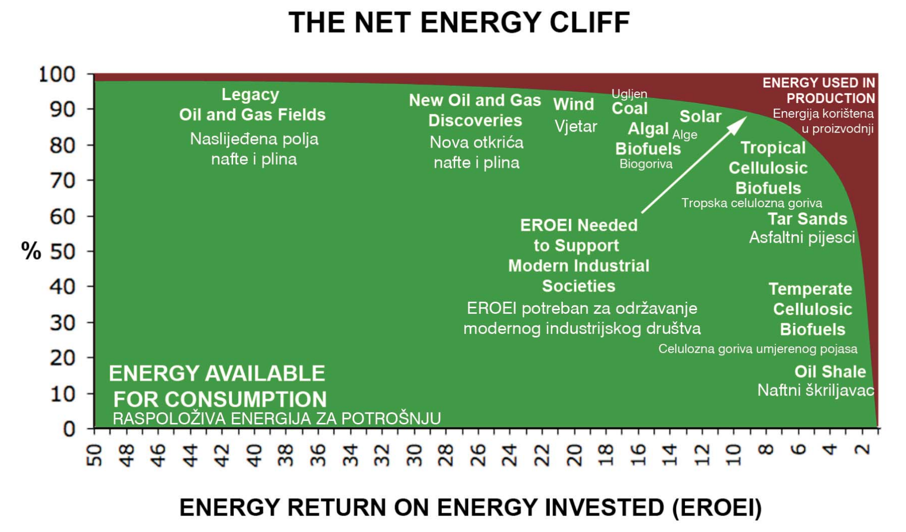

Fig. 6. The energy cliff concept
Sl. 6. Koncept energetske litice
Source / Izvor: http://deepresource.wordpress.com/2012/11/11/eroi-threshold-net-energy-cliff/

An objective macroeconomic analysis of energy consumption and efficiency of energy use across entire chain of energy transformations would show real sustainability of individual energy sources. From this point of view, fossil energy sources are not positioned well due to their constrained energy supply and ecological footprint. If calculations would also include energy consumed for production of energy equipment and energy required for the development of new energy systems in the entire technology chain, including the development of new technologies in renewable resources and energy used for equipment production, it is very probable that neither renewables would be much more efficient than fossil fuels.

5. Conclusion

"Energy Cliff" theory and "energy for energy" concept open up numerous questions on economic growth and energy policies. Any longterm planning should include 'energy for energy' assessments because they can indicate if a fuel is a net energy gainer or loser - and to what extent. Such assessments could help in quantifying total energy rationality of national, continental or global economy.

Future energy policies will certainly have to consider energy return on energy investment across the entire chain of energy production, transport, distribution and use. Moreover, the assessments will have to take into account the energy used for manufacturing of equipment for energy generation, elements of national and energy security, in which the share of domestic component in obtaining 'energy for energy' or 'domestic value added energy' are not negligible issues. Therefore, it is expected that the future energy policies will be a complex combination of quantifying modelling, stochastic analyses and economic policies, quite different from the current simplistic, and almost ideologised favouring of fossil fuels or renewable energy resources.

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