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OPTIMAL ENERGY MIX: A TOOL FOR JUDICIOUS USE OF ENERGY SOURCES TO MITIGATE THE RELATED PROBLEMS

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ABSTRACT

Today the world is on track for dangerous climate change, reached to an extreme limit having nearly lost room for further pollution in the mix of gases that make up the atmosphere. Despite a rise in clean, renewable energy supplies in certain countries, and a partial shift from coal to natural gas in others, global greenhouse gas pollution continues to rise at an increasing pace in the most recent years. Nations worldwide have to make major changes in energy supply, soon, if they are to restrain climate change to no more than 2 degrees Celsius. That is a threshold beyond which serious harm is likely to occur to human civilization as well as the natural world, as concluded by the IPCC and other's scientific judgements. Geo-engineering will probably also be required to solve the planet's global warming pollution problem.

To meet its energy needs, every country uses various energy sources available to it, in different proportions as single energy source is not sufficient to satisfy all the needs. The energy mix of an individual country is formed up by the contribution of their available resources. During the last decade, the establishment of proper energy mixes for countries has gained much importance, and energy drivers should enforce long term plans and policies. The structure of energy mix vary significantly from one country to another, fossil fuels dominate the energy mix at the global level, accounting for over 80% of the total. Although, every energy source has its limits, merits & demerits, if they are used in combination with balance proportion, the gravity of demerits can be reduced.

This paper evaluates energy issues the market and countries are facing today regarding energy mix, scheduling and panorama and seeks to improve methodology available that are applicable to optimal energy mix plan for the future. It covers the themes driving the future energy mix methodology proposal and estimation of energy supply & demand by mathematical model for selection of optimum variant and Key Factors identified, established and assessed through this paper for the common implementation. Those have a clear influence and are closely related to future environmental policies.

KEYWORDS*: Energy Sources, Energy Mix, Key Factors, EROI, EROEI, Renewable and Non-Renewable Energy Sources, Multi-Criteria Optimization, Energy Supply Chains, VIKOR*

INTRODUCTION

Energy supply chain is the trajectory of all energy transformations from the fuel source or primary energy sources to useful energy form delivered to end users. In general, every single energy supply chain can be uniquely defined by several criteria. These criteria are generally categorized into the three groups: energy, environmental and economic criteria. Optimal energy supply chain can be chosen by using multi-criteria optimization. Selected optimal energy supply chain fulfills an important set of criteria, which are defined and adopted for energy supply. The term "energy mix" refers to the combination of the various primary energy sources used to meet energy needs in a given geographic region. It includes fossil fuels, nuclear energy and renewable energy sources etc.

For Each Region or Country, the Composition of the Energy Mix Depends on

- The availability of usable resources domestically or the possibility of importing them. A nation's energy consumption is likely to come from various sources as different types of energy are more suitable for some uses than others:
- The extent and type of energy needs to be met for (i) Transport, (ii) Domestic energy, (iii) Business and Commerce.
- Policy choices determined by historical, economic, social, demographic, environmental and geopolitical factors.
- Some countries are heavily dependent upon a narrow range of energy sources; some depend upon a **diversified** energy mix. For some countries, they can exploit their own energy supply mix; others rely on imports. The likely reliability of supply can determine the Energy Security of a country.

Energy Mix and Power Generation Mix

The energy mix is the group of different primary energy sources from which secondary energy for direct use - usually electricity - is produced. Primary energy in the form of fossil fuels is nowadays still mostly used directly for motor-driven vehicles, i.e. transport. Power generation mix, is the percentage of different energy sources (fossil fuels, nuclear, hydro and other renewable energies) used to generate electricity. The generation energy mix varies widely from one country to another due to the influence of various factors. For example:

- France's generation energy mix in 2016 was made up of 42.5% nuclear power, 30.6% oil, 14.2% natural gas, 3.3% coal and 9.4% renewable energies and waste.
- United States' generation energy mix in 2016 includes natural gas 33.8%, coal 30.4%, nuclear power 19.7% renewable 14.9% and others 1.2%. (https://www.eia.gov/tools/faqs/faq.php)
- China's energy mix in 2016 includes coal 65.2%, other thermal 3.3%, gas 3.1%, hydro 19.7%, nuclear 3.6, wind 4% & solar 1.1%.
- India's energy mix in 2017 includes coal 58.4%, oil 0.3%, gas 7.6%, hydro 13.5%, nuclear 2.1%, renewable 18.2%.

ENERGY SOURCES AND ENERGY MIX

Key Factors

Following are the Key Factors which take into consideration sustainability, energy security, social and economic growth, climate change, air quality and social stability. The strength of the Key Factors application on energy system planning to different countries is contingent on country resources, location, electricity demand and electricity generation industry, technology available, economic situation and prospects, energy policy and regulation, etc.

Resources

- Mining
- Gas
- Uranium
- Water
- Renewable (wind, sun, geothermal, waves, etc.)

Availability of Resources

- Reserves
- Situation / Location
- Climate
- Topography

Social

- Demography
- Environmental concerns
- Culture
- Waste production and management capacity
- Skills & education
- Power subsidy policy
- Health and safety culture
- Equality
- Production capability

Economic

- Production capacity
- Profile of electricity demand, end-use sectors (present and projection)
- Electricity demand allocation (located or distributing)
- Existing energy
- Infrastructure

- Energy security vulnerability
- Potential investments
- Technology

The process of selecting the right energy mix requires taking into account those energy issues, by introducing simple, clear and impartial Key Factors, as the key indicators to drive the suitable energy planning for a region or country. Key factors take into consideration features like sustainability, energy security, social and economic picture and growth capacity, growth capability, climate change, air quality and social stability.

Renewable and Non-Renewable Energy Sources

Renewable resources are resources that are replenished by the environment over relatively short periods of time. This type of resource is much more desirable to use because often a resource renews so fast that it will have regenerated by the time we have used it up. Solar, Hydro, Geothermal, Tidal etc. are some of the examples. In contrast to renewable resources, non-renewable resources are resources that are not easily replenished by the environment such as fossil fuels like coal, oil and gas. We will see the advantages & disadvantages of above.

NON-RENEWABLE ENERGY SOURCES: ADVANTAGES AND DISADVANTAGES

Advantages of Non-Renewable Energy

- High in energy content
- Transportable
- Profitable
- Traditional
- Easy to use
- Cost effective
- Creating jobs

Disadvantages of Non-Renewable Energy

- Time consuming to extract
- Contribution to climate change, Acid rain etc.
- Dangerous for nature
- Not viable for future generations
- Dirty

It seems that, though non-renewable sources of energy have their advantages, these are far outweighed by their disadvantages. Though they are convenient and rich in energy, for example, non-renewable fossil fuels are also very bad for the environment and dangerous to human health.

RENEWABLE ENERGY SOURCES: ADVANTAGES AND DISADVANTAGES

Advantages of Renewable Energy Sources

- Nature friendly
- Sustainable & storable energy
- Low operating cost
- Easily integrated into daily life

Disadvantages of Renewable Energy Sources

- Expensive to set up – high initial cost
- Not suitable for all climates
- Difficult to transport
- Not the most efficient energy sources
- Reliant on certain technologies

As non-renewable energy sources start to run out, and as the world faces the threat of substantial climate change it is imperative that we switch over to using more sustainable, greener sources of energy. Renewable energy sources such as solar energy, wind energy, wave energy and so on seem to provide a sustainable and ecologically friendly solution to our future energy needs.

Energy Returned on Investment (EROI): A Tool to Predict Best Energy Mix

Modern society was born a hundred and fifty years ago when coal began providing sufficient energy to make steel and steam, lifting ordinary citizens out of poverty and soon after, we added oil, into the newly-developing middle class. The energy obtained from these sources was obvious and immediate as it took little energy input to get a lot of energy out.

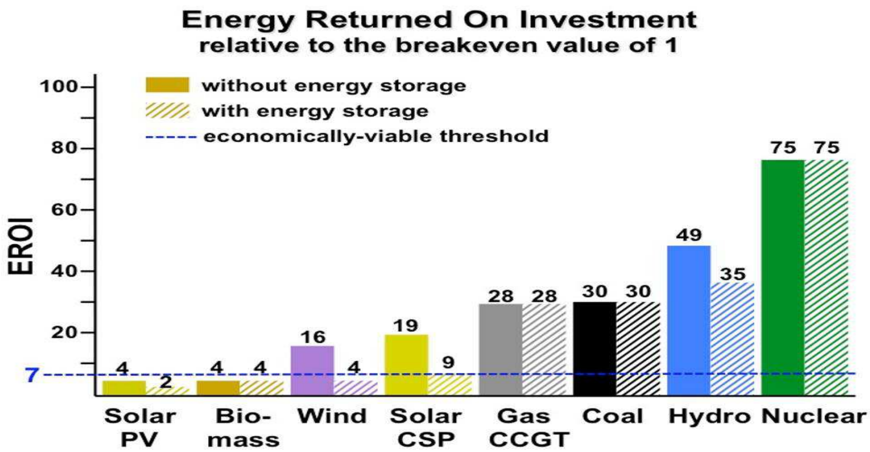


Figure 1: Energy Returned on Investment

Energy Returned on Investment, or EROI was an early concept that easily demonstrated the advantages, as well as the investment needed, to exploit these new energy sources. Also referred to as Energy Returned on Energy Invested

(EROEI), EROI is the ratio of energy returned to energy invested in that energy source, along its entire life-cycle. When the number is large, energy from that source is easy to get and cheap. However, when the number is small, the energy from that source is difficult to get and expensive. When the number is one, there is no return on the energy invested, and the entire investment has been wasted. The break-even number for fueling our modern society is about 7. Energy sources must exceed the economic threshold of about 7 (Dotted blue line) in order to yield the surplus energy required to support a modern society.

When fossil fuel emerged in early 20th century in America, the return on investment was enormous. In 1930, 1 joule of energy put into oil got 100 joules of energy out, an EROI of 100. Similarly, for coal the economies of the industrialized world became super-charged by fossil fuel, and the standard of living increased proportionately. These early fossil fuel deposits were the most easily recoverable. As time went on, they became more difficult to recover, it cost more energy and effort, and the return was less. The environmental costs also became larger. So in 2006, 1 joule of energy put into oil got only 15 joules of energy out, still enough to bring billions in profits to oil companies.

New technologies have brought the EROI of unconventional sources like tar sands oil and shale gas into the profitable range, but they will always be lower than conventional sources. Hence their production becomes marginal when oil prices drop below $60/barrel.

The decreasing EROI was obvious and they push to develop other, more diverse sources, resulted in the emergence of hydroelectric, natural gas and nuclear. Recently, we've added biomass, wind and solar, again as a result of technological advances that brought the EROI above 1. But EROI is still the method to evaluate whether an energy source is sufficient to power our society into the future. Recent EROI determinations have become better at capturing the total life-cycle costs, and eliminating temporary economic fluctuations and politically motivated influences and policies that distort the actual return.

Results from the most recent study by Weißbach (2013) are summarized in the figure 1. EROI was evaluated for power plants fueled by wind, photovoltaic solar, solar thermal, hydroelectric, natural gas, biomass, and coal and nuclear. Because some sources require buffering, storage or load-following, there are two values for each source, with and without energy storage or buffering.

For societal needs, the buffered value, or the value with energy storage, is more representative of the EROI. Only in situations where the energy produced is used directly and the demand can vary with the supply, is the value without energy storage. The buffered EROI for each energy source is – Nuclear 75, Hydro 35, Coal 30, Closed-Cycle Gas Turbine 28, Solar Thermal 9, Wind 4, Biomass 4 and Solar PV 2.

Weißbach uses the least energy intensive storage technology, pumped hydroelectric energy storage, as the buffering technology that lowers the EROI the least. Batteries are about ten times more energy intensive than pumped hydro storage, so battery storage is not viable at all for very large-scale applications. Rooftop solar is an exception because it is used directly at the source and is not supporting the outside society at large.

It is critical to understand these EROI values, when making difficult decisions about energy policy. Many claim that renewables alone, or in the majority, can fuel our future are not consistent with their EROI. America's present EROI averages about 40. A mix of 50% renewables, 30% fossil and 20% nuclear gives an average EROI of about 25.

Economies with access to higher EROI energy sources have greater potential for economic expansion and diversification. Thus, there was a rush to coal by developing countries like China and India. **Because of this, coal is now the fastest growing energy source in the world. This is why serious environmentalists, and the United Nations IPCC, strongly urge the world to adopt some mix of nuclear, hydro and renewables as the best mix to can replace fossil fuels.**

It was previously thought a global energy mix by mid-century of a third fossil, a third renewable and a third nuclear, which has an average EROI of about 36. This mix would cut carbon emissions in half over the present mix and is achievable by 2040 with existing technologies.

If we are to enter a cleaner energy future, and continue to lift people out of poverty around the world, every country's energy mix has to have as high EROI as possible, or it will not be sustainable, or acceptable, to humanity as a whole.

EROI = Quantity of Energy Supplied ÷ Quantity of Energy Used in the Supply Process

(The units are usually given in BTUs, kWhs or other units available to both, energy supplied and used).

Quantity of Energy Used in the Supply Process includes: - mining activities from exploration, drilling, winning, extraction, handling, refining, construction, installation, smelting, operations, maintenance, decommissioning, transportation, etc.

Quantity of Energy Supplied includes: - Electricity, useable heat, power for useful work

Energy Supply and Demand

The method used to achieve optimum integration of heating, cooling, electricity and transport fuel provision with more efficient energy systems will vary with the region, local growth rate of energy demand, existing infrastructure and by identifying all the co-benefits (high agreement, much evidence). The wide range of energy sources and carriers that provide energy services need to offer **long-term security of supply, be affordable and have minimal impact on the environment**. However, these three goals often compete. There are sufficient reserves of most types of energy resources to last at least several decades at current rates of use when using technologies with high energy-conversion efficient designs. How best to use these resources, in an environmentally acceptable manner while providing for the needs of growing populations and developing economies is a great challenge.

- Conventional oil reserves will eventually peak, as will natural gas reserves, but it is uncertain exactly when and what will be the nature of the transition to alternative liquid fuels such as coal-to-liquids, gas-to-liquids, oil shales, tar sands, heavy oils, and bio-fuels. It is still uncertain how and to what extent these alternatives will reach the market and what the resultant changes in global GHG emissions will be as a result.
- Conventional natural gas reserves are more abundant in energy terms than conventional oil, but they are also distributed less evenly across regions. Unconventional gas resources are also abundant, but future economic development of these resources is uncertain.
- Coal is unevenly distributed, but remains abundant. It can be converted to liquids, gases, heat and power, although more intense utilization will demand viable CCS technologies if GHG emissions from its use are to be limited.

- There is a trend towards using energy carriers with increased efficiency and convenience, particularly away from solid fuels to liquid and gaseous fuels and electricity.
- Presently, contribution of Nuclear energy is low compared to total primary energy, which could make an increasing contribution to carbon-free electricity and heat in the future. The major barriers are: long-term fuel resource constraints without recycling; economics; safety; waste management; security; proliferation, and adverse public opinion.
- Renewable energy sources (with the exception of large hydro) are widely dispersed compared with fossil fuels, which are concentrated at individual locations and require distribution. Hence, renewable energy must either be used in a distributed manner or concentrated to meet the higher energy demands of cities and industries.
- Non-hydro renewable energy-supply technologies, particularly solar, wind, geothermal and biomass, are currently small overall contributors to global heat and electricity supply, but are the most rapidly increasing. Costs, as well as social and environmental barriers, are restricting this growth. Therefore, increased rates of deployment may need supportive government policies and measures.
- Traditional biomass for domestic heating and cooking still accounts for more than 10% of global energy supplies, but could eventually be replaced, mainly by modern biomass and other renewable energy systems as well as by fossil-based domestic fuels.

Global Energy Demand

In the report World Oil Outlook 2015, OPEC estimates that by 2040 global energy demand will increase by 49%, from 268 mboe/d in 2013 to 399 mboe/d. Future global demand for energy, according to OPEC is affected by many factors, these are: Technology, Laws, Regulations, Macroeconomic trends, Development processes, Global prices, Population size and Levels of urbanization.

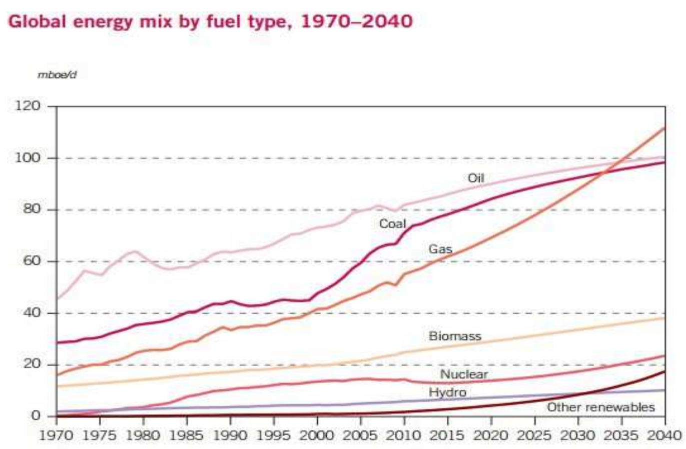


Figure 2: Global Energy Mix by Fuel Type 1970-2040

World primary energy demand in the Reference Case

	Levels mboe/d				Growth % p.a.	Fuel shares %			
	2013	2020	2030	2040	2013–40	2013	2020	2030	2040
Oil	84.4	90.1	96.1	100.6	0.7	31.5	30.2	27.9	25.2
Coal	76.1	84.2	92.4	98.3	1.0	28.4	28.3	26.8	24.6
Gas	59.2	69.1	87.7	111.5	2.4	22.1	23.2	25.5	27.9
Nuclear	13.1	13.9	17.5	23.5	2.2	4.9	4.7	5.1	5.9
Hydro	6.3	7.4	8.9	10.2	1.8	2.4	2.5	2.6	2.5
Biomass	26.2	29.1	33.6	38.1	1.4	9.8	9.8	9.8	9.5
Other renewables	2.4	4.3	8.4	17.4	7.6	0.9	1.4	2.4	4.3
Total	267.6	298.0	344.6	399.4	1.5	100.0	100.0	100.0	100.0

Figure 3: World Primary Energy Demand

Source: OPEC: World Oil Outlook 2015. Retrieved May 24, 2016

Exxon Mobil Estimation

Each year, Exxon Mobil estimates, analyses, updates on long term views on energy supply and demand. The main outcomes from a recent report from Exxon Mobil about the future global energy demand are:

- Global demand for energy rises by 25 percent 2014–2040
- Demand could have more than doubled without efficiency gains
- All demand growth comes from developing world, but China plateaus around 2030
- Demand in OECD32 falls by 5 percent 2014–2040.

It, Predicts about Future Global Energy Mix that

- Oil remains the world's top fuel, but natural gas grows the most
- Oil remains essential to transportation and chemicals
- Gas overtakes coal, driven by need for cleaner, reliable fuel
- Nuclear, renewables see strong growth; total more than 20 percent of supply by 2040
- All energy sources needed to meet rising demand to 2040 and beyond.

Some Other Future Energy Trends in this Report from Exxon Mobil are

- 40% of the growth in global energy demand from 2014–2040 is projected to be met by natural gas.
- 1/3 of the world's energy is expected to be provided by oil in 2040.
- In 2014, there were about 10 cars per 100 people in China. By 2040, this is expected to rise to about 30.

Until 2040, according to the report the Outlook for Energy 2016 Version from Exxon Mobil the future electricity generation trends are:

- World shifting to cleaner fuels for electricity generation, led by gas
- Coal's share to shrink while natural gas, nuclear, wind and solar gain

- Coal provides about 30 percent of world's electricity in 2040, vs. 40 percent in 2014
- Wind and solar will provide more than 10 percent of electricity by 2040, vs. 4 percent in 2014
- Shift to cleaner fuels driven by tighter CO2 emissions and air quality policies.

British Petroleum Estimation: According to the Report BP Energy outlook for the Year 2016, until 2035 the Annual Demand Growth for

- Oil will be 0.9%
- Natural Gas will be 1.8%
- Coal will be 0.5%
- Nuclear will be 1.9%
- Hydro will be 1.8%
- Renewables will be 6.6%.

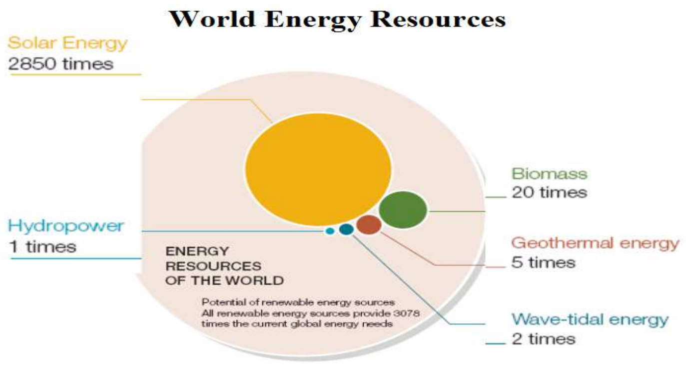
In the Same Report BP Predicts that the Future Global Energy Mix is Changing Significantly, the key Changes Will be

- Oil future share in global future energy mix is decreasing
- The combined increase of oil and gas over the Outlook is similar to the past 20 years
- Coal share in the global future energy mix will decline slightly
- Fossil Fuels will remain the primary source of energy until 2035 with a share of 80% of the future global energy mix
- Renewables share will increase from 3% today to 9% by 2035.

Based on the above chart, the oil and gas proportion in the future global energy mix until 2035–2040 will be between 53–58%, which guarantees the business future of global oil and gas companies but in a business environment with restricted rules about environmental footprint.

World Energy Resources and Challenges for Energy Producers

The world's energy mix is changing and fast. A recent report from the World Energy Council found that renewable sources of power now represent around 30 percent of the world's total capacity and 23 percent of total global electricity production. However, Fossil fuels remain key to powering the planet, and as concerns over climate change and energy security mount, the question of what our planet's energy mix will look like in 2050 is becoming increasingly pressing.



(from the EREC's *RE-thinking 2050*)

Figure 4

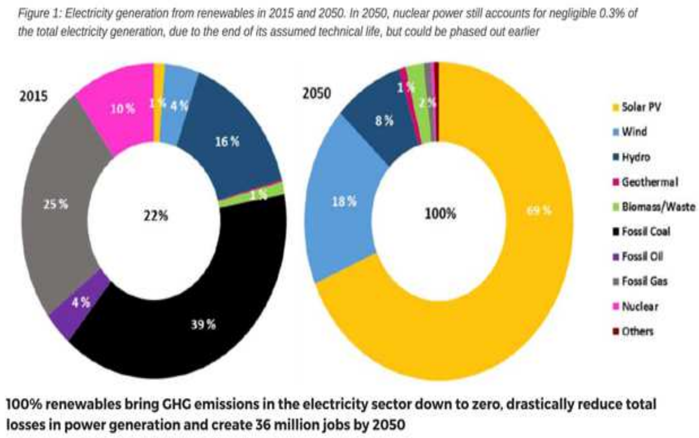


Figure 5: World Energy Resources & Energy Generation from Renewable in 2015 & 2050

Gunnar Luderer, from the Potsdam Institute for Climate Impact Research (PIK), told CNBC said "If the world is serious about tackling climate change, the world's energy mix in 2050 will have to look fundamentally different from the one we have today. Limiting global warming to well below 2°C, as agreed by the international community at the climate summit in Paris last year, requires close to carbon-free electricity supply and a drastic reduction of fossil fuel use in the industry, transportation and buildings sectors," Bearing all of the above in mind, solar looks set to have a very big role to play in the world's energy mix. In 2014, the International Energy Agency stated that the sun could be the planet's biggest source of electricity by 2050.

Solar is at the heart of this revolution. Innovative, high-tech and inexpensive, solar is a disruptive force whose growth has been highly unsettling to entrenched energy producers. It's sure that solar will power our economy in the future, but a question is when and how quickly. Other renewables are also pushing hard for a bigger slice of the energy pie. Wind energy is one such source. According to Wind Europe, the offshore wind industry in Europe saw 14 billion euros ($15.67 billion) in new investments in the coming year. Oliver Joy, spokesperson for Wind Europe, told "With the great leaps that wind energy has made in cost reduction in recent years, there is no reason why it should not be the centerpiece of energy systems around the world, particularly Europe. Costs for onshore wind are expected to fall by 41 percent by 2040 as larger turbines with higher energy capture make the economics even more attractive. Offshore wind is also rapidly moving down the cost curve." He went on to add that wind energy was able to meet 12 percent of Europe's electricity demand, with

WindEurope seeing that figure rising to 28 percent of demand by 2030, provided the right policy decisions were made. For the PIK's Gunnar Lederer, "the resource potential for solar and wind is vast." Potential of renewable Energy sources: All renewable sources provide 3078 times all current global energy needs.

Global Energy Mix Changing and the Strategic Challenge for Energy Producers

Advances in technology and environmental policy are among the factors influencing demand growth and shaping what may be a very different energy mix in the future. Our Energy view to 2035, led by Paul McConnell of our Global Trends team, distills the work of our team of analysts working across energy commodities. Five main themes leap out.

First, China has been the mainstay for two decades or more and will still be the world's biggest consumer of energy in the foreseeable future. India's emerging lead role in global energy demand growth. But China's economy is pivoting away from industrialization towards services. Environmental policy, focusing on clean air in particular, will also slow the rate of energy demand growth. India will take over the mantle, becoming the biggest growth engine in the 2020s. An economic focus on manufacturing will spur demand growth at 3% CAGR (**compound annual growth rate**) through 2035. Energy security is India's concern, as an importer of oil and gas; a planned rapid build-out of solar and wind capacity provides just part of the answer.

Second, 'Lift off' for zero carbon energy. Energy systems are being transformed by the rapid progress of technology and by regulation. Globally, carbon intensity and energy intensity have already peaked and will trend down through 2035. But the revolution, with the Paris Agreement a signal moment, has only just begun and carbon emissions continue to rise over the period. Developing economies' dependence on coal is one of the factors. But China is already showing how swiftly change can come as energy intensive/high emissions developing economy matures. Other high growth economies will follow the same path, in time.

Third, transportation goes electric. It's not going to happen quickly, but it will certainly happen. We aren't believers in peak oil demand, at least not yet - oil dominates the transportation sector and will still do so in 2035. Electric vehicles have come a long way in the last year or two, in aspiration at least. The oil industry is beginning to grasp the nettle, the Majors investing in renewables to build optionality for future proofing. The fundamentals aren't there yet for a decarbonized transport sector. But air quality initiatives in China and other emerging markets, and the audacious entrepreneurial zeal of the tech sector, point to disruption some time down the line.

Fourth, the power sector's influence on the changing commodity mix. Gas demand will grow by 41% over the next two decades, overtaking coal as the second most consumed energy source by 2030. The rise of gas consumption is a global phenomenon; as increasingly is renewables, which are set to triple their share of energy supply to 13% from 2015 to 2035. Coal will remain vital to global energy supply through the period, but incremental demand growth is isolated to India, South Korea and SE Asia, as environmental policy and competition from other fuels eat into the traditional OECD (Organization for Economic Co-operation and Development) coal heartlands.

Fifth, shifting regional supply dynamics: It is expected that US to be energy independent by 2021 and a near Saudi Arabia-scale exporter (oil and gas combined) by 2035. The EU in contrast becomes increasingly reliant on imports. Climate change policy and other regulation are dampening demand in Europe, but indigenous oil and gas production continues to decline long-term. Asia Pacific supply is set for rapid growth, driven by gas and to a lesser extent coal;

whereas oil is in decline. Most of these themes are only just emerging, and the energy mix in 2035 may not be vastly different to what it is today. But there is, presently, the sense of an incipient paradigm shift in energy consumption with decarburization at the centre - the global energy mix will look very different by 2050.

Adjusting for what the world may look like more than 20 years from now is perhaps the biggest strategic challenge ahead for energy producers.

Optimal Energy Mix from Renewable Energy sources

Determination of optimal energy mix comes down to determination of the percentage share of each component of renewable energy supply in defined boundary of the observed problem. To meet its energy needs, each country, region or defined area uses the energy available to it, in different proportions. This is what we call the energy mix. Depending on the definition of the criteria matrix for optimization, this matrix will define the possibility of applying this method on different energy supply chains and regions. For a total ranking of renewable energy chains for production of fuel or energy and selection of optimum variant, the multi-criteria optimization and VIKOR method can be applied. (VIKOR method is a multi-criteria decision making or multi-criteria decision analysis method.) In VIKOR approach, the compromise ranking is performed by comparing the measure of closeness to the ideal alternative. This is the main reason why this methodology is very good for application in the determination of the optimal sustainable energy mix. The measure of closeness to the ideal alternative is directly in correlation with percent of shares in the modelled renewable energy mix. This approach for determination of optimal energy mix have been applied and tested on several real supply bio energy chains in CHP plant, pellet plant and wood heating boiler.

It is necessary that other countries which have energy reserves and resources (potentialities), they need to pay attention to rational use of energy and the selection of future energy sources in order to provide an optimal energy mix. It can significantly affect to that with selecting effective technologies and disposable fuel. The challenge is to ensure optimal energy mix while minimizing unwanted impacts on the environment, ensure energy security, and necessity of using renewable energy, or sources that reduce overall greenhouse gas emissions.

Review of Research According to Optimization of Energy Mix

Methodologies to optimize the energy mix can be divided into two groups: methodologies appropriate to the economic objectives and methodology directed to the techno-operational objectives. As can be found in the optimization of RES in systems, which are observed with the techno-operational point of view, the methodologies typically used the following variables as the optimization criterion: reserve / backup capacity, import and export dependence, primary energy consumption and fuel saving, the share of renewable energy, carbon dioxide emissions (CO2) and the excess electricity production.

Economic optimization utilizes: societal costs or cost-benefit data, utility costs, the impact of exchange rates, the levelized cost of energy or, levelizes the unit electricity costs, the total resources spent by consumers, energy companies and government bodies, as well as marginal costs.

The idea of creating optimal mix obtained from economic approach corresponds to the situations in where the economic "effects" of RES minimize or where supply or demand strategy, claims that the integration of renewable energy economically was viable. Economic optimized mix of limited business and economic needs, reflect the views of the private sector that wants to maximize its profit.

Heide et al investigated that which is a seasonal optimal mix of RES (wind and solar energy). In doctoral thesis Vasković uses the compromise ranking method, also known as a VIKOR method. Method VIKOR introduces multi-criteria index ranking is based on individual measure "proximity", "ideal" solution, some of the analyzed alternatives.

Evaluation Criteria of Biomass Chain, Approach to Optimal Variant of Energy Production and Mathematical Model for Selection of Optimum Variant

Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. It is necessary to properly select the set of criteria which would have given a better assessment of the value chain of biomass energy. The following criteria which must be defined:

- Energy efficiency of observed chain, criteria function noted as f_{1j};
- Energy efficiency of chain, criteria function noted as f_{2j};
- The coefficient of energy quality for different products at energy chains f_{3j};
- Specific investment cost per totally installed power of all machines and plants in the energy chain, €/kW, criteria function, f_{4j};
- Production cost of energy chain per 1 kWh of the lower heating value of produced biofuels or energy, €/kWh, criteria function, f_{5j};
- CO_2 emission in the total chain due to the fossil fuels consumption for 1 kWh of the lower heating value of produced bio-fuel or energy, kg/kWh, criteria function, f_{6j}.
- Availability of usable resources on its territory and possibility for its use in defined percent, f_{7j}.

The energy chains modelling should be based on modularity. It practically means that it is necessary to do a mathematical modelling of every energy chain element as an independent entity which will for itself present a mathematical model as an elementary part of the energy chain. The mentioned criteria are different for differently defined initial conditions of a problem.

Mathematical Model for Selection of Optimum Variant and Percent of Energy Supply

The VIKOR method was developed for multi-criteria optimization of complex systems. It determines the compromise ranking list and the compromise solution obtained with the initial (given) weights. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It introduces the multi-criteria ranking index based on the particular measure of “closeness” to the “ideal” solution. Here, VIKOR optimization method is applied as a proposal of an adequate method for the solution of multi-criteria optimization related to the selection of optimal energy chain of production. The VIKOR method requires the values of all the criteria functions for all the alternatives in the form of a matrix to be familiar. Because of that, at the beginning of the optimization process we set a general form of the problem (evaluation matrix). The matrix of criterion functions for all variants of the production of fuels or energy is of 7xn dimensions, (7 criteria and n alternatives of energy production), obtained from calculation for different cases of energy chains composition:

$$F = \begin{array}{c} \\ f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \end{array} \begin{array}{c} \begin{array}{ccccc} a_1 & a_2 & a_3 & \dots & a_n \end{array} \\ \begin{bmatrix} f_{11} & f_{12} & f_{13} & \dots & f_{1n} \\ f_{21} & f_{22} & f_{23} & \dots & f_{2n} \\ f_{31} & f_{32} & f_{33} & \dots & f_{3n} \\ f_{41} & f_{42} & f_{43} & \dots & f_{4n} \\ f_{51} & f_{52} & f_{53} & & f_{5n} \\ f_{61} & f_{62} & f_{63} & \dots & f_{6n} \\ f_{71} & f_{72} & f_{73} & & f_{7n} \end{bmatrix} \end{array} \quad (1)$$

Where:

$\{a_1, a_2, a_3, \dots a_n\}$, j = n, are a finite set of possible alternatives for the n energy chains of production, $\{f_1, f_2, f_3, f_4, f_5, f_6, f_7\}$, i = 7, are a finite set of criterion functions for five defined and adopted criteria on the basis of which the chains of energy production from biomass are analysed, $\{f_{11}, f_{12}, \dots, f_{7n}\}$ are the set of all the criterion functions values in matrix F. An ideal solution is determined on the basis of the criterion functions values from the equation:

$$f_i = \underset{j}{\mathrm{ext}}\, f_{ij},\ i=1,\ 2,\ \dots,\ 7. \quad (2)$$

The operator ext denotes a maximum if the function f_i describes a benefit or profit, and a minimum if f_i describes damages or costs or others variables which are interest to optimize (minimization or maximization criterion functions). This is the best way to define an ideal solution for energy production from different energy chains based on biomass. The criterion functions within the matrix F are commonly not expressed in the same units of measurement (i.e. the belonging criterion space is heterogeneous). For that reason, to perform the use of multi-criteria optimization at all it is necessary to convert all the criterion functions to dimensionless functions whose values will be in the interval [0, 1]. It process is called the normalization of dimensional units in area of multi-criteria mathematics. Firstly, the best values of criterion functions are determined. In our case, those are the maximum values of four criterion functions (energy and energy efficiency, the coefficient of energy quality for different products at energy chains and availability of usable resources) and minimum values of the other three criterion functions (minimization of: CO_2 emission per 1 kWh produced energy, production cost per 1 kWh produced energy and specific investment cost per an installed kilowatt in the production chain). Then we have mathematically:

$$\begin{array}{l} \max f_1(f_{1j}) = f_1^*, \quad \max f_2(f_{2j}) = f_2^*, \quad \max f_3(f_{3j}) = f_3^*, \\ \min f_4(f_{4j}) = f_4^*, \quad \min f_5(f_{5j}) = f_5^*, \quad \min f_6(f_{6j}) = f_6^*, \end{array} \max f_7(f_{7j}) = f_7^*. \quad (3)$$

In the same way, the worst values of the criterion functions can be determined, which are obtained by the same criterion functions:

$$\begin{array}{l} \min f_1(f_{1j}) = f_1^-, \quad \min f_2(f_{2j}) = f_2^-, \quad \min f_3(f_{3j}) = f_3^- \\ \max f_4(f_{4j}) = f_4^-, \quad \max f_5(f_{5j}) = f_5^-, \quad \max f_6(f_{6j}) = f_6^-. \end{array} \min f_7(f_{7j}) = f_7^-. \quad (4)$$

Then all the elements of the matrix f are converted in the value domain [0, 1]. That is achieved by the following formula:

$$d_{ij} = \frac{f^* - f_{ij}}{f_i^* - f_i^-}, \text{ and a matrix is formed, in the form } D = \left[d_{ij}\right], \text{ for i=1...7 and j=1, n.} \quad \textbf{(5)}$$

Considering the difference $f_i^* - f_i^-$ in the expression for d_{ij} it is necessary for all the elements of matrix D to be the values in the interval [0, 1]. The value of criterion functions is obtained by maximization or minimization of criterion functions. The criterion weights for our problem related to ranking variants of energy chains, for the defined main six criteria are mutually equal. The reason for that is very simple, because we strive for the minimal: CO_2 emission amounts, production cost and specific investment cost per totally installed power in the energy chain. Also, in the same time, our aims are maximization of energy efficiency and energy efficiency, quality of energy forms and availability of usable resources. All criteria functions have equal weight and importance. Due to that, it will be valid that the criterion weights are:

$$w_1 = w_2 = w_3 = w_4 = w_5 = w_6 = w_j = \frac{1}{7}. \quad \textbf{(6)}$$

After that, the values of the elements of matrices S_j and R_j are calculated. Considering the equality of the criterion weights, they are obtained as:

$$S_{j=1...n} = w_j \cdot \sum_{i=1}^{7} d_{ij} = \frac{1}{7} \cdot \sum_{i=1}^{7} d_{ij} = \left[\frac{1}{7} \cdot \sum_{i=1}^{7} d_{i1}, \frac{1}{7} \cdot \sum_{i=1}^{7} d_{i2}, \frac{1}{7} \cdot \sum_{i=1}^{7} d_{ij}, ... \frac{1}{7} \cdot \sum_{i=1}^{7} d_{in}\right],$$
$$R_{j=1...n} = w_j \cdot \max_i \left[d_{ij}\right] = \left[\frac{d_{i1}\max}{7}, \frac{d_{i2}\max}{7}, \frac{d_{ij}\max}{7}, ... \frac{d_{in}\max}{7}\right]. \quad \textbf{(7)}$$

In this way, the problem is reduced from a multi-criteria space to a two-criterion problem. The values of minimal and maximal element are determined from the matrices S_j and R_j.

$$S^* = \min_j S_j, \; S^- = \max_j S_j, \; R^* = \min_j R_j, \; R^- = \max_j R_j. \quad \textbf{(8)}$$

The decision strategy weight will be taken as $\upsilon = 0,6.$ this is valid for the criterion number m=7. For other case and number criterion m, we have:

$$\upsilon = \begin{cases} 0.5, & m \le 4 \\ 0.6, & 5 \le m \le 10 \\ 0.7, & m \ge 10 \end{cases}. \quad \textbf{(9)}$$

On the basis of that, it is possible to calculate the value of the matrix q_j pursuant to the formula:

$$q_j = \upsilon \cdot \frac{\left(S_j - S^*\right)}{S^- - S^*} + (1-\upsilon)\frac{R_j - R^*}{R^- - R^*}. \quad \textbf{(10)}$$

A certain value of q_j corresponds to every chain, in the following matrix:

$$Q_j = \begin{bmatrix} CH_1 & CH_2 & CH_j & CH_n \\ q_1; & q_2; & q_j; & q_n \end{bmatrix} \cdot \; Q^* = \min_j Q_j \qquad \textbf{(11)}$$

The optimum variant of production is defined by the minimal value. The ranking of alternatives is formed from the lowest value of q_j to the highest value of q_j, that is from the best to the worst variant. In our case, the alternatives are the mentioned energy chains for fuels and energy production.

Possible Proposal for Calculation of Optimal Shares in the Components of Energy Supply

After calculating values in matrix Qj, we can calculate the optimal percent of shares for all components of mentioned energy supply chains according with following formula:

$$p_j = \frac{(1-q_j)}{\sum_{j=1}^{n}(1-q_j)}. \qquad \textbf{(12)}$$

Where is $(1-q_j)$ measure of closeness to the ideal alternative of energy chain and j is the number of energy supply chains. This value is directly related to the distribution of the optimal percentage of the energy production in overall observed energy supply mix.

Acceptable Advantage and Stability of the Selected Variant of Optimal Energy Chain on the Basis of the VIKOR Method

This step is after the selection of optimal variant, values of ranks in matrix Q_j and calculation, percent of shares of different components of energy chains in the energy supply mix. If the cases are analyzed in which the values of criterion weights are different and some criteria are given a greater importance in relation to the others, the stability of the obtained solution should be checked on the basis of the VIKOR method. The alternative (a’) is suggested as a compromise solution, which is the highest ranked value on the Q measure (matrix). Then, two conditions have to be met:

Acceptable Advantage

$Q(a'') - Q(a') \geq DQ$ **(13)**

Where: a" is the second-position alternative on the rank list (Q);

$DQ = 1/(m-1)$ is advantage threshold; **(14)**

Where: m is the number of alternatives (energy chains)

Acceptable Stability

The alternative a’ should also be ranked as the best in S and/or R rank (matrix). In that case, the solution has been selected correctly.

Method VIKOR is one of multi-criteria optimization methods with which ranks different variants of conceptual solutions from the best to the worst. The ranking is done according to the closeness of the observed values q_j calculate the ideal point defined in accordance with the given parameters of the problem. These are the values from a matrix Q_j. The highest ranked value is the one which is closest to zero, i.e. ideally coincides with a predetermined point, while the worst is the one corresponding to the value 1 according to the normalization process conducted adopted criteria. This closeness is ideal defined point that can be used for the issue of how the ranking of alternatives but also to define their character to participate in a defined set of observed variants. Except that method VIKOR can rank the various chains of energy production, also can be calculated and percentage share of participation observed variants of energy supply. This is accomplished with the help of the calculated values of the rank of the matrix Qj. Practically, it means, that the percentage share of the individual components of the energy supply with its defined value of the ideal distance from the point $(1-q_j)$ and opposite to the sum of the individual values of distance from the ideal point for all variations of the energy production analyzed $\Sigma\ (1-q_j)$. So that, any given state of the optimization criteria of the energy chains from F_j corresponds to one optimum redistribution of their participation in the production of energy defined with the values Q_j of the matrix according to a previously proposed concept. It was intended to open towards the direction of defining the optimal energy mix with the application of criteria optimization.

CONCLUSIONS

The appropriate energy mix and energy strategy agenda of a region/country need to be planned long-term, 30 - 40 years span at least. The plans should not be address-isolated and neighboring regions/countries should have to be considered or even contributing. It is possible to achieve a sustainable and satisfactory energy mix agenda for a region/country, provided that impartial factors, and their correlation, effects and implications between them have been identified and assessed by experts and capable people (scientists, engineers, humanists, sociologists, economists, etc.), leaders and decision makers together, addressing realistic targets. More strength is needed to put the global energy system in a more sustainable path. Fossil fuels keep playing a key role in the global energy mix; technology improvements for emission mitigation and efficient integration of renewable sources are increasingly possible scenarios on the way to enhance sustainability. Energy-efficiency policies can play a key role managing demand, thus reducing pressure on the supply side without detriment of growth. Consumer behavior, technology developments and challenges in direct financing have slowed energy efficiency in realizing its full potential. Water and electricity are highly interconnected, being both two of the most important energy vectors. Water constraints could affect the reliability of operation and viability of projects, imposing in some regions additional costs. The future of electricity could be in the home, with individuals generating enough power to satisfy their own needs, although large located electricity generation centers will still be necessary.

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