Technology forecasting using TRIZ on global production trend of non-fossil fuels.

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Abstract: Technology forecasting is helpful in deriving insights on utilisation of resources effectively. The analysis helps in decision making towards preserving the resources and exploring alternative means that meet the increasing demands of the society. Generative models that comprise of probabilistic forecasting of changes in technology and discriminative models such as logistic are popular towards such estimates. Global non-fossil fuel production data in particular the solar, nuclear and wind are considered and forecasting models are developed. The present work highlights the predominant exploration of the energy generation based on wind is expected to be prominent during next few years. The approach in general can be applied to similar studies. These results reflect the importance of such studies and associated information towards forecasting based decision-making pertaining to the technology trends.

Keywords— Technology forecasting, non-fossil fuels, loglet lab 4, TRIZ, S curve

1. Introduction:

Technology forecasting plays an important role in planning of effective utilisation of resources for sustainable development. Globally, consumption of power is increasing day by day and it has become imperative to look for non-fossil fuels having less carbon foot print. Even though fuels like shale gas, tight oilare promising, there is a lot of scope to explore such fuels [1-5]. On the other hand,non-fossil fuels such as nuclear, wind and solar energy are beingexplored globally. To curb the consumption of the energy irrationally, government has to strategize energy policy by promoting diverse energy portfolio's and encouraging industrial sectors using clean energy. Predicting the trend in the global production of the non-fossil fuels will help thedecision makers to streamline the diverse energy portfolio among the industries by reducing the burden on the conventional energy resources. Industries embracing the fuels with less carbon emissions strategizing their energy consumption will be benefitted by earning carbon credits [6,7].So, inputs from technology forecasting studies are useful for taking an informed decision.

There are two popular approaches for doing technology forecasting, exploratory and normative. Exploratory approach comprises of Delphi, analytical methods, multivariate analysis, growth models etc. Normative approach involves, operation research models, SEER, Relevance trees, dynamic modelling etc [8-10].Choosing an appropriate technique for a particular situation is complex and depends on various factors like, purpose of prediction, reliability, precision, time period of data, other interdependent factors etc. Even though there are various methods for technology forecasting, it is acknowledged that they are lacking in the consideration of multidisciplinary aspects contributing either directly or indirectly to the problem leading to inaccuracies in forecasting. To overcome this, a methodology is adapted in TRIZ, applied across the industrial domain.

TRIZ methodology with commercial software is developed by scientist Genrich S. Altshuller and his colleagues in 1989. In the inventor's words, "TRIZ is general theory of advanced thinking." TRIZ is an acronym for "Theory of Inventive Problem Solving" [11-14]. Application of TRIZ methodology is widely observed for both engineering and non-engineering systems as well.

Due to climate change, sustained growth of society and economy, demand for fuels with less carbon emissions are paving a path for new energy revolution. For green ecological environments, nuclear, wind solar energies have become increasingly prominent. If we assume, oil industry has a life cycle of 300years and it started in 1859, now we still have 150 years [15-16]. So, before its depletion, new energy revolution comprising wind, solar, nuclear, geothermal are showing promising prospects.

In the present work, data for Global non-fossil fuel energy production is taken to fit in the log let lab 4 [17]. The data source comprises of global production of nuclear, wind and solar energies in the previous years and using log let lab, a prediction is made for the global production of these fuels. By studying the energy trends globally right from the past, transformation of using wood as energy to coal and then liquid to gas us observed. In the coming years, there will be another energy revolution focusing transformation from fossil fuels to non-fossil fuels.

2. Materials and Methods:

In the present work, for carrying out technology forecasting of global production of non-fossil fuels like nuclear, wind andsolar, data for nuclear power is taken from IAEA (International Atomic Energy Agency) from the year 1954 to 2015, for wind the data is collected from GWEC (Global Wind Energy Council) from the year 1996 to 2015, for Solar power, the data is collected from Clean Energy Business Council from the year 1992 to 2017[18-20]. This data is used to fit in the Loglet Lab 4[17] for predicting the global production of these non-fossil fuels. Over the decades, several growth curve studies were carried to predict the growth of technology and among them studies on 'S' curve are used for forecasting technological performance. A curve is plotted for technology performance right from its inception and the graph is extrapolated to predict its performance in the future by considering other multidisciplinary technological advancements. S shaped curve used in this study is a mathematical model, logistic curve, estimating the growth of technology in each stage. Typically, 'S' curve comprises of inception, growth, maturity and decline stages mimicking biological cycle. Within each stage of development, technological advancements are studied based on TRIZ methodology. Further, the curve is extrapolated, to arrive at a logical forecasting of the technology.

Loglet lab software was developed by Rockefeller University in 1994, for performing analysis on time-series datasets. An analogy is drawn between the life cycle of a technology and the growth of the sunflower. After the germination of the seed, the growth rate is fast and it stops before reaching 20 feet. A logistic equation is developed on the parameters, germination time, growth and saturation limit. In loglet lab software, logistic equation is applied on observation series collected over a period of time.

3. Results and Discussion:

S curve has three important stages. In a logistic curve, it is assumed that growth of the system is exponential till it reaches maximum capacity inherent to the system. At this point of the cycle, it can be said that the technological advancements are at the stage of maturity or saturation. In loglet lab, the 'S' curve is a regression model testing non-linearity between the technology versus time.

After a sunflower seed germinates, the plant grows faster and faster because each cell produces two, then the two produce two and so on. But multiplication does not go on ad infinitum because the seed produces a sunflower, not Jack's beanstalk; a sunflower stops before it reaches 20 feet. The simplest description is the so-called logistic equation of three parameters: the time of germination, the relative rate of growth and the limit. Loglet Lab fits a single logistic equation to a series of observations through time.

3.1 S-Curve analysis:

Various studies were carried out by researchers for understanding non-linear growth of different disciplines of knowledge [21,22]. For this reason, it has different names like logistic curve, pearl curve, Richard's curve, sigmoidal curve etc., Researchers have used'S' curve to forecast trends in different domains of knowledge. In the present work, TRIZ methodology is used for forecasting global energy production of non-fossil fuels like nuclear, wind and solar. Fig.1. shows the 'S' curve obtained from loglet lab 4 using the TRIZ methodology. 'S' curve symbolises cumulative growth and is logistic implying that the rate of growth is proportional to the growth accomplished and the amount of growth to be accomplished.

Let the production of non-fossil fuel is represented by N. The production rate is proportionate to the amount of production. This can be represented by an equation:

$$\frac{dN}{dt} \propto N \qquad (1)$$

Solution of this equation has two components -$\alpha = N(0)$ time independent component and subsequent time dependent component. $N(t) = \alpha\, e^{\beta t}$. Here α is growth rate constant. and β is growth rate. Though the non-fossil fuel production growth is expected to grow at a faster rate, it is not necessary that growth rate is sustained considering the pure exponential growth under various external parameters such as consumption levels, global factors. Hence logistic correction to the exponential model can be more realistic. The corresponding logistic model can be obtained by introducing damping factor (**κ**) representing the slowing down of this rate.One can obtain the resulting equation as:

$$N(t) = \frac{\boldsymbol{\kappa}}{1+\exp\{-\alpha(t-\beta)\}} \quad (2)$$

The equation (2) above is akin to sigmoid function expect that the asymptotic value is **κ**instead of 1 (which is the case in case of sigmoid function). Consider denoting $z = \alpha(t-\beta)$, as z →∞ it approaches κ/2as t →*β.* This can be converted into the characteristic duration indicating the time period (Δt) during which N can grow from 10% to 90% of the limit damping factor. The resulting equation is given by:

$$N(t) = \frac{\kappa}{1+\exp\{-\ln(81)\,/\Delta t\,(t - t_m)\}} \qquad (3)$$

The parameter β specifies the time that corresponds to the value of N =0.5κ, denoted by t_m, mid- point trajectory.It is evident from the data that κ*Wind* is twice that of κ*Nuclear* reflecting that nuclear energy is sustainable non-fossil source of energy compared to other two counterparts. It can be seen that nuclear energy production is increasing but almost appearing to be constant. International Energy Outlook (IEO) in 2016, made a forecast that nuclear energy production across the world is increasing by 2.3% every year and the present study is also in agreement with the statement [21]. As per October 2021 statistics, World's 10% electricity contribution is from 440 power reactors and is the second largest source for low carbon power. Covid-19, has influenced many sectors and power sector is no exception. During the pandemic situation, uninterrupted power supply was crucial to handle the global medical crisis.

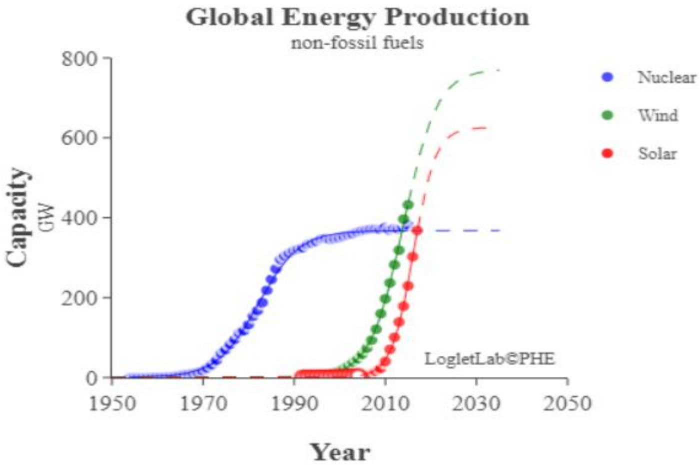


Fig1: 'S' curve statistic on global production of nuclear (blue), wind (green) and solar (red)

As observed in the graph, the wind power is showing a significant increase in the forecast. From the reports of GWEC, growth of wind power has to be tripled in a decade to mitigate with climate change. Beyond 2030 also, global production of wind power will increase towards sustainable power. During the pandemic situation also, wind power has made a record in 2020 with an increase of 93GW in its newproduction capacity. As observed in the Fig: 1, Solar power will see a steep rise in its production capacity. According to International Energy Agency (IEA), there will be an average addition of 125 GW solar power annually from 2021 onwards and there can be an increased growth also with global market giant players like US, China and European countries. The same prediction is also observed in the study taken up by International Renewable Energy Agency (IRENA)[22].

3.2 Component Analysis:

The non-fossil fuel production is akin to some of the diffusion processes which can be viewed in terms of say, bi-logistic or two growth phases sub processes namely, N_1, N_2:

$$N(t) = N_1(t) + N_2(t)$$

In this analysis we highlight two different phases of overall growth and one can extend this to multiple number of phases based on the nature of the use case and the S curve.

The individual phase component expressions can easily obtain using equation (3) with respective parameters of $N(t;\ \kappa,\ \ \Delta t, t_m)$. The phase 1 curves are given below in Fig2:

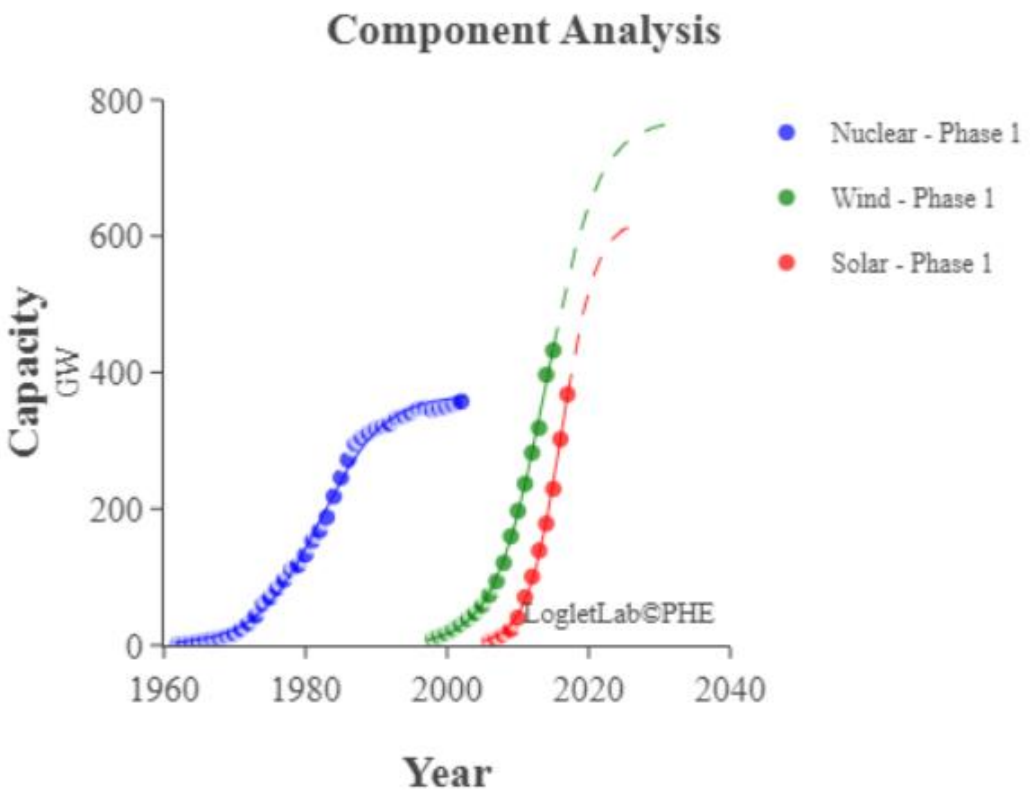
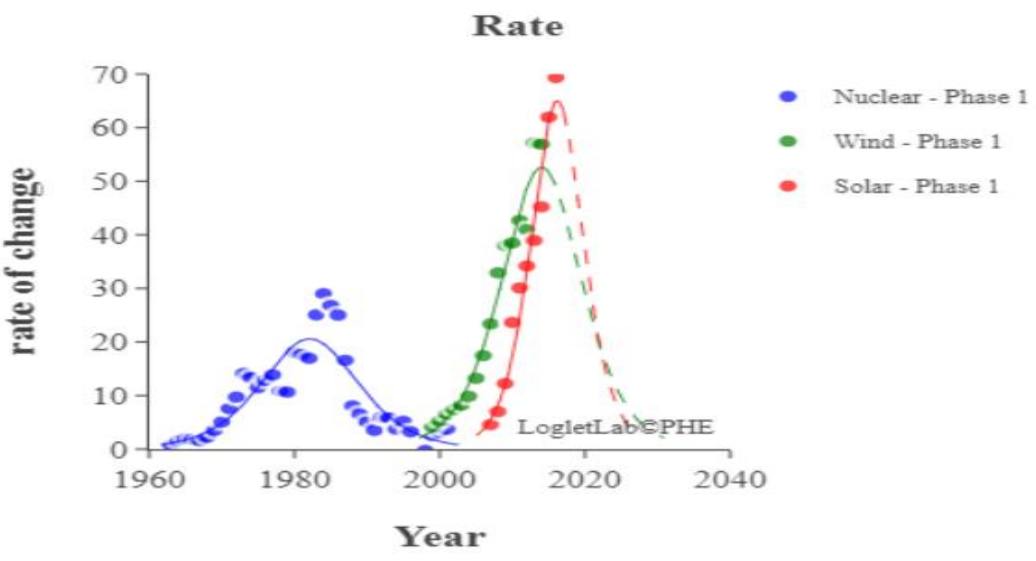


Fig2: Componenet analysis on global production of nuclear (blue), wind (green) and solar (red)

The corresponding rate of changes pertaining to the Phase1 are of helpful as phase2 is relatively slower. These rates are plotted and given in Fig3:

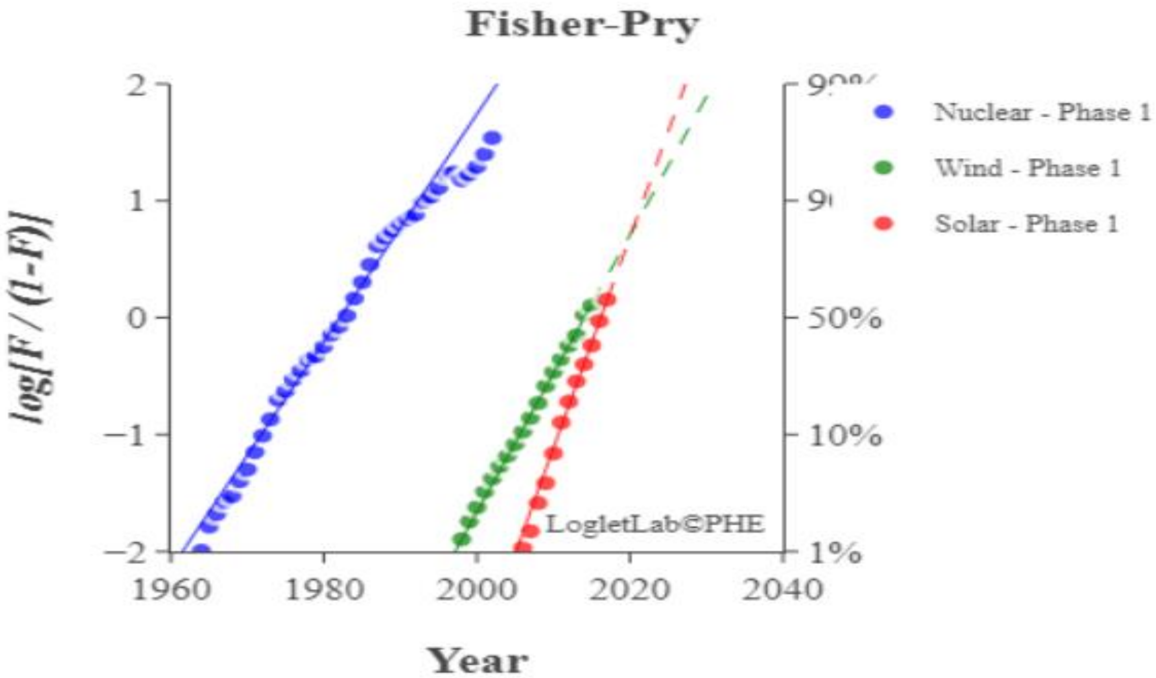


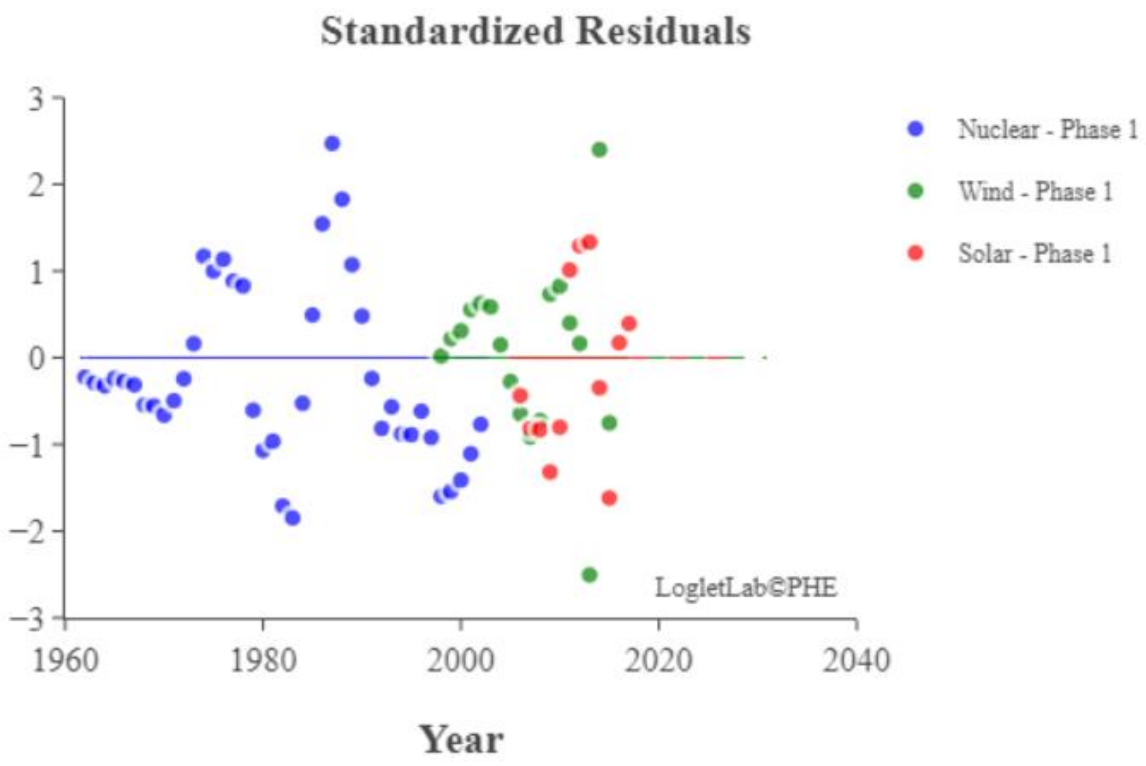
3.3 Fisher-Pry plots:

Fisher-Pry (FP) plots provide better visualization of the logistic model where the logistic growth can be noticed using linear function in logarithmic scale. Using the transformation, we consider $F(t) = N(t)/\,\kappa$ and perform the semi-logarithm transformation FP:

$$\ln\big(\mathrm{FP(t)}\big) = \frac{ln81}{\Delta t}\{t - t_m\}$$

With FP(t) = $\frac{F(t)}{1-F(t)}$; $F(t) = \frac{N(t)}{\kappa}$





4. **Conclusions:**

Non-conventional energy sources play an important role in minimising the carbon footprint and protecting global eco-system. In the present work TRIZ based technology forecasting model isused to understand the non-fossil fuel production over a time period beginning with 1960. We considered global production of non-fossil fuelsdatasetthat comprises of Nuclear, Wind and solar data. In the present work,log let lab is explored and forecastingmodels are developed using logistic and component analysis. These results indicate Δt values for nuclear, wind and solar data are obtained as 22 years while that of solar energy is 15.3 years. The corresponding $t_m$values for nuclear, wind and solar data are 1982.313, 2027.874 and 2026.531 respectively. The forecasting model highlights importance of nuclear fuel as non-fossil energy resource compared to the wind and solar energy in terms of production and overall growth rate. These studies highlight wind resources production will be considerably high growth rate compared to the past (early nineties and before 2020).

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References:

1. IEA (2021), *Global Energy Review 2021*, IEA, Paris https://www.iea.org/reports/global-energy-review-2021
2. World Energy Council. (2019). World Energy Scenarios 2019: Exploring Innovation Pathways to 2040.

3. Turton, H., Panos, V., Densing, M., & Volkart, K. (2013). Global Multi-regional MARKAL (GMM) model update: Disaggregation to 15 regions and 2010 recalibration. *Villigen (CH). url: www. psi. ch/sites/default/files/import/eem/PublicationsTabelle/PSI-Bericht_13-03. pdf*
4. Kober, T., Panos, E., & Volkart, K. (2018). Energy system challenges of deep global CO 2 emissions reduction under the World Energy Council's scenario framework. In *Limiting global warming to well below 2° C: energy system modelling and policy development* (pp. 17-31). Springer, Cham.
5. Tanveer Ahmad, Dongdong Zhang, A critical review of comparative global historical energy consumption and future demand: The story told so far, Energy Reports, Volume 6, 2020, 1973-1991,ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2020.07.020.
6. Li Shanshan, Siu Yam Wing, Zhao Guoqin, Driving Factors of CO2 Emissions: Further Study Based on Machine Learning , Frontiers in Environmental Science, 9, 2021, https://www.frontiersin.org/article/10.3389/fenvs.2021.721517,10.3389/fenvs.2021.721517.
7. Acheampong, A. O. (2018). Economic Growth, CO2 Emissions and Energy Consumption: What Causes what and where? *Energ. Econ.* 74, 677–692. doi:10.1016/j.eneco.2018.07.022.
8. Gaetano Cascini, Niccolò Becattini, Igor Kaikov, Sebastian Koziolek, Dmitry Kucharavy, Christopher Nikulin, Pierluigi Petrali, Mateusz Slupinsky, Mahmoud Rabie, Balachandar, Ramadurai, Luca Ruggeri, Katrien Vanherck, FORMAT – Building an Original Methodology for Technology Forecasting through Researchers Exchanges between Industry and Academia,Procedia Engineering,Volume 131,2015,1084-1093,https://doi.org/10.1016/j.proeng.2015.12.426.
9. Crawford, Megan & Wright, George. (2016). Delphi Method. 10.1002/9781118445112.stat07879.
10. Kendall, Julie E. et al. 'SEER: A Divergent Methodology Applied to Forecasting the Future Roles of the Systems Analyst'. 1 Jan. 1992: 123 – 135.
11. Ekmekci, Ismail & Nebati, Emine. (2019). Triz Methodology and Applications. Procedia Computer Science. 158. 303-315. 10.1016/j.procs.2019.09.056.
12. Kim Jung-Hyeon & Lee Jun-Young South, "The Acceleration of TRIZ Propagation in Samsung Electronics", in Proc. ETRIA TRIZ Future 2005 Conference, Graz, Austria, November 16-18, 2005, Leykam Buchverlag, 2005.
13. Mann D. & Domb E., "40 Inventive (Management) Principles With Examples", The Online TRIZ Journal, September, 1999. http://www.triz-journal.com/archives/1999/09/a/index.html.
14. Webb, A., TRIZ: an inventive approach to invention. Eng. Manage. J., 117–124, June, (2002).
15. Caineng Zou, Qun Zhao, Guosheng Zhang, Bo Xiong, Energy revolution: From a fossil energy era to a new energy era, Natural Gas Industry B, Volume 3, Issue 1, 2016, Pages 1-11.
16. Paulauskiene, Tatjana. (2018). Petroleum Extraction Engineering. 10.5772/intechopen.70360.
17. Jason W Yung, Perrin S Meyer, Jesse H Ausubel, The Loglet Lab Software: A Tutorial,

Technological Forecasting and Social Change, Volume 61, Issue 3, 1999, Pages 273-295.

18. https://www-pub.iaea.org/mtcd/publications/pdf/pub1032_web.pdf
19. https://www.gwec.net/wp-content/uploads/2015/03/GWEC_Global_Wind_2014_Report_LR.pdf
20. https://www.nrel.gov/docs/fy19osti/72170.pdf
21. https://antares.dci.uia.mx/eortiz/Gestion_de_la_Innovacion_Tecnologica/Archivos_files/ExploringLimitsSCurveClaytonCh.pdf
22. Zartha, J.. (2016). S- - Curve analysis and technology life cycle. Application in series of data of articles and patents. Espacios. 37. 19.