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Global Prospective Electricity Systems Generation to the year 2025

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Abstract. This article presents a prospective study on the power systems and its primary energy sources in the world until 2025. The implementation of strategic planning was made by tools such as SWOT and SPACE matrices. The methods used in the prospective study were MACTOR and SMIC, which allowed prospective analysis of systems of electricity generation by 2025. For the development of the study was required to consult relevant information from the last 30 years in the energy aspect of the different regions of the world, as well as research on technological development in electricity generation. This article can be a valuable tool in the planning of energy resources as it addresses the experiences of other countries.

Key words

Prospective, DOFA, PEEA, energy resources, electrical systems generation, MACTOR and SMIC.

1. Introduction

Currently, the dependence of the society for conventional energy resources in order to produce electricity is a major concern. In this context situations such as the oil crisis of the 70's, the recent increase in oil prices in the early twenty-first century, the growing concern about environmental degradation, in addition to the constant changes in prices of energy mix global states a need for checking what countries are doing to deal with adverse situations in the supply of energy.

The global economic crisis in the last quarter of 2008 has caused great changes in international markets particularly in the financial markets. The rapid economic growth in several countries stopped what has caused financial problems in the implementation of development policies. The effect of this global crisis has been reflected in a reduction for electric demand, which provoked adverse economic consequences to the world.

Therefore, planning in order to achieve certain objectives is so complex, since there are many possible events, including pandemics, terrorist attacks or technological advances which can have a major influence on the outcome of the planning. Then, it is necessary to evaluate the factors that may affect the sustained and adequate evolution of power systems. This situation highlights the importance of using modern techniques for strategic planning and foresight that allow identifying trends and driver of change in power systems.

First section shows a comprehensive review of the current state of power systems in different regions and countries according to their economic and political importance. The second section presents the developed methodology for the implementation of strategic planning and prospective analysis. In third section, the implementation of the proposed methodology is showed. Finally, it is proposed some elements for discussion about the possible development of power systems.

2. Current status of power systems in the world

The development of electricity production in the world since 1980 until 2006 is presented in Fig. 1. It shows that the increase in electricity demand has been remarkable over the last 30 years, where the economic growth in many countries have contributed to this increase in energy consumption, specially electricity.

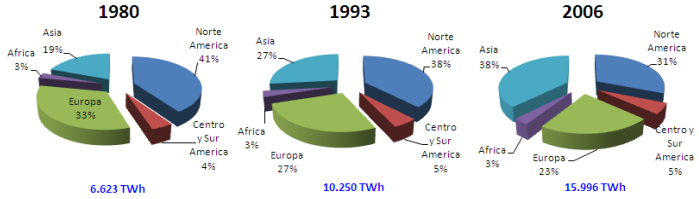

Fig. 1. Development of global electricity production from 1980 until 2006. Source: EIA [1].

A. Power generation in Asia

Asia is the most extensive and populated continent of the world with approximately 45 million km^2, that represents 8.65% of the total of the terrestrial surface, and, 4 thousand million habitants that cover 60 % of the human population roughly. Asia has the largest reserves of minerals in the world, and it concentrates the greatest worldwide economic growth. Globally, on this continent is made the highest investment in science, technology and education, which is reflected in a steady growth in different economic sectors.

Cooperation between government and industry, as well as the growing technological development placed several Asian countries among the most successful in the global economy. Figure 2 shows the evolution of electricity consumption from 1980 until 2006. China is the country with the highest demand for electricity, among other reasons because it has the highest population density in the world. Since 1980 economic growth is notable mainly due to the reform of economic policies adopted by China in 1979 which allowed the opening of international markets. Electricity consumption in 1980

was close to 300,000 GWh, while in 2006 exceeded 2.5 million GWh [2].

On the other hand, Japan is one of the major economies of Asia, its electricity consumption in 2006 was 1,000,000 GWh, the evolution of its electricity consumption has remained at stable levels from the early 90's, despite the slight slowdown that stand in this decade due to excessive investment in the 80's, in addition to the difficulties experienced by housing policies.

Finally, since 2000 India has become the third largest economy in Asia, its electricity consumption in 2006 was 500,000 GWh, while in 1996 was around 250,000 GWh, i.e. within a decade its consumption has doubled, this is a result of economic policy reforms aiming to encourage their participation in the global free trade [2].

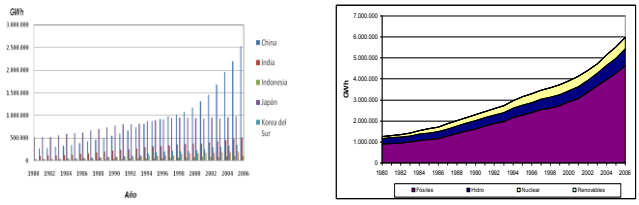

Fig. 2. Sources of electrical power systems generation for electric power in the Asian continent. Source: EIA [1].

B. Power generation in África.

The African continent is the third largest in the world; its population is about 1,000 million representing 16% of world population. Because of their status as former European colonies, most African countries have close economic relations with the European Union (EU).

South Africa is one of the fastest growing African countries. Since 80's, it has a higher consumption of 100,000 GWh, which remained in the 90s, reaching a point where consumption surpassed the 200,000 GWh in 2002. Since the 80's, South Africa has an electricity consumption exceeding 100,000 GWh, which remained in the 90s, in 2002 surpassed the 200,000 GWh[2].

Unfortunately since 2005 the impressive industrial development in South Africa had to decline, mainly to the lack of electricity infrastructure and poor investment to expand the capacity of the electrical system which accompanies the rate of economic growth that the country was developing.

C. Power generation in Europe.

Europe is the smallest continent in terms of area, which covers about 2% of the planet's surface. From Europe, Russia is the largest country in both area and population, while the Vatican is the smallest. Europe is the third most populous continent after Asia and Africa, with around 732 million habitants.

The Europe economy is the largest in the world, many of its states belong to called as first world countries. Germany is economically the most powerful nation in Europe, followed by France, the United Kingdom and Italy.

There is a marked difference in economic wealth of the various European countries, while in the five major economies, GDP is over 20,000 euros per person in other countries such as Moldova barely exceeds 2,000 euros per person. Much of the dynamics of the continent economy depends on the European Union (EU).

According to an economic and monetary union it is used a unique currency within the unique market, where people, goods, services and capital move without restrictions, including the exchange of electric power. The trade between EU member states reaches 60% of their total trade. The most important country in the region is Germany, which despite the construction of the Berlin Wall in the early 60's, what marked the division between East Germany and West Germany, their consumption of electricity has been the highest in Europe.

After the Berlin Wall fall in 1989 the electricity consumption decreased due to the reunification of Germany, while in the year 1987 had a demand of 520,000 GWh, it became a low point of 480,000 GWh in 1994. However, its electricity demand in 2006 was 550,000 GWh[2].

France is the second largest consumer of electric power in Europe with a consumption of 450,000 GWh in 2006. Despite its limited natural resources, France is partly independent because of the nuclear industry, which represents 78% of the total national electricity production.

The UK consumed 350,000 GWh in 2006, mainly due to its strong presence in the manufactured sectors and heavy industry for so-called emerging countries.

In Europe Fig. 3 shows that coal is almost one third part of primary energy source for generate electricity, producing about 550,000 GWh of electricity. Moreover, there are countries that rely heavily on coal for electricity between them Germany, where coal provides about 55% of total generation, and Poland, where it provides 95%.

Since 1971, coal has remained the main source of power generation, reaching its peak between 1981 and 1991, this fell slightly as a result of including new sources of generation such as renewable energy and power generation through combined cycle. Nuclear energy is the second most important Europe's power source, its installed capacity is about 140 GW in 2005. Another important resource is the gas, this is an energy source which high growth which is expected to generate electricity according to the enormous resources owned by Russia.

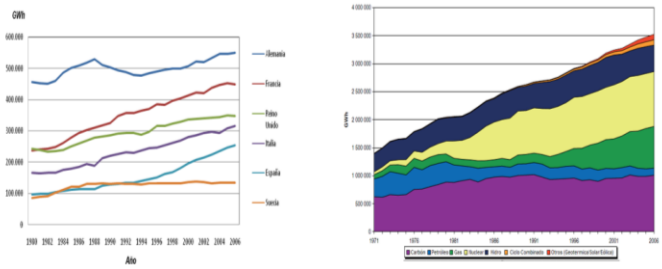

Fig. 3. Energy sources for electricity power systems generation in Europe. Source: IEA [1].

The country with the largest installed power capacity in Europe is Germany with 120,376 MW by 2005, representing 15% of the total power installed in Europe. France holds the 14% and United Kingdom, 9%. Then, these three countries encompass 38% of the total capacity of power generation on the continent, which is 801,151MW [2].

On the other hand the growth in installed capacity in recent years has remained constant, for Germany from 1997 to 2005 was 8%, in the same period France had a growth of 7%, UK 10%, while Sweden has not produced an increase in installed power capacity. Spain and Italy had the fastest growing in terms of power capacity from the year of 1997-2006; Italy had an increase of 25%, while Spain's growth was 38%.

D. Power generation in Northamerica

North America is a subcontinent that is part of America. In 2009 its population was estimated at 448 million habitants. It is considered the third continent in terms of area, after Asia and Africa, and fourth in population after Asia, Africa and Europe.

The countries in this sub continent are United States (U.S.), Canada and Mexico, which developed a Free Trade Agreement (NAFTA), what is a trade bloc that establishing a free trade area. In 2005, electricity generation in North America was 4.9 million GWh, accounting for 28% of the global total generation.

The U.S. is the largest consumer of electricity in North America; it is believed that it continues in coming years. Canada and Mexico are important countries which remain at a competitive level with the United States, due to the close trade relations between them. There are large differences in the mix of energy sources used to generate electricity by the countries in North America.

In the United States, coal is the main source of energy for electricity, which represents 50% in 2006. While in Canada, renewable energy sources (mainly hydropower) represent 60% of its total production at the same time. Most electricity generation in Mexico is currently generated by coal, oil and gas, constituting between 61% for electricity production, according to statistics from 2006.

Fig. 4 shows both the electricity consumption by the three countries that make up North America, and their consumption by primary energy source. It is important to note that the use of renewable energy in the United States will grow, due to the hydropower projects being developed in addition to the boost from the current government, the use of wind energy, solar, among others. [1] [3].

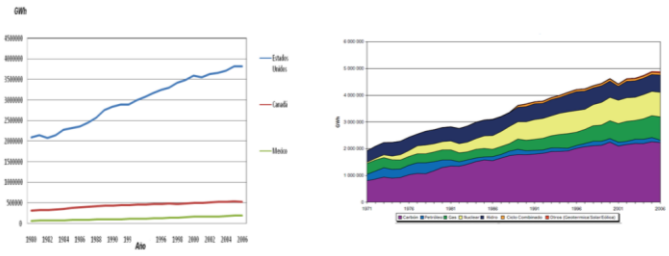

Fig. 4. Energy sources for electric power systems generation in North America. Source: IEA [1].

The U.S. is the country with the largest installed power capacity, with a value of 956,673 MW in 2005, representing a 84% in North America and 25% in installed capacity in the world. The importance of this country in energy development makes it a reference for other countries. The changes that occur in this country in energetic point to the global trend to other countries. Between Canada and Mexico have the remaining 16% of installed power capacity in North America [2].

E. Power generation in Latin America (excluding Mexico).

Ranking as the leading economy in Latin America, and second of America, Brazil has been one of the biggest beneficiaries of global growth and has accumulated significant wealth through exports to the U.S., Europe and Asia. Brazil is a leader in several economic sectors such as industry and agriculture; it is also a member of BRICs (Brazil, Russia, India and China) countries considered as emerging nations. In 2006 according to Fig. 5, the Brazil's electricity consumption was 380,000 GWh, this value shows its high economic development in comparison with consumption levels in countries like Argentina and Venezuela which were 97,000 GWh and 83,000 GWh respectively [2].

In Argentina, the electricity demand has grown steadily since 1991, with a fall due to the economic crisis from 2000 to 2002. Finally, Colombia is mentioned, it is the fourth largest country in land in South America and the third in population in Latin America.

Colombia's economy is the fifth in Latin America and has experienced average annual growth of 5.5% from 2002 to 2007. However, the unequal distribution of wealth has remained at 49.2% of Colombians living below the poverty line. The consumption of electricity in Colombia, although it is low compared to the countries mentioned above, it must be noted that in 2006 reached 52,246 GWh. Colombia is a country that generates its electricity through hydroelectric plants primarily, which represents around 66% of total installed capacity, the remaining proportion is due to thermal generation.

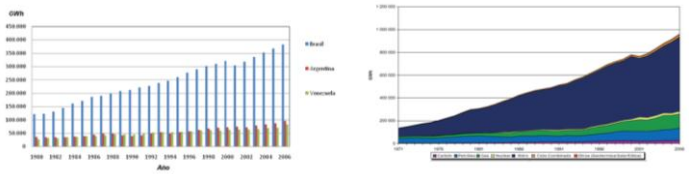

Fig. 5. Energy sources for electric power systems generation in Latin America. Source: IEA [1].

3. Methodology

To prospectively evaluate the power systems by 2025, it is applied the following methodology:
i. Initially an extensively review about current situation in continents and countries is made, it deals with energy resources and power generation technologies, It was presented in section I of this article.
ii. It is applied two methods of strategic planning: the SWOT matrix and SPACE Matrix, which permit to know the possibilities on the strategies for the future provision in generating electricity.
iii. Finally when it is identified the strategies, they are modeled in two prospective methods known as MACTOR and SMIC.

A. SWOT Matrix

The matrix of strengths, opportunities, weaknesses and threats (SWOT) is an important adjustment tool that helps to recognize feasible actions by identifying strategies, where all actions must be possible and that the feasibility must be found in the system reality. In other words, the ability to overcome the weakness that impedes the attainment of a purpose, it just be possible, if the system poses strengths and opportunities which allow do that. From the above this tool permits the creation of four types of strategies: strategies of strengths and opportunities (SO), weaknesses and opportunities (WO) strategies, strategic strengths and threats (ST), and strategies of weaknesses and threats (WT). The adjustment of external and internal factors is the most difficult in a SWOT matrix and requires a successful focus [6] [7].

B. SPACE (PEEA) Matrix

The matrix of the strategic position and action evaluation (SPACE) is a tool to know the trend to be followed by strategies based on a diagram. This matrix becomes a four-quadrant diagram that indicates whether a strategy is intensive, conservative, defensive or competitive. The axes of the SPACE Matrix represent two internal dimensions (financial strength and competitive advantage) and two external dimensions (environmental stability and industrial strength). These four factors determine the strategic position taken by a system and possible actions will be implemented [4].

C. Prospective method

In this paper, the methods used in order to evaluate the prospective of power systems by 2025 are the SMIC (Cross-Impact Matrices and Systems) and MACTOR (Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations). The aim of these methods is to highlight the most likely scenarios, and also to examine the combinations of hypotheses that will be excluded a priori.

The cross impact method is a generic term for a family of techniques which attempt to evaluate changes in the probabilities of a series of events or scenarios following the occurrence of one or several such events, as well as the probabilities of combinations of these, taking into account the interactions between events and / or assumptions.

The MACTOR method focuses primarily in determining the motivations, conflicts and potential strategic alliances among the actors in order to face adverse situations in the future. Once the structural analysis is made, then key variables and actors in the system that might have some influence or control over the future development of the variables are identified [9].

On the basis of information gathered and prospective methods which were mentioned above, it was evaluated the development of the power systems until 2025.

4. Results

Next, the results of applying the proposed methodology are presented. First, the implementation of the SWOT matrix is shown in Fig. 6, where are showed the current conditions of the analyzed system, which will allows to structure the SWOT matrix. Fig 7 presents both the results of the S-O, W-O, S-T and W-T strategies and the result of SWOT matrix analysis [6].

A. SWOT Analysis of strategies for power systems in the World.

From the state of art was made a parameterization of the main variables internal, strengths (S) and weaknesses (W); and external, opportunities (O) and threats. The evaluation of the matrix constructed in table 1, allows obtaining the strategy matrix known as S-O, W-O, S-T and W-T.

Table I. – Swot Matrix

SWOT MATRIX	
Strenghts (S)	Weaknesses (W)
1. Significant reserves of gas and coal.	1. Restrictions on CO2 emissions.
2. R+D+i investment.	2. Different cost between conventional technologies vs. new technologies.
3. Reduce emissions of CO2.	3. Availability new technologies before fifteen years.
4. High investment in renewable energy.	4. Limited use of nuclear energy.
	5. Weather changes
Opportunities (O)	Threats (T)
1. Various market energy opens	1. Emissions CO2
2. Increased demand electricity energy	2. Uneven economic growth
3. Diversifying the energy matrix	3. High cost of technological innovation
	4. Social and environmental impacts in development projects in power systems generation of large scale

According to the Table II, assessment made above, it is possible to obtain among the most influential issues, namely:

SO Strategies would ensure competitiveness in the kWh price for the entry of renewable energy. The future efforts in technology, regulation and market for the entry of such renewable energy are evident in such way.
WO Strategies would allow the reduction of CO2 emissions, clearly the world is concerned by the reduction of emissions..
ST Strategies would encourage the development of new power generation projects in order to ensure sustainable global development. Additionally, considering national security issues, some countries have increased the number of power projects (Generation, Transmission and Distribution) in order to have enough reserves in the energy supply system.

Table II. – Strategies Matrix SWOT

SWOT Strategies Matrix	
Strategies (SO)	Strategies (WO)
1. Ensure the competition to generation of price of kWh in projects with renewable energies.	1. CO2 reduction emissions.
2. International cooperation in technological development in developing countries.	2. Various alternative power generations to address climate changes.
3. Increase efficiency in power generation through fossil fuels.	3. Regulatory reforms that encourage the entry of new Technologies.
Strategies (ST)	Strategies (WT)
1. Development new projects for power generation environmental friendly.	1. Strict regulation to reduce emission of CO2.
2. Increase the investment on R+D+i.	2. Ensure power supply to avoid economic constraint on the growth of countries.
3. Balance between conventional and renewable energy.	

B. SPACE Analysis of strategies for power systems in the World.

The second analysis tool of strategic planning is the SPACE Matrix, Table III shows the results. According to these results, it is found that power generation systems are dominant in the world. The competitive advantages allow to the electricity market to facilitate a rapid growth in the power generation systems, what let to diversify the energy resource. Similarly the last 20 years, investment in research and innovation has allowed the production of electricity by new alternatives, which was accompanied by a reduction in the costs of adaptation through the application of economies of scale.

C. Prospective study for power systems in the World.

1) MACTOR: The MACTOR method determines the weight of the actors that influence the analyzed system. This happens because objectives, forces and conduct of the strategic variables are taken into account for each actor in order to assess the development of scenarios and possible actions to take [8].
For this study, the MACTOR is composed of several phases:

- Identify actors that impact the future development of the system.
- Define a list of strategic variables from the structural analysis that the actors want to achieve.
- Recognize dependency and influence of actors.
- Describe the current attitude of every actor in front of strategic variables.
- Measure forces of the actors according to their purpose.

Table III. – Space Matrix

SPACE MATRIX			
Internal strategy position		External strategy position	
Score	Financial strength (FS)	Score	Enviromental stability (ES)
3	Investment in technological innovation	-5	Technological innovation
3	Energy market	-3	Enviromental Politicies
2	Reduction of CO2 emissions.	-2	Growth of electricity consumption
		-3	Competitive environment
8	Total	-13	Total
2.7	Average	-3.25	Average
Score	Competitive advantage	Score	Industrial strenght (FI)
-3	Geographical position	6	Growth potential
-2	Technological development	4	Use of resources
-3	Economic growth Crecimiento económico	3	Technological growth
-4	Fosil fuels reserves	2	Financial stability
-12	Total	15	Total
-3	Average	3.75	Average
RESULTS			
		X	Y
Competitive Advantage (CA)		-3	
Enviromental stability			-3.25
Industrial strength		3.75	
Financial strenght			2.7
		0.75	-0.58

From the direct influence matrix, it is obtained the cartesian plane of influences and dependencies among actors. Next, it is described the relative strengths of the actors for each objective or hypothesis resulting from the evaluation:
i. Hypothesis 1: In 2025 traditional technologies have been preserved as leaders in the systems of power systems.
ii. Hypothesis 2: In 2025 alternative power generation technologies will have an important position in global growth.
iii. Hypothesis 3: In 2025, governments will be key factors for the development of systems for power systems.
iv. Hypothesis 4: In 2025 the systems of alternative power generation dominate the global market

2) SMIC scenarios: This approach is used to determine the most likely scenarios and to examine the combinations of hypotheses that should be excluded. Initially it is developed a baseline scenario, and then alternative scenarios. Next, 5 or 6 hypotheses are formulated considering strategic variables; here it is evaluated the simple probability of each scenario and the conditional probability of realization of a hypothesis.

The "strategic variables" may evolve into the future (year 2025) of two ways:
Follow a baseline, this means that it is possible to maintain the present situation; it is directed by the present direction of each factor. In this way the first scenario called "trend" is getting.
Follow alternatives status, positive or negative, of each factor. In this way, the following possible scenarios and alternatives are designed, they will be explained below.

Table IV. – Hypothesis

Hypothesis	Tendencia
1 – Leader	Moderate
2 – Presence	Weak
3 – Intervention	Weak
4 - First	Weak

The relative strengths of the actors for each objective or hypothesis resulting from the review is described:
i. Scenario 1. Traditional Technologies (Trend Scenario)
In 2025, the key variables will behave like this:
Leader: Traditional technologies remain as leaders in the power systems in the world.
Presence: The thermal generation will exceed 70% of total electricity generation in the world.
Intervention: The regions seek to maintain economic growth following the evolution of globalization, to achieve this; it seeks to ensure the supply of electricity through more traditional means to provide continuity of service.
First: The regions of the world maintain uniformity in the systems of power generation.
ii. Scenario 2. Innovative Technologies
In 2025, the key variables will behave like this:
Leader: Technological innovation dominates the market, what do both create high levels of competition with traditional technologies, and increase their participation in all world regions.
Presence: Technological innovation has coverage of 20% share of electricity production.
Intervention: The regions of the world create laws that promote innovative development.
Top: World powers are the first to impose technological development in the energy market.
iii. Scenario 3. Energy policy
In 2025, the key variables will behave like this:
Leader: Traditional technologies remain as the most important driver for the generation of electricity.
Presence: Technological innovation as an agent which achieves significant position in the power systems
Intervention: Nations amend the law in order to allow and facilitate the renewal systems for power generation.
Top: Countries with more investment and development are placed at the front position in the use of new technologies; this shifting from traditional technology is made gradually.

5. Discussion

After using the analytical tools of strategic planning, as the SWOT and SPACE matrixes, and SMIC and MACTOR prospective methods, the following results were obtained for power systems in the world by 2025:

1. Due to the high dependence on fossil fuels for power generation, it has developed technologies that improve efficiency in thermal processes for the production of electricity. This condition makes traditional technologies remain on the market and also a further strengthen the traditional structure in different regions of the world.
2. In the past 20 years, investment in R & D has grown considerably; this has enabled the strengthening of technological innovation through the contribution of developed countries.
3. Alternative and renewable energies for power generation, overcame the technology barrier for application, its progress and development will create a high impact and will become an important factor in order to change power systems in different regions, this can be seen in the actions of different developed countries made towards energy security in order to diversify their energy mix.
4. A key aspect that has raised awareness in developing nations, is the environment, in this context, it have been increased efforts in research and application of technologies for mitigation of phenomena such as climate change. Although it should be noted that the regulatory signals and regulations in this area are still weak.
5. The largest movement of skilled workers in the world will allow a growing knowledge in developing countries. The efforts of the manufacturing companies for developing new technologies in electricity production will diversify and spread its high technology operations in a more simple way; this will allow faster and effective development.
6. When the governmental policy intervenes in order to encourage or discourage trends and technologies, it is an important factor which affecting all stages for the power systems. The politician drives the restructuration through fiscal measures, supported by laws. It seeks to develop and promote the use of renewable energy, enhance environmental awareness, and promote energy conservation.
7. As electricity demand is growing at a steady pace, especially in developing countries, it is expected to accentuate regional differences in terms of power generation systems. In first world economies, the high age of the structures is causing problems. In emerging economies would have to build new facilities at great scale which must take account environmental aspects.

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