STRATEGIC FORESIGHT USING AN ANALYTIC HIERARCHY PROCESS: ENVIRONMENTAL IMPACT ASSESSMENT OF THE ELECTRIC GRID IN 2025

Ronald Mac-Ginty*
Department of Industrial Engineering
University of Santiago of Chile
E-mail: ronald.macginty@usach.cl

Raul Carrasco
Department of Industrial Engineering
University of Santiago of Chile
raul.carrasco.a@usach.cl

Astrid Oddershede
Department of Industrial Engineering
University of Santiago of Chile
astrid.oddershede@usach.cl

Manuel Vargas
Department of Industrial Engineering
University of Santiago of Chile
manuel.vargas@usach.cl

ABSTRACT

This paper presents a strategic foresight study of the electrical grid throughout the South American region until 2025. The study considered the Climate Change phenomenon and many different energy sources, proposing a new methodology through the Analytic Hierarchy Process (AHP) and the Monte Carlo simulation. The study also considered the earthquake in Japan and nuclear plant accident in Fukushima, and the technological convergence that will occur over the next 15 years in the electric grid sources. The research involved political, economic, social and technological (PEST) factors. Through PEST analysis and the involvement of an expert panel, it was possible to select the most influential variable for each PEST factor. In order to prioritize these factors and evaluate the different technological alternatives, an AHP model was developed. Then a Monte Carlo simulation was run 1000 times for electric generator source clusters. Four prospective scenarios of the electrical grid structure until 2025 in the South American region were defined. The study highlighted the contribution of renewable energy adding nuclear power as the main mix group as a source of energy by 2025. This indicates that it is possible to anticipate an electric grid until 2025 in the South American region with low impact on Climate Change.

Keywords: Climate Change, Energy Sources, AHP, PEST Analysis, Monte Carlo Method

http://dx.doi.org/10.13033/ijahp.v5i2.195

1. Introduction

The sustainability of the electricity industry is a matter of study and debate in all societies. Decisions for the construction of the electric grid through a set of energy sources should consider a host of factors associated with the environmental and economic impact of the installations. In addition, the accident of the nuclear plant in Fukushima has had an effect on the decisions made regarding the capacity and composition of the electric grid. The technological convergence is allowing the development of new sources for generating energy with the contribution from different fields such as biotechnology, nanotechnology, information technology and so on. The consideration of these new technologies and their impact over the next 15 years was performed by the use of suitable methodologies that include the Analytic Hierarchy Process. All of the above compelled us to consider the following two research questions. First, considering the Climate Change phenomena as a global environmental problem, what will the structure of the electric grid be in the South American region by the year 2025? Second, how do you evaluate the impact of technological convergence?

The paper is organized as follows: section 2 provides a literature review for prospective analysis while section 3 provides the proposed methodology, its application and results analysis. The conclusions are given in section 4.

2. Literature review

For strategic foresight and planning scenarios to establish the conditions and actions necessary to build the best possible future, foresight should be able to identify the probable scenarios according to their probability of occurrence (Godet, 2000). Those who have the responsibility of making decisions should consider all the variables that delineate the most likely scenario through the use of validated and recognized methodologies by the scientific community in order to define future scenarios of a community, organization or a geographic region(Godet, i Buisán, & Posiello, 1995; Godet & MONTI, 2000).

In our review of the literature we found that the Delphi method, the odds of Bayes method, the cross-impact matrix method, and exploration of the environment and morphological analysis method are used the most (Glenn & Gordon, 2009). The AHP, developed by Professor Saaty (Saaty, 2001, 2007), has shown great capacity of prioritizing both, quantitative and qualitative criteria. This method in conjunction with the Monte Carlo simulation allows the reduction of the uncertainty of the actions for decision-making (Emblemsvåg & Tonning, 2003; Liu, Rasul, Amanullah, & Khan, 2010). All of the above encourages us to study the phenomenon of the growth of energy consumption, its impact, and decision-making of prospective scenarios using these tools.

According to Vecchiato (2012), strategic management literature defines the micro environment and the macro environment by distinguishing sectors with which the firm has direct contact and from sectors that affect the firm indirectly respectively. The macro environment is made up of the political, economic, societal and technological landscapes (PEST) which surround the business micro environment.

2.1 Emerging trends in electricity generation

In the last decade, 70% of the energy consumed by the global economy was fossil fuels (Canton, 2006). Hubbert model, according to Canton, designates the maximum level of oil production during this decade, increasing the average price trend projection. It is crucial to replace fossil fuels with cleaner sources in order to reduce the carbon footprint. This is the starting point for all the new technologies like hydrogen, magnetism and superconductivity.

Trends and the newly discovered state of the art technologies that can be applied to emerging power generation technologies are shown in Table 1. These technologies were divided into the following categories: superconductor materials, quantum computers, photovoltaic paints, nanoscience and biotechnology. Each of these categories raises potential scenarios that have different impacts on quality of life.

Table 1
Trends of emerging power generation technologies that underpin the major changes

Category	**Area of knowledge**	**Applications**	**Potential scenario**
Materials	Physics of materials	• Superconductivity, in which some metals and alloys lead electricity without meeting resistance.	Roads and railway with superconductors at room temperature may cause super-magnetic effect, capable of making vehicles and trains to move through magnetic levitation.
Information technologies	Quantum computers	• The physicist David Deutsch, envisioned how officer a tidy realizing that calculations that needed a time virtually infinite in a traditional computer could be done quickly in a quantum computer.	Nuclear fusion will be available.
Nanotechnologies applications	Nanotechnology and new materials	• Processing, storage, distribution technologies, the new advanced photovoltaic catalysts (organic solar cells). • Nano-electronics.	• Energy generation, as through the paintable solar technologies applied to buildings and outdoor solar structures. • Built environments capable of adapting to future climates.
	Environmental Nano photonics: Nano science for energy efficiency and environmental sustainability	• Painted "cooling" coatings that reduces the demand of energy. • Switchable 'smart' surfaces, properties change according to conditions or needs. • Nano-structured windows for more energy efficient buildings.	Reduction of the urban "heat island" effect through "colder suburbs" created through the application of roofs of all the buildings nanostructured coatings to reflect heat. • Reducing the "maximum load" energy demand during the summer.
Biotechnology and the environment	Biotechnology, energy and industrial production	• Petroleum diesel and substitute fuels • Conversion of lignocellulose to ethanol, biodiesel from algae technologies. • Bio-industry focused on crops genetically modified high-value industrial engineering.	• The transport of liquid fuel safety is achieved without affecting food production / security. • Bioeconomy mitigates future oil shocks / price rises.
	Biotechnology and food production	• Genetic modification (GM) to change the performance characteristics.	• Access to good price essential nutrients, for the rapid expansion of the world's population
"Clean technology"	New solutions for energy, water and transportation	• Next generation of energy systems. • The adaptation of technologies for water purification. • Biological sequestration technologies. • Functional "green wall / ceiling systems".	• New energy technologies well adapted in poor countries • Charging power base renewable (for example, using biomass as a source of energy undervalued) • Affordable and low-cost energy

Source: Adapted from (Alford, Keenihan, & McGrail, 2012; Kaku, 2011; Kurzweil, 2005; National Nanotechnology Initiative, 2012).

2.2 Prospective studies for the electrical industry

Prospective studies related to electric energy sources are divided into two phases until 2025. The literature review indicates the global installation of traditional green technologies. Wind and solar power lead investments on all continents. This first phase will be accompanied by substantial improvements in the production of uranium enriched by laser (Weinberger, 2012). This method will drastically reduce the production cost and increase the ability to obtain the product for nuclear fission plants. Finally, electric vehicles with lithium or hydrogen batteries generated a double effect on the economy of big cities. More efficient, less polluting vehicles with storage capacities of energy equivalent to several nuclear power plants will allow the duality in the flow of energy, with vehicles possibly buying and selling power to the electrical grid system (Kaku, 2011).

The second phase involves the convergence of emerging trends that will allow more capacity to generate electricity where the emerging technologies will be connected to large regional or national distribution networks and technologies. More efficient solar cells, photovoltaic batteries including nanotechnology and smart distribution will begin sometime in the next decade.

2.3 Greenhouse gas emission

The various energy sources used in power generation create emissions of greenhouse gases when considering the full life cycle of each project. These emissions can be seen from the construction of the project, the power production, to the energy *expenditure* in operation and maintenance, and decommissioning and closure of the facility.

In Table 2, the emission values for each technology can be explained by factors specific to each installation as climatic variables, energy demand and the method of power production. The largest variation corresponds to the photovoltaic technology. In the last few years this technology has improved ostensibly regarding energy efficiency per unit of surface, and in its manufacturing process (Edenhofer, Pichs-Madruga, & Sokona, 2011; Laguna, 2002; Meier, 2002; Monroy, 2002; Weinberger, 2012). The first units had a broadcast life cycle comparable to fossil fuel-based computers, a decade later photovoltaic units maintain cycles similar to renewable energy.

Table 2
Different energy source's emissions during the life cycle in tons of CO_2 per GWH

Technology	Average	Minimum Value	Maximum Value
Brown Coal	1.054	790	1372
Coal	888	756	1310
Oil	733	547	935
Natural gas	499	362	891
Solar Photovoltaic	85	13	731
Biomass	45	10	101
Nuclear	29	2	130
Hydropower	26	2	237
Wind	26	6	124

Source: Adapted from report Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources (World Nuclear Association Report, 2010).

Through statistical analysis of hierarchical grouping (Ward with Euclidean distance measurement methodology), we obtained two hierarchical groups: sources with high level of gas emission greenhouses (lignite, coal, oil and Natural Gas), and sources of low-emission (photovoltaic, biomass, Nuclear, hydropower and wind).

2.4 Fukushima Effect

The effect in the international community of the Fukushima accident created pressure for the deactivation of nuclear power units in many countries. However, the difficulty in the short term of replacing this energy source with others with less impact on climate change, taking into consideration the fear in the population regarding possible nuclear accidents, compels us to explore two aspects of nuclear units. These are the equipment installed in seismic geographical areas, and units planned or installed in safe areas.

3. Methodology and Analysis

The prospective analysis of the impact of energy sources to the electricity grid considered the full lifecycle of energy sources. The proposed methodology can be summarized in six steps as indicated in section 3.1, and represented in six steps as depicted in Figure 1.

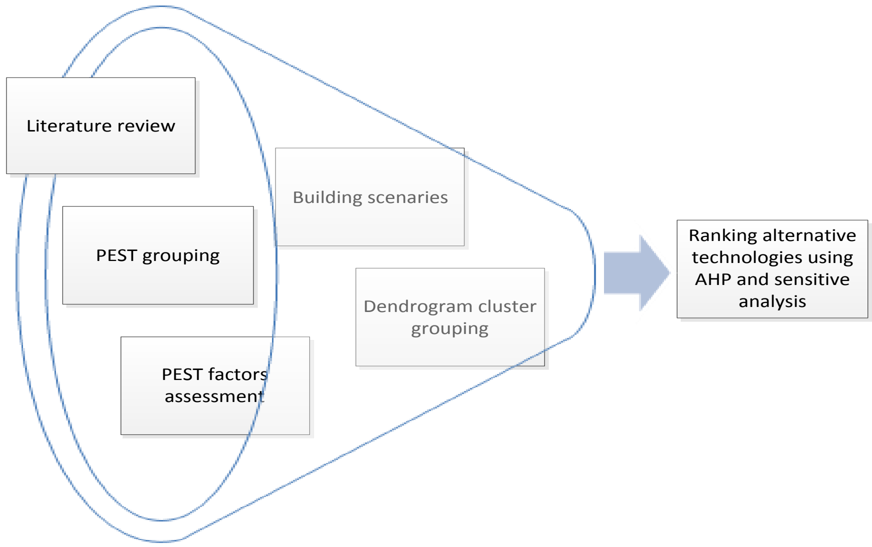

Figure 1. Proposed methodology

3.1 Proposed Methodology

1) Literature review: A comprehensive literature review is required to recognize the main factors involved in electricity generation, the development of new technologies and the control of environmental impacts from different sources (See Table 1).

2) PEST grouping: Main factors are grouped to each of the PEST factors according to the judgments of a previously selected expert team (See Table 3 and Table 4).

3) PEST factors assessment: An AHP model is designed for PEST factors prioritization (Figure 2).

4) Building Scenarios: Four scenarios are created in graphic XY using the method described by Godet (2000). Mean objective is to mitigate impact of "Climate Change", so our scenario target is in quadrant I (Figure 3).

5) Dendrogram cluster grouping: Dendrogram technique is proposed to group technologies in family clusters. This allows for identification of a technology with a similar impact to the environmental impact (See Table 3).

6) Ranking alternative technologies using AHP and sensitive analysis: In this step the overall outcomes are obtained, furthermore a Montecarlo simulation is run with a VBA excel 1000 times to improve the results (Momani & Ahmed, 2011).

3.2 Application

According to step 1 of the methodology, a list of associated variables of energy generation technologies is arranged in Table 3 based on Chatzimouratidis & Pilavachi, (2008, 2009) and the World Nuclear Association Report (2010).

Table 3
Associated variables list of energy generation technologies

Item	Technology	Polluting emissions(3)	Land occupied(2)	Cost(1)	new jobs(1)	Social rejection(1)	Energy efficiency(2)	technological availability(2)
Units		TCO_2/GWh	Ha	cents/kWH		1-300	%	1-100
1	Brown coal	1.054	2,5	5,4	2500	100	39	85
2	Coal	888	2,5	5,4	2500	100	39	85
3	Oil	733	2,5	5,0	2500	100	37	92
4	Natural gas	499	2,5	4	2460	33	39	91
5	Solar photovoltaic.	85	35	75	5370	20	9	20
6	Biomass	45	5000	14	36055	33	14	80
7	Nuclear	29	2,5	4	2500	300	33	96
8	Hydropower	26	750	8	2500	33	80	50
9	Wind	26	100	7	5635	20	35	38

Source: Adapted from (1) (Chatzimouratidis & Pilavachi, 2008),(2) (Chatzimouratidis & Pilavachi, 2009) and from (3) (World Nuclear Association Report, 2010).

The involved variables from Table 3 are studied and grouped into the four PEST factors according to the judgments of the expert team (environmental engineers, chemical engineers, sociologist, energy specialists, economists), as shown in Table 4.

Table 4
Variables associated to PEST factors

PEST factors	Variable
Political	Polluting emissions
	Land occupied
Economic	Cost
Societal	New jobs
	Social rejection
Technological	Energy efficiency
	Technological availability

According to step 3, the PEST factors will be assessed through AHP. An AHP hierarchy model is structured and validated by the expert team. Then a pair wise comparison through the hierarchy structure to derive the priority matrix for each level of the structure is carried out. Figure 2 shows the initial basic AHP model.

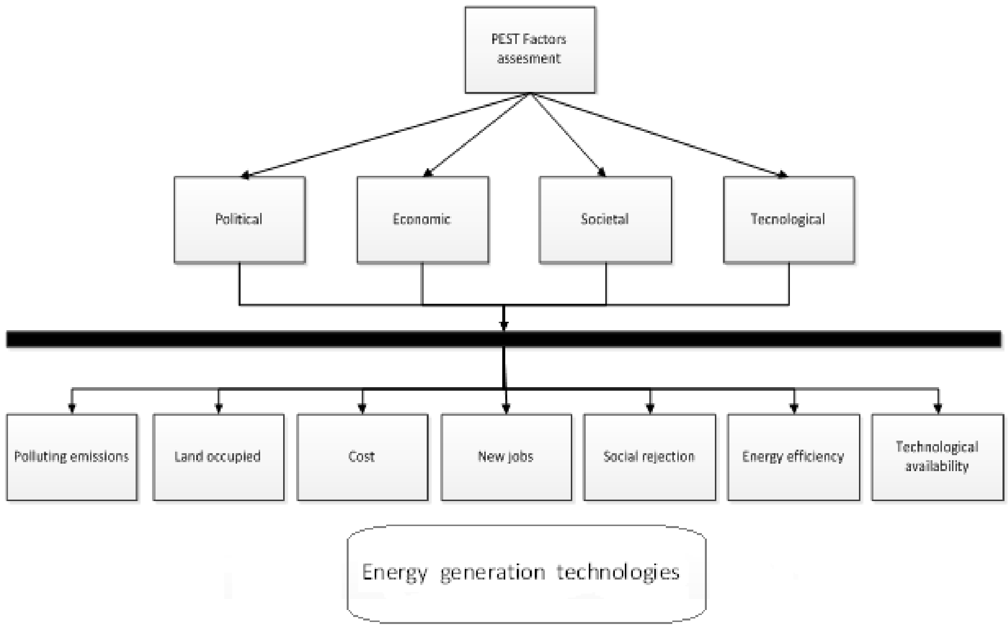

Figure 2. The basic AHP decision model to assess factors

The resultant relative weights for PEST factors are indicated in Table 5.

Table 5
PEST factors relative weights

Factors	**Relative weights (%)**
Political	38.06
Economic:	30.60
Social:	8.59
Technological:	22.75

3.3 Building scenarios

Building scenarios is the subsequent recommended step. Variables are related the variables by pairs, such as political-social and economic-technological which facilitates the creation of four scenarios and are introduced into the X-Y diagram using the procedure specified by Godet (2000). See Figure 3.

The first scenario named “Conquering the Future” supports positive thinking to mitigate the impact of “Climate Change”. This might be possible if the selected technologies produce low levels of carbon footprint and if they are less expensive (Axis Y positive).

On the other hand, Axis X, positive socio-political presents the expectation of achieving government support related to environmental politics and social approval issues. This scenario defines the objective of this study, which is to find the most adequate technology for power generation source for the scenario “Conquering the Future” to 2025.

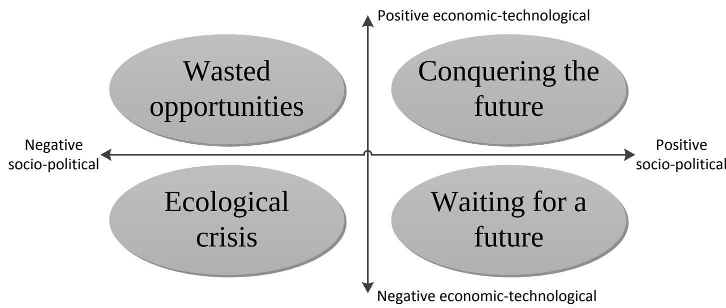

Figure 3. Scenarios of the electric grid in 2025

On the other hand, all restrictions on global energy supply policies will establish any of the other three remaining scenarios where restrictions will reduce the capabilities and benefits of clean and low cost energy for human life.

3.4 Dendrogram cluster grouping

A Dendrogram cluster is used to group technologies with similar environmental impact according to Table 3. An initial classification of technologies, revealing three major groups is shown in Figure 4. The first focuses on all the energy sources from fossil fuels, (1, 2, 3, and 4), the second focuses on nuclear energy (7), and the third focuses on all renewable sources (5, 6, 8, and 9).

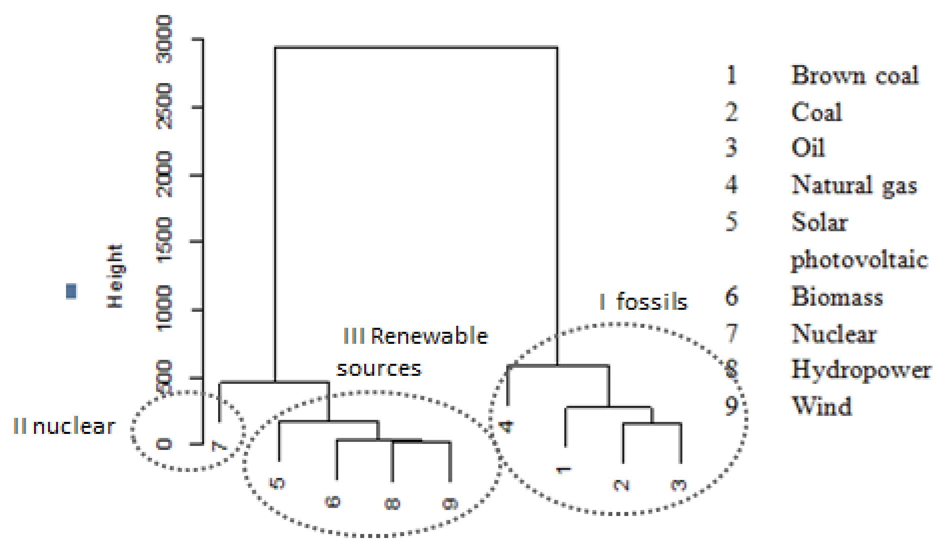

Figure 4. Cluster Dendrogram for evaluating similarity between energy sources (software R, 2012)

Considering the initial Dendrogram classification and the energy generation capacity of these groups (I, II, III) from Figure 3, the expert team proposed another arrangement involving four clusters to be evaluated through AHP. The resultant clusters are indicated in Table 6.

Table 6
Resultant Clusters

Energy Generation Sources Cluster	
i)	Nuclear energy
ii)	Renewable energy and nuclear
iii)	Fossil energy
iv)	Fossil energy and Nuclear

The ranking results and sensitivity analysis obtained from Montecarlo simulation between the four selected technologies clusters are presented in Figure 5. The simulation features predominance in the use of renewable technologies supported by nuclear sources with 78% of the preference.

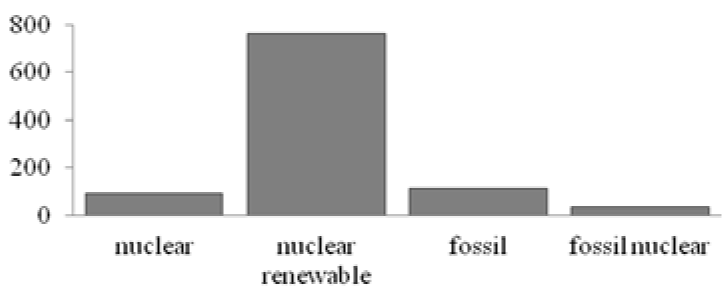

Figure 5 Ranking results and sensitivity analysis

With the highest score of the selected choice, the renewable nuclear mix source meets a positive PEST evaluation as is therefore located in quadrant I as seen in Figure 6.

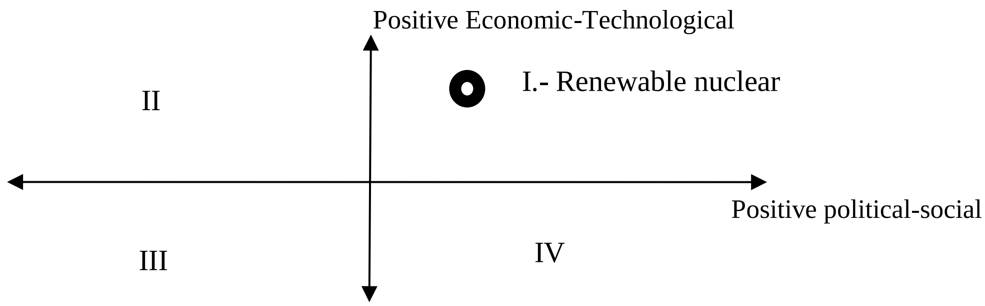

Figure 6. Selected electric generation source in the positive scenario according to the PEST criteria.

4. Conclusions

The proposed methodology used the AHP method based on PEST criteria to evaluate different energy source groups. A sensitivity analysis using Montecarlo simulation, to take into account the uncertainty in human judgment supported the cluster ranking. The renewable-nuclear group was the best choice for the South American region that considered the impact of the “Climatic Change” phenomena until 2025.

Grouping the alternatives according to similarity or choosing a representative variable between many alternatives contributes to the understanding of the problem and can save resources. A matrix of scenarios allows for defining the exploratory stages and components that identify and determine the future of the industry. In our case, PEST criteria define the expected scenario.
The renewable-nuclear cluster reached 78% of the preference, which means that with this kind of technology the “Climate Change” impact in the South American region until 2025 will be minimized. Finally, it is necessary to say that at any time new energy technology sources might emerge and may change the projections, so it is advisable to use this methodology on a periodic basis and to analyze the trends.

Acknowledgements
The authors would like to thank the Industrial Engineering Department of University of Santiago of Chile for their support.

REFERENCES

Alford, K., Keenihan, S., & McGrail, S. (2012). The complex futures of emerging technologies: challenges and opportunities for science foresight and governance in Australia. *Journal of Futures Studies, 1*6(4), 67–86.

Canton, J. (2006). *The extreme future: The top trends that will reshape the world for the next 5, 10, and 20 years*. New York: Dutton.

Chatzimouratidis, A. I., & Pilavachi, P. A. (2008). Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process. *Energy policy, 36(3)*, 1074–1089.

Chatzimouratidis, A. I., & Pilavachi, P. A. (2009). Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process. *Energy Policy, 37(3)*, 778–787.

Edenhofer, O., Pichs-Madruga, R., & Sokona, Y. (2011). *Renewable energy sources and climate change mitigation: special report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Emblemsvåg, J., & Tonning, L. (2003). Decision support in selecting maintenance organization. *Journal of Quality in Maintenance Engineering, 9(1)*, 11–24. doi:10.1108/13552510310466765

Glenn, J. C., & Gordon, T. J. (2009). *Futures research methodology: The Millennium Project: Version 3.0*. Washington, D.C.: Milennium Project.

Godet, M. (2000). The art of scenarios and strategic planning: tools and pitfalls. *Technological forecasting and social change, 65(1)*, 3–22.

Godet, M., i Buisán, E. P., & Posiello, J. G. (1995). *De la anticipación a la acción: Manual de prospectiva y estrategia*. Alfaomega México.

Godet, M., & MONTI, R. R. (2000). *La caja de herramientas de la prospectiva estratégica*. Gerpa.

Kaku, M. (2011). *Physics of the future: How science will shape human destiny and our daily lives by the year 2100.* Knopf Doubleday Publishing Group.

Kurzweil, R. (2005). *The singularity is near: When humans transcend biology*. New York: Viking Penguin.

Laguna, I. (2002). Generación de energía eléctrica y medio ambiente. *Gaceta Ecológica*, *(65)*, 53–62.

Liu, G., Rasul, M. G., Amanullah, M. T. O., & Khan, M. M. K. (2010). AHP and fuzzy assessment based sustainability indicator for hybrid renewable energy system. In *Universities Power Engineering Conference (AUPEC), 2010 20th Australasian* (pp. 1–6).

Meier, P. J. (2002). *Life-cycle assessment of electricity generation systems and applications for climate change policy analysis*. (Unpublished doctoral dissertation). University of Wisconsin, Madison.

Momani, A. M., & Ahmed, A. A. (2011). Material handling equipment selection using hybrid Monte Carlo simulation and Analytic Hierarchy Process, *World Academy of Science, Engineering and Technology*, *59*, 953–958.

Monroy, I. L. (2002). La generación de energía eléctrica y el ambiente. *Gaceta Ecológica*, *(065)*, 53–62.

National nanotechnology Initiative. (2012).

Saaty, T. L. (2001). *Decision making with dependence and feedback: The Analytic Network Process (2 ed.)*, Pittsburgh: RWS Publications.

Saaty, T. L. (2007). The analytic hierarchy and analytic network measurement processes: Applications to decisions under risk. *European Journal of Pure and Applied Mathematics*, 1(1), 122–196.

Vecchiato, R. (2012). Environmental uncertainty, foresight and strategic decision making: An integrated study. *Technological Forecasting and Social Change*, *79(3)*, 436–447. doi:10.1016/j.techfore.2011.07.010

Weinberger, S. (2012). Laser plant offers cheap way to make nuclear fuel. *Nature*, *487(7405)*, 16–17.

World Nuclear Association Report. (2010). *Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources*.