Assessment & anthology of sustainable sources of energy using an approach of PROMETHEE
Deepak Sharma1,*, Atul Pandey2, Chandan Kumar3, R K Ranjan4
1Department of Mechanical Engineering, IET, GLA University Mathura 281406, UP, India
2Department of Mechanical Engineering, NIET, Gr Noida GB Nagar 201310, UP, India
3Department of Mechanical Engineering, NIET, Gr Noida GB Nagar 201310, UP, India
4Director NIET, Gr Noida GB Nagar 201310, UP, India
E-mail*: deepak.sharma@gla.ac.in

Abstract. The energy mix in India relies heavily on the energy sources basically categorized as conventional. Renewable energy (RE) encouragements in India have to be seen from a long term and wider frame of reference, so that it contributes towards reliability and energy security. This paper vital motive is to assess and prioritize the sustainable energy sources in India which are accomplishing utmost factors like acceptability, space limits, availability, gestation period, safety considerations, localization and execution. Sources consider for analysis are solar, wind, hydro and nuclear energy. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) have been used to achieve the suitability among the sources of energy and to persuade different factors. This paper concluded solar energy as the most profitable and economical energy source for India, followed by wind energy, than hydro energy and in the last nuclear energy. Nuclear energy acceptability is low in view of the fact of public oppression and the corresponding dangers bound with unbinding power of atom. This paper may help the decision makers to formulate long-term energy policy aiming for sustainability.

Keywords: Selection and Prioritization, Multiple criteria decision making, Energy case study, PROMETHEE.

1. Introduction
Energy has been the backbone of human civilization since time immemorial & its desires is increasing gradually with increase in population, industrialization, economic growth all around the world. Business & trading is expanding readily, but our fossil fuel sources are diminishing, the rate of energy is increasing which slowly giving rise to the biggest threat to humanity & nature that is climate change [Sanjeev et al. 2017]. The point of concern is the high dependence on fossil-fuel based energy sources, which suffice the need of 85% of the world’s energy requirements. But, it is a known fact that if we keep on extracting this precious fuel at this alarming rate, which can’t be replenished quickly, we would be certainly out of energy stock. India is in a censorious spot, due to its high population growth, economic growth, civilization, industrialization, up gradation in per capita utilization of electricity, exhaustion of coal reservoirs, hike in the import of coal, crude oil & other energy sources. Population
of India has reached 1.34 billion till June 2, 2017 (estimated by United Nations Department of Economic & Social Affairs) & there is a prediction that it will take over China by 2030 in terms of population. The primary energy demand in India has grown from about 450 million tons of oil equivalent (toe) in 2000 to about 770 million tons in 2012. This is expected to increase to about 1250 (estimated by International Energy Agency) to 1500 (estimated in the Integrated Energy Policy Report) million toe in 2030.

Sole opportunity is under way of RE sources to sort out the problem of energy ingress in India [Garg P et al. (2012)]. An effort is required for a changeover of fossil based power to renewable in order to abstain from extended energy block off. RE resources are the only promising & prospective way to reduce these emissions & to cope up with future energy needs of both developed & developing countries [A report by WWF India and The Energy and Resources Institute 2013]. Incentives are motivating/boosting up the energy sector for adoption of RE but two critical aspects which is actually hindering its adoption is its distribution network & development of advanced storage technology [Wee et al. 2012]. Adoptions of RE sources have been retarded in Indian context, due to the existence of multiple numbers of barriers: - twenty eight such barriers sorted into seven dimensions were suggested by Sunil Luthra et al. (2015). In order, to resolve the above explain obstacles, objective turns out to be the selection of RE source, its optimal utilization & a need of smart grid concept [Sola M et al. (2016)].

Hence, the objective of this research paper is to outrank various RE sources i.e. Solar (thermal), Wind (Onshore), Hydroelectric, Nuclear, and Biomass based on the major constraints such as availability, acceptability, affordability, intermittency, space limits, safety considerations, gestation period, execution, and localization. For ranking these sources, this research paper consider PROMETHEE technique in two phases, i.e PROMETHEE I approach helps in finding the partial ranking and PROMETHEE II helps in finding the complete ranking of these sources of energy. In addition ranking position for a given set of criteria is done with the application of PROMETHEE GAIA (Graphical Analysis for Interactive Aid) software [De Smet, 2004; Mareschal and Brans, 1985, 1988].

The framework of this paper is in the following fashion:- Chapter 2 narrates literature review of the RE sources followed by Indian electricity structure & intensity. Chapter 3 & Chapter 4 corroborate the application of PROMETHEE I & PROMETHEE II on a case study of Indian energy sector for five RE sources i.e Solar (thermal), Wind (Onshore), Hydroelectric, Nuclear, and Biomass & lastly Chapter 5 concludes our research objective.

2. Literature Review.

Ravindran et al. (2007) have studied the energy needs of India and have come up with solutions in the form of ocean energy, wave and tidal energy and have also highlighted the benefits of using LED lighting systems. Li (2007) has focused on the interactions between the economic rise of China and India and the global energy crisis. He has discussed the changing relative positions of these two countries in the world economy and its potential implications on the gross world energy consumption. He has also highlighted the need for alternate sources of energy in view of the coming peak of the global oil production and its subsequent decline. He has also discussed environmental impacts in the
form of global warming from the current trend of energy consumption and also predicted the future energy supply prospects and its limitations.

Damirbas (2006) has studied biomass, hydropower, geothermal, solar, wind and marine energies as the Renewable Energy Sources (RES). Since RES contribute only 14% towards the total energy consumption, this figure needs to be quickly increased. He has stated that any country wishing to harness RES more efficiently should gather statistics to document how much energy is available, the current rate at which it is being exploited and also the effectiveness of any policy measures to encourage uptake of various technologies.

Kumaraswamy (2013) has discussed the energy security of India in terms of its relations with Iran. India’s growing needs for oil and natural gas can be partly met with the help of Iran but factors such as the nuclear deal between India and the US have raised concerns over such transactions. Lohan et al. (2011) have analyzed Jammu and Kashmir- the northern most state in India for its potential for various renewable energy sources. They have analyzed the potential of each renewable source in this region and concluded that the state has a vast potential to harness renewable energy. Narula (2013) has highlighted the energy security and the energy sustainability of India and their interactions. He has introduced a framework for quantifying the sustainable energy security based on various criteria and indicators and has evaluated their interrelationship. Kaygusuz (2010) has studied the hydro power and its place in the world energy future. He has reflected on the advantages and disadvantages of the hydel power, its social and environmental impacts and its related developmental possibilities.

Mishra et al. (2013) have also studied SHP in great detail and discussed its technical feasibility and economic viability. They have developed correlations for the cost of the electromechanical equipment used in SHPs based on various criteria and factors. They have carried out a cost analysis for all the requisites in setting up a SHP and documented them. Pandey et al. (2014) have employed the Digital Elevation Model (DEM) for estimating the hydropower potential of the Mat River basin of southern Mizoram in India. Along with DEM, stream network data and a hydrological model help in correct assessment, as in the SWAT model. Using this, they have identified three hydropower potential sites within the Mat River basin.

Vinod Kumar (2014) has described India’s nuclear energy programme in retrospect, highlighted the ambitious plans of India in developing nuclear energy in the coming decade and also the various measures being adopted to acquire as much uranium. Chaki et al. (2011) have highlighted the global uranium deposits distribution and India’s share in it. The low grade uranium deposits in India are mainly hydrothermal vein type, strata bound type and unconformity related. They have highlighted the challenge related to mining of high grade uranium deposits and shown how even low-grade uranium deposits can serve India’s purpose in the years to come for energy security as well as employment generation. Heo et al. (2011) in his study tried to explore the long-run and short run root causes that are prevailing between economic growth of India and nuclear energy by using error correction and co-integration models. Barry et al. (2014) have studied nuclear energy and established it to be essential in the energy mix of the future and also discussed its sustainability. They have considered its economic viability, environmental consequences, safety and the potential diversion of weapons-grade material to justify their stand.
Ramachandra and Subramanian (1997) have estimated the potential and prospects of solar energy in certain Indian states. They have evaluated the global solar radiations at two stations and documented all the relevant data for Goa and Mangalore and hence evaluated their solar potential. Vachaparambil et al. (2014) deal with the possibility of wind-mediated power supply for Chennai city and also deal with the feasibility of installing wind farms at the potential sites based on calculations of the downwind impact on a wind farm. Matthew and Mariappan (2014) have calculated the wind power potential in India using Arc GIS, WAsP and Multi Criteria Decision Analysis (MCDA) and based on the results, the region under study has been divided into four zones depending upon their potential to tap wind energy. Brans and Vinche (1985) have proposed the PROMETHEE approach as a useful tool for decision making. They have described the methodology thereof and the process of selection of the thresholds for easy and accurate quantitative ranks for the alternatives under consideration. Tomic et al. (2011) have represented the mathematical model used in PROMETHEE and its implementation for the evaluation process. Using the approach, they have evaluated the logistic strength and the stability of the BP countries. Patrick and Serge (2011) have used the PROMETHEE approach to define new exploration strategies for rescue robots. Deshmukh (2013) has given an overview of the PROMETHEE approach methodology for MCDM. He has described the related preference functions, associated criteria and their weights describing their relative importance. He has also described PROMETHEE I and PROMETHEE II as two forms of the model and their use in a decision making scenario. He has also taken the case study of begampur branch canal to describe the methodology of the approach.

3. Research Methodology

For a decision making problem that involves complex issues like the selection of the best alternative source of energy for a country as large and diverse as India, we also need to engage our decision-making skills. It pays to use an effective and robust process in these circumstances to improve the quality of the decision and to achieve consistently good results. Difficult or challenging decisions demand more consideration. These are the sort of decisions that involve:

a) Uncertainty – Many of the facts may be unknown.

b) Complexity – There can be many, interrelated factors to consider.

c) High-risk consequences – The impact of the decision may be significant.

d) Alternatives – There may be various alternatives, each with its own set of uncertainties and consequences.

e) Interpersonal issues – You need to predict how different people will react.

The major problem faced by decision makers is to assess broad range of options and to select best from a set of conflicting criteria. There is not always a single well defined criterion of selection, decision maker have to consider many number of criteria. This is a need of hour for effortless, organized, logical methods that will assist decision makers during interrelation. Thus, efforts need to be extended to identify those criteria that influence an alternative selection for a given problem, using simple and logical methods, to eliminate unsuitable alternatives, and to select the most appropriate
alternative to strengthen existing selection procedures. This paper presents one such simple, systematic and logical method, called PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations).

4. Energy Case Study

In the Indian context, five important source of sustainable energy have been shortlisted for the analysis. These sources are Solar (thermal), Wind (Onshore), Hydroelectric, Nuclear, and Biomass. These energy sources may serve as the alternatives for the conventional sources of the energy such as coal fired thermal power plant, diesel power plant, gas power plant etc. To compare these sources of the energy, the information has been collected from annual report of the Ministry of New and Renewable Energy (MNRE) Govt. of India, Indian Renewable Energy Development Agency (IREDA) and the report produced by some consultancy companies. Some of the attributes are compared on 10-point rating scale on the basis of opinion of the expert concerned with the energy sector. This information aided the decision-makers in deciding on the type of preference function in PROMETHEE as discussed in the research methodology section. PROMETHEE I approach helps in finding the partial ranking and PROMETHEE II helps in finding the complete ranking of these sources of energy. The important things to be determined for each attribute are whether it is cost attribute or benefit attribute. The cost attributes are supposed to be minimized and the benefit attributes are supposed to be maximized. Secondly, it is to be observed that the attributes are either quantitative or qualitative. If it is quantitative, the actuate value from the various source of information may be used and if it is qualitative, it is to be rated on 10-point rating scale.

The type of preference function to be used for various attributes is very important and it must suits the attribute. Based on this decision, values of l, m, p, q, r and s has to be ascertained. Absolute weights of each attribute on a 10-point rating scale are defined by the decision-maker or expert. The attributes used for comparing the sources of energy are introduced as discussed in the following paragraphs:

- **Availability**: Availability refers to the maximum energy that can be harnessed from a particular energy source if it is fully exploited. In other words, it refers to the sum of the already harnessed energy form a particular source and the additional capacity of the energy source that can be harnessed at the maximum level. This is a benefit attribute and is to be maximized. It is a quantitative attribute and measured in terms of MW (mega watt). The preference function selected for the attribute is of Type V. It is assigned weights of 9 on 10-point rating scale.

- **Acceptability**: Acceptability implies the degree to which a particular source of energy is socially accepted or within the limits of social tolerance. The acceptability is also a benefit attribute and it is to be maximized. The acceptability of the particular source of energy is rated on 10-point rating scale which is based on the opinion of the experts concerned worth the energy sector. The preference function is Type II. It is assigned a weight of 7 on 10-point rating scale.

- **Affordability (Levelized cost of Energy)**: Affordability is a common way of comparing the capital costs involved in harnessing a source of energy. Since electricity is the most common and viable source of energy, it can most easily be expressed in terms of the price that is incurred per watt generation of electricity. It is supposed to be minimized. It is a quantitative
attribute whose unit is taken as USD $/MWh. Preference function proposed for this attribute is Type III. It is given an absolute weight of 8 on a 10-point rating scale.

- **Intermittency:** No plant set up can produce its theoretical power all the time, e.g. nuclear power plants have to be shut down for refueling, dams do not always have enough water, wind does not blow steadily and the sun does not shine 24 hours a day. Thus, it can be observed that the actual harnessing of energy is not continuous rather intermittent. Capacity factor gives a good reflection of intermittency of a source of energy. It is supposed to be minimized. It is a quantitative attribute measured in percentage total operating time. Preference function proposed for this attribute is Type III. It is given an absolute weight of 8 on a 10-point rating scale.

- **Space Limits:** This reflects the amount of space required to harness a particular source of energy and whether it is economically viable or not. In order to make a level comparison, it is advised to assume the generation capacity of each of the sources to be the same. It is required that maximum energy be produced from the least possible space. It is supposed to be minimized. It is a quantitative attribute measured in square miles unit. Preference function proposed for this attribute is Type II. It is given an absolute weight of 7 on a 10-point rating scale.

- **Safety Consideration:** Safety of the workers is of utmost importance to any industry. No plant can operate without efficient inputs from its workers, and without proper safety inductions made into the entire process of harnessing the energy, it cannot be made functional. Also, its ecological consequences need to be considered, whether it has adverse effects on the environment. It is supposed to be maximized. It is a qualitative attribute rated on a 10-point rating scale. Preference function proposed for this attribute is Type II. It is given an absolute weight of 9 on a 10-point rating scale.

- **Gestation Period:** Any major change in the energy generation target and method has to go through certain policy initiations from the government and the subsequent follow up like the identification of suitable land, land clearance, setting up of the infrastructure, finding the stakeholders or the financers and others of the like. All these activities take a lot of time generally- in years- to be completely functional and able to produce energy at the stated potential. This period is referred to as the gestation period. It is supposed to be minimized. It is a quantitative attribute. Its unit is taken to be years. Preference function being used for this attribute is Type V. It is given an absolute weight of 6 on a 10-point rating scale.

- **Execution:** Building a team of talented project managers and experienced trouble shooters is very important for any energy harnessing process. As these projects consist of substantial front-end costs, delays can create a big loss. Also, stakeholder management has to be carried out at decentralized levels- from national to state level to local levels. This can at many times stand in the way of ensuring efficient project execution and sustained operation. It is supposed to be maximized. It is a qualitative attribute rated on a 10-point rating scale. Preference function proposed for this attribute is Type IV. It is given an absolute weight of 6 on a 10-point rating scale.
• **Localization:** This refers to the ability of an energy source to be efficiently harnessed locally. This also takes into account the ability of the local design and engineering to steer the generation of energy from the available sources. Hence, it takes into its ambit the geographic localization of a particular harnessing process as well as the technical localization of the required technology. It is supposed to be maximized. It is a qualitative attribute rated on a 10-point rating scale. Preference function proposed for this attribute is Type V. It is given an absolute weight of 6 on a 10-point rating scale.

Hence, now our problem narrows down to 5- alternatives- \(a_1, a_2, a_3, a_4, a_5\), being compared on the basis of 10 attributes \(f_1, f_2, \ldots, f_{10}\); \(f_i(.)\) being the availability of an alternative, \(f_i(.)\) being the acceptability and so on. The data of the problem can be tabulated as shown in Table 1.

| Alternative Sources of Energy | Availability (MW) | Acceptability (10-point rating scale) | Affordability (LCOE, $/MWh) | Intermittency (in %) | Space Limit (Sq. miles) for 1800MW | Safety Considerations (10-point rating scale) | Gestation Period (Years) | Execution (10-point rating scale) | Localization (10-point rating scale) | Life (year) |
|------------------------------|------------------|--------------------------------------|-----------------------------|----------------------|-------------------------------------|-----------------------------------------------|--------------------------|-------------------------------|--------------------------------|------------|
| Solar (Thermal)              | 748940           | 9                                    | 232.1                       | 25                   | 21                                  | 9                             | 4                        | 9                            | 9                        | 25        |
| Wind (Onshore)               | 49130            | 7                                    | 122.7                       | 33                   | 169                                 | 8                             | 2-3                      | 8                            | 4                        | 25        |
| Hydro                        | 148701           | 5                                    | 97.2                        | 50                   | 125                                 | 7                             | 10                      | 7                            | 3                        | 35        |
| Nuclear                      | 20000            | 3                                    | 84.2                        | 10                   | 2                                   | 4                             | 7                        | 7                            | 3                        | 40        |
| Biomass                      | 17536            | 6                                    | 71.7                        | 40                   | 2                                   | 7                             | 2                        | 6                            | 6                        | 20        |

These data are used as the inputs for the visual PROMETHEE software as shown in the Figure 1.
Based on these out flows, $\Phi^+$ and $\Phi^-$ for each of the alternatives can be evaluated by taking the weighted summation for the entire positive and the negative attributes respectively.

**Table 2. Values of Preference Flows**

| Action   | $\Phi^+$ | $\Phi^-$ | $\Phi$ |
|----------|----------|----------|--------|
| Solar    | 0.5649   | 0.2090   | 0.3560 |
| Wind     | 0.3157   | 0.2188   | 0.0969 |
| Hydro    | 0.2690   | 0.4110   | -0.1421|
| Nuclear  | 0.2173   | 0.4254   | -0.2081|
| Biomass  | 0.2018   | 0.3045   | -0.1027|

This positive and negative flow for each of the alternatives forms the basis for PROMETHEE I.

PROMETHEE I: Based on just the positive and the negative outflows, PROMETHEE I gives us a graph which shows something like shown below in Figure 2.

The scale on the left hand side shows the positive outflows of the alternatives and progresses from 0 at the bottom to a value of 1 at the top. On the right hand side, the scale indicates the negative
outflows of each of the alternatives separately but its scale is opposite to that on the left hand side. Here, the scale progresses from 1 at the bottom to 0 at the top. Obviously, in the negative range, a larger magnitude implies a smaller absolute value and vice-versa.

**PROMETHEE II:** These values are then used to calculate the net flows for each alternative as is required in the working of PROMETHEE II. These calculations are shown in Figure 2. Based on these, the PROMETHEE-GAIA software gives the following absolute ranking:

![Figure 2. Ranking of sustainable energy sources using PROMETHEE and it is a PROMETHEE-GAIA Software Screen shot.](image)

5. **Conclusion**

It is not shocking news to know that sources of fossil fuels are depleting at alarming rate than expected. It is also a well known fact that these conventional energy sources (CER) are concentrated in a very small region of mother earth. So, to avoid monopoly of those countries and to ensure sovereignty of any nation, we required to develop renewable energy sources (RES).

We have number of alternatives for RES like wind, solar, hydropower etc., but to choose an effective source is a very tedious job because numbers of parameters are need to analyze. PROMETHEE gives an answer for the above issue as it gives the detail analysis of attributes, on which decisions are needed. Two RES can be compared by various scenarios and at the same time number of attributes can be considered.

Using PROMETHEE, the energy scenario of India has been studied for identifying the most profitable and appropriate alternate source of energy. Nine attributes or criteria have been identified based on which the decision has been made. Both PROMETHEE I and PROMETHEE II have been employed to get a partial as well as total ranking. Based on the entire analysis, the results obtained are as follows:
Solar energy is the most profitable and prudent source of energy for India.

Wind provides the second most potential for acting as an alternate source of energy after solar energy.

Hydropower ranks third among the alternatives considered.

Nuclear the least appropriate source of energy based on the criteria employed and should be preferred after the rest three.

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