Impact of local factors on decision making – a multi criteria modelling framework in wind energy investment

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Wind power is an important renewable energy generation technology, but the location of wind potential and wind power plant installation are not in complete sync with each other. Many national, state and local variables other than wind potential play a role in site selection. The weights given to different local variables during wind power investment decisions are not known and are difficult to estimate in data paucity settings in India. Accordingly, this study proposes a framework to estimate the weights given to different local parameters in wind power investment decisions. We use the case study of select districts in Maharashtra, India to test the framework. The investment predictions based on priority of local factors estimated by the proposed approach are in agreement with the actual investment in the wind energy sector.

Keywords: Agricultural hierarchy process, renewable energy, wind portal, wind power plant.

AMONG the renewable energy technologies, wind power has emerged as the most reliable and efficient technology for power generation[1]. Notably, India has been at the forefront in promoting wind power and has consistently ranked among the top five countries in the world in installed capacity of wind. While wind power is a promising technology which is strongly dependent on the wind potential of a site, the distribution of wind power plants installation has not been completely driven by the availability of wind potential at that site[2]. While some states, including Maharashtra and Tamil Nadu are able to exploit more than 50% of their wind potential, others like Gujarat and Andhra Pradesh have exploited less than 30% of their wind potential[2].

Studies have shown that the decision to install wind power plants is influenced by national[3], state[4] and local factors[5]. Here we focus on local factors as they are more closely associated with on-field characteristics. Maharashtra has managed to exploit 60% of its wind potential, but similar to other Indian states, some of its high wind potential districts, including Nashik and Pune have exploited less than 15% of their wind potential while installed capacity in some other districts, including Satara, Sangli, Dhule and Nandurbar has exceeded their wind potential (Table 1). Hence, it is imperative to establish weighted criteria for the decision-making process of wind power plants.

In India, one of the main challenges in studying investment decisions is the lack of robust data availability. The World Bank report on Indian renewable energy sector in 2010 showed that the sector lacks good-quality data, especially wind energy sector which lacks data accuracy despite huge investments[5]. Further, it may not be economical to maintain data on local factors[6]. Under these circumstances, it is important to have a framework that could allow the estimation of priority given to local factors in wind energy investment, which is independent of the historical data. Accordingly, this article focuses on developing a conceptual framework for identifying and assigning weights to local factors impacting in the location choices of firms in wind power plants. The select districts of Maharashtra are used as a case study to determine the priority given to local factors in wind energy investment decisions.

Theoretical framework

Figure 1 shows the theoretical framework proposed in this study. The local factors can be categorized into two, viz. mandatory and peripheral factors. Mandatory local factors can be defined as those necessary for establishing any functional wind power plant at a location. The framework includes wind speed and site accessibility as mandatory factors. Peripheral factors can be defined as those whose favourable values can improve the benefits from a functional wind power plant. The national and state level factors along with mandatory local factors are used for shortlisting of locations for investing in wind power.

The final selection of location to invest for wind energy depends on the local peripheral factors. Lee *et al.*[7]

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Table 1. District-wise installed capacity and wind potential for Maharashtra, India

District	Wind potential (MW)	Installed capacity (MW)	Installed capacity as percentage of potential
Nashik	954.65	101	10.58
Satara	931.23	1176.24	126.31
Pune	843.10	106.4	12.62
Ahmednagar	794.15	233.85	29.45
Beed	616.65	56.95	9.24
Kolhapur	430.72	4.25	0.99
Dhule	229.54	535.25	233.18
Nandurbar	210.00	313.75	149.4
Sangli	155.66	813.97	522.92
Total	5165.7	3386	62.25

Source: Personal communication with National Institute of Wind Energy in 2015.

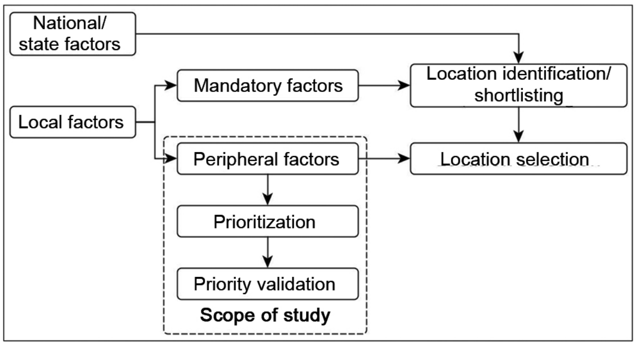

Figure 1. Theoretical framework.

examined the role of various local factors, namely local wind resource, power evacuation, and social acceptance in prioritizing the wind power plant. Wüstenhagen *et al.*[8] and Wolsink[9] have discussed the concept of social acceptance as a constraining role in renewable energy like wind energy in select European nations. Our framework first identifies the local peripheral factors followed by the weights given to these factors. These weights are then used to predict installed capacity in select districts and compared against historical data on the performance of different sites in terms of wind energy investment.

Methods

The proposed framework is explained using the case study of districts in Maharashtra using three common local peripheral factors as follows. This framework is applicable provided locations have been pre-selected based on national, state and local mandatory factors.

Identification of local peripheral factors

We propose local bureaucratic/administration efficiency, capital stock and societal perception as peripheral factors for the case study. These factors are chosen based on learnings from informal field interactions with experts. The local-level administrative and political structures prevalent in the government system play the role of sanctioning projects and their facilities[10]. Further, land is the primary requirement for a wind power plant and bureaucratic issues can cause delay in its acquisition[5]. Accordingly, in the current context, bureaucratic efficiency is defined as the time taken by the local administration to obtain land acquisition clearances.

The firms in early and late majority adopter segment prefer to make low risk investments compared to early adopters and innovator firms[11]. Accordingly, such firms would rely on the capital stock, including raw material characteristics and infrastructure that could help them sustain with lower risks. Raw material characteristics refer to the properties of the input material which determine the range of its usability[12]. Infrastructure refers to the structures/facilities required by the industry from an area for its smooth functioning[13]. Accordingly, capital stock factor is divided into two sub-factors. In the current context, raw material characteristics are considered as the number of wind sites available to the firms and infrastructure is considered as the number of substations present in a district. These substations are important as they help in power evacuation by allowing the generated power at the wind power plant to be immediately transported to the grid for distribution. While the presence of at least one wind site in a district is considered as local mandatory factor, the total number of wind sites in a district is a local peripheral factor.

The perception of the local populace could play an important role in determining the ease of getting local support and access to local resources like land[8,9]. Further, education level of the local populace could play an important role in determining their general awareness level which is critical in shaping people's perception[14]. Accordingly, in the current context, social perception is considered as the literacy rate of the local people. Overall, these factors and sub-factors result in taxonomical hierarchy (Figure 2). While bureaucratic efficiency criterion is the cost criterion, the remaining two criteria including capital stock and societal perception are benefit criteria.

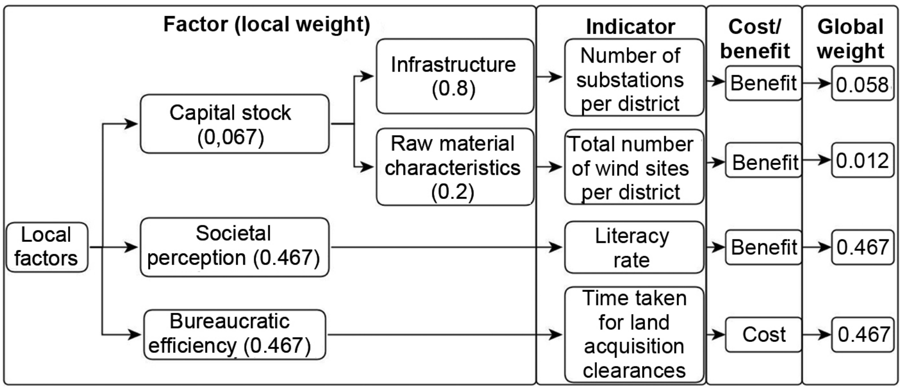

Figure 2. Local peripheral factors taxonomy and weights.

Prioritization of factors – criteria weight modelling

The weights assigned to these local peripheral factors need to be estimated without using the historical data. Pair-wise comparison is one approach that could be used to determine the priority given to different factors and sub-factors[15]. This approach provides relative priority based on the perspective of an individual/firm. Separate pairwise comparison matrix is created for factors and sub-factors. On the numerical scale of 1–9, the relative weights are given to obtain the global and local weights to the factor. The pairwise comparisons provide local weights from which global weights are derived by multiplying local weights in a given row. The relative weights for each comparison, say, bureaucratic efficiency and social perception could be obtained in different ways like interviewing a respondent and literature review. In the present case, literature review and anecdotal information from experts are used for arriving at relative weights.

Criteria weight validation

The weight obtained from the pairwise comparison approach may not necessarily provide optimal results as it significantly incorporates subjective judgment. In order to ascertain that the weight obtained from pairwise comparison is of relevance, weights need to be validated. The proposed validation approach is a two-step process. In the first step, various available real-world scenarios are selected and these are ranked for their potential to obtain wind power investments based on the local peripheral factors. In the second step, the ranking obtained for these scenarios is then compared with the actual wind power investments made in those scenarios. A positive association will validate the weights.

In the present study, the factor weights are validated by performing correlation analysis between the ranking of the different investment scenarios and ‘added wind capacity’ value of wind power plant for each scenario. Ranking of the different investment scenarios is performed in three stages. The first stage is selection of the region in which different scenarios are ranked. The second stage involves preparing various investment scenarios for the study. The third stage involves using analytic hierarchy process (AHP) technique for determining the ranking of the different investment scenarios.

Stage 1 – Selection of state and districts: In this study, the method of selecting districts has been a process of elimination based on state and local mandatory factors to select only those districts which satisfy all these preliminary criteria. The whole state is considered as the region for the study because it is the smallest unit for policy-making for wind sector in India[16]. Particularly, Maharashtra is selected because it has been found to have the highest policy attractiveness index for 14 out of 20 years, i.e. 1993–2012 (ref. 4).

Maharashtra comprises 36 districts out of which 9 are selected based on significant wind potential, site approachability and presence of at least 1 wind power project. Site approachability criterion is an outcome of preliminary interactions with a few investors who consider it as a mandatory criterion for selecting the site. Accordingly, nine districts, namely Ahmednagar, Beed, Dhule, Kolhapur, Nandurbar, Pune, Sangli and Satara were selected (Table 1).

Stage 2 – Investment scenarios (or, alternatives) preparation: The investment scenario matrix, $A_{ij} = m_i * n_j$ is prepared, where A_{ij} represents the individual investment scenario, m_i the ith district among the selected districts and n_j the jth year in the chosen period. This is done to represent the set of $i * j$ investment scenarios for the study, which are considered for AHP-based modelling.

Stage 3 – Analytical hierarchy process: AHP has been proposed for multi-criteria decision making with over 200 known applications[17]. AHP allows the user to consider the subjective part of decision, including intuition and personal experiences while using both quantitative and qualitative data[18,19]. AHP provides a systematic criteria prioritization[20] based on eigen-value method[21]. It allows

Table 2. Matrix of alternatives ($A = m \times n$, where m = year, n = district) for bureaucratic criterion measured by the time taken for various clearances related to land acquisition

	District							
Year	Ahmednagar	Beed	Dhule	Kolhapur	Nandurbar	Nashik	Sangli	Satara
2006	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2007	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2008	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2009	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2010	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2011	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2012	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17
2013	0.2	0.57	0.49	0.36	0.23	0.77	0.19	0.17

Table 3. Matrix of alternatives ($A = m \times n$, where m = year, n = district) for societal criterion measured by literacy rate (%)

	District							
Year	Ahmednagar	Beed	Dhule	Kolhapur	Nandurbar	Nashik	Sangli	Satara
2006	77.5	71.5	73.8	80.5	60.1	78.1	79.5	81.5
2007	77.9	72.1	74.1	81.2	60.8	78.8	80	82.2
2008	78.3	72.8	74.4	81.8	61.5	79.5	80.5	82.8
2009	78.7	73.4	74.7	82.4	62.3	80.3	81	83.4
2010	79.1	74	75	83	63	81	81.5	84
2011	79.4	74.6	75.3	83.6	63.7	81.7	82	84.6
2012	79.8	75.3	75.6	84.3	64.5	82.5	82.5	85.3
2013	80.2	75.9	75.9	84.9	65.3	83.2	83	85.9

Data source: Socio-economic review reports for districts of Maharashtra.

the user's perspective-based criteria categorization into benefit or cost and accordingly, requires maximization of benefit criteria value and minimization of cost criteria value[22]. Raju *et al.*[23] solved the benefit–cost integration problem by converting cost into benefit using the normalization scheme as

$$\text{Benefit criteria:} \quad p_{ij} = \frac{t_{ij} - t_i^{\min}}{t_i^{\max} - t_i^{\min}}, \tag{1}$$

$$\text{Cost criteria:} \quad p_{ij} = \frac{t_i^{\max} - t_i}{t_i^{\max} - t_i^{\min}}, \tag{2}$$

where t_{ij} is the criteria value of the jth alternative with respect to the ith criterion and $t_i^{\max}$ and $t_i^{\min}$ are the absolute maximum and minimum values among all the alternatives for the ith criterion.

AHP method comprises criteria identification, criteria weights, criteria value for alternatives and score of alternatives. In this study, criteria identification and criteria weight steps are not carried out because they represent identification and prioritization step for peripheral factors. Tables 2–5 give criteria value for alternatives. The alternative score based on the factor weights is computed by measuring the alternative score which in turn is obtained by summation of the product of the criteria and alternative weights for the different alternatives. Equation (3) gives the mathematical formulation of computing alternatives score.

$$R_j = \sum_{i=1}^{N} P(i, j) w(i). \tag{3}$$

Here, R_j is the ranking of the alternatives, P_{ij} the normalized criteria score of the alternatives using eqs (1) and (2) and w_i is the criteria weightage. The overall attractiveness of alternatives is based on their total weighted score for a given criterion.

Results and discussion

Local peripheral factor weights

Figure 2 shows the local and global weights obtained for each of the factors. Equal weight is given to bureaucratic efficiency and societal alternatives and score of alternatives. Local administration and societal behaviour are externalities for the investors. Therefore, although more capital stock in terms of number of wind sites and substations is desirable, it is given lesser importance compared to ease of getting land acquisition clearance and local population support. Further, it should be noted that such weight-based criteria are adopted by investors in the districts which have cleared the criteria of local mandatory factors indicated by availability of wind potential. In this regard, Gupta and Sravat[24] have given recommendations related to governance and financing for improving the power plant development in developing countries.

Table 4. Matrix of alternatives ($A = m \times n$, where m = year, n = district) for resource availability measured by the number of windy sites

	District							
Year	Ahmednagar	Beed	Dhule	Kolhapur	Nandurbar	Nashik	Sangli	Satara
2006	4	1	3	1	1	2	3	10
2007	4	1	3	1	1	2	5	10
2008	4	1	3	1	1	2	5	10
2009	4	1	3	1	1	2	5	10
2010	4	1	3	1	1	2	5	10
2011	4	1	3	1	1	2	5	10
2012	4	1	3	1	1	2	5	10
2013	4	1	3	1	1	3	5	10

Data Source: Maharashtra Energy Development Agency (2014).

Table 5. Matrix of alternatives ($A = m \times n$, where m = year, n = district) for evacuation criterion measured by the number of substations

	District							
Year	Ahmednagar	Beed	Dhule	Kolhapur	Nandurbar	Nashik	Sangli	Satara
2006	2	0	3	0	1	0	4	2
2007	2	0	3	0	1	0	5	2
2008	3	0	5	0	1	0	5	3
2009	3	0	6	0	1	0	5	4
2010	3	0	6	0	1	0	6	6
2011	3	0	6	0	1	0	7	7
2012	3	0	6	1	1	0	9	12
2013	4	0	6	1	1	0	12	16

Data source: Personal communication with Maharashtra State Load Dispatch Centre in 2015.

Infrastructure has more weight than raw material characteristics due to inability to use raw material owing to infrastructure issues. Countries including India and China are facing issues related to load management in terms of managing reserve capacity and underutilization of networks which has resulted in utilities refusing to accept wind power by the grid[3]. Germany was able to increase its wind energy share in total energy by addressing some factors pertaining to infrastructural issues related to local-level distribution systems[25].

Weights validation

Scenario ranking: The ranking of the investment decisions alternatives from the eight selected districts and eight years was obtained (Table 6). The scenario of 'Satara in year 2013' was allotted the first rank based on weighted local peripheral factors. Further, the first five ranks were given to all scenarios of Satara from 2009 to 2013, indicating favourable investment environment.

Scenario-predicted ranking comparison with field scenario: The ranking for scenarios was compared with actual investment decisions using the indicator 'added wind capacity'. A correlation of 0.43 at 95% confidence level was obtained, which indicates a weak positive association between local factor weights and actual investment decision-making. This association indicates that the proposed framework can be used to estimate weights of local peripheral factors in data paucity scenario. However, weak strength of association could be due to the weights given to the factors or missing out other important local peripheral factors.

The study has certain policy implications. The high weightage to bureaucratic efficiency indicates that policy-making alone is not sufficient to increase utilization of wind potential. In other words, this indicates that another form of government intervention, apart from policy making, is needed and can attract the wind projects in a district. Accordingly, districts with higher potential and lagging capacity could attract investment with efficient government intervention at the ground level. Interestingly, policy learning in this regard could come by benchmarking Satara's bureaucratic efficiency variable for the remaining districts. Another finding is the dominance of societal perception, which indicates the prevalence of not-in-my-back-yard attitude in Maharashtra. Accordingly, it necessitates the inclusion of local communities as beneficiaries of wind projects.

Like most of the studies, this one also has limitations. The weight estimation is based on the perception of the individual rather than on any mathematical model, so it can vary from individual to individual. Further, the reliance on subjective judgments could prevent achieving

Table 6. Year-wise and district-wise ranking of alternatives based on analytic hierarchy process (AHP) technique and actual added wind capacity(MW) (ranking (added wind capacity; MW))

District	2006	2007	2008	2009	2010	2011	2012	2013
Ahmednagar	25 (71.2)	23 (42.5)	22 (46.6)	21 (13.8)	20 (0)	19 (2.25)	18 (0.5)	16 (0)
Beed	61 (0)	59 (0.6)	57 (18.6)	55 (3.6)	54 (0.5)	52 (1)	49 (3.25)	47 (29.4)
Dhule	43 (212)	42 (58.6)	40 (0)	38 (0)	37 (23.1)	35 (12.6)	34 (0)	33 (0)
Kolhapur	32 (0)	31 (0)	30 (0)	29 (0)	28 (0)	27 (0)	26 (0)	24 (4.25)
Nandurbar	51 (72.5)	48 (1.25)	46 (0)	45 (8.7)	44 (37.15)	41 (76.65)	39 (0)	36 (0)
Nashik	64 (7.2)	63 (35.9)	62 (33.3)	60 (12)	58 (0)	56 (0)	53 (12.6)	50 (0)
Sangli	17 (117.6)	15 (64.8)	14 (15.15)	13 (0)	12 (1.5)	10 (46.15)	8 (183.75)	6 (199.6)
Satara	11 (26.23)	9 (56.32)	7 (75.73)	5 (84.94)	4 (165.91)	3 (169.44)	2 (88.2)	1 (192.95)

optimal weights for factors. The study has been only performed in a single state and with a small set of local factors. The ranking obtained using AHP does not allow estimating the relative overlap and differences between the alternatives.

Conclusion

The present study provides a framework to estimate the weights given to local factors during wind power investment decisions. The investment decision estimated based on the weights obtained from the proposed framework for local factors showed a positive association with field investment status in wind power. The proposed framework could be used to determine relevance of different local factors in wind power investment decisions in scenarios of data paucity. Such a framework would help policy makers understand issues and barriers faced by investors adopting wind energy. Accordingly, new policies could be framed which would help in maximizing the utilization of existing wind potential.

1. Dalla Valle, A. and Furlan, C., Forecasting accuracy of wind power technology diffusion models across countries. *Int. J. Forecast.*, 2011, **27**, 592–601.
2. Ministry of New and Renewable Energy, *Annual Report 2014–2015*. MNRE, Govroment of India, 2015.
3. Panse, R. and Kathuria, V., Modelling diffusion of wind power across countries. *Int. J. Innov. Manage.*, 2015, **19**, 1550037.
4. Panse, R. and Kathuria, V., Role of policies in deployment of wind energy – evidence across states of India. *Renew. Sustain. Energy Rev.*, 2016, **53**, 422–432.
5. Sargsyan, G., Bhatia, M., Banerjee, S. G., Raghunathan, K. and Soni, R., *Unleashing the Potential of Renewable Energy in India*, World Bank, Washington DC, 2010.
6. Abelson, J., Forest, P., Eyles, J., Smith, P., Martin, E. and Gauvin, F., Deliberations about deliberative methods: issues in the design and evaluation of public participation processes. *Soc. Sci. Med.*, 2003, **57**, 239–251.
7. Lee, A. H. I., Chen, H. H. and Kang, H.-Y., Multi-criteria decision making on strategic selection of wind farms. *Renew. Energy*, 2009, **34**, 120–126.
8. Wüstenhagen, R., Wolsink, M. and Bürer, M. J., Social acceptance of renewable energy innovation: an introduction to the concept. *Energy Policy*, 2007, **35**, 2683–2691.
9. Wolsink, M., Wind power implementation: the nature of public attitudes: equity and fairness instead of 'backyard motives.' *Renew. Sustain. Energy Rev.*, 2007, **11**, 1188–1207.
10. Tummala, K. K., *Public Administration in India*, Allied Publishers, New Delhi, 1994.
11. Rogers, E. M., *Diffusion of Innovations*, Simon and Schuster, New York, 2010.
12. Barham, B., Bunker, S. G. and O'Hearn, D., *States, Firms, and Raw Materials: The World Economy and Ecology of Aluminum*, University of Wisconsin Press, Wisconsin, 2013.
13. Elmer, V. and Leigland, A., *Infrastructure Planning and Finance: A Smart and Sustainable Guide* Routledge, New York, 2013.
14. MSU Land Policy Institute and The Great Lakes Commission, *Perceptions of the Impact of Wind Energy Generation in Coastal Communities: Imapct Perceptions*, Michigan, 2011.
15. Saaty, T. L., *The Analytic Hierarchy Process*, McGraw-Hill, New York, USA, 1980.
16. Constitution of India, Seventh Schedule (Article 246), 1949.
17. Zahedi, F., The analytic hierarchy process – a survey of the method and its applications. *Interf. (Providence)*, 1986, pp. 96–108.
18. Montevechi, J. A. B., Guimaraes, I. F., Oliveira, M. L. M. D. and Friend, J. D., Decision-making with multiple criteria in the selection of ultrasound scavenging system in a private hospital in Brazil. *Int. J. Anal. Hierarchy Process*, 2010, **2**, 14–29.
19. Palcic, I. and Lalic, B., Analytical hierarchy process as a tool for selecting and evaluating projects. *Int. J. Simul. Model.*, 2009, **8**, 16–26.
20. Kurttila, M., Pesonen, M., Kangas, J. and Kajanus, M., Utilizing the analytic hierarchy process (AHP) in SWOT analysis – a hybrid method and its application to a forest-certification case. *For. Policy Econ*., 2000, **1**, 41–52.
21. Brudermann, T., Mitterhuber, C. and Posch, A., Agricultural biogas plants – a systematic analysis of strengths, weaknesses, opportunities and threats. *Energy Policy*, 2015, **76**, 107–111.
22. Nijkamp, P. and Van Delft, A., *Multi-criteria Analysis and Regional Decision-making*, Martunus Nijhoff Social Sciences Division, Leiden, 1977.
23. Raju, U. S., Rangaraj, N. and Date, A. W., The influence of development perspectives on the choice of technology. *Technol. Forecast. Soc. Change*, 1995, **48**, 27–43.
24. Gupta, J. P. and Sravat, A. K., Development and project financing of private power projects in developing countries: a case study of India. *Int. J. Project Manage.*, 1998, **16**, 99–105.
25. Martinot, E., How is Germany integrating and balancing renewable energy today? *Energy Transit: The Global Energiewende*, 2015; http://energytransition.de/2015/02/how-germany-integrates-renewable-energy/ (accessed on 22 October 2015).

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