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Original Research

Environmental and Socio-Economic Aspects of Public Acceptance of Wind Farms in Tamil Nadu, India – Key Observations and a Conceptual Framework for Social Inclusion

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Abstract

The planning and implementation of large-scale projects such as wind farms can have significant impacts on the perceptions and attitudes of people. Many times, it is necessary to consider the scope of social inclusion in a democratic decision making system. In this study, a questionnaire survey was conducted to assess the public opinion on health impacts, energy costs, environmental impacts and social developments associated with a wind farm located in the neighborhood of Gudimangalam, Tamil Nadu in India. The overall weightage of concerns obtained were mainly about health and environment in terms of higher noise levels (87%), visual obstructions (45%), obstructions to the movement of birds (43%) and dust accumulation (35%). A comprehensive response score was formulated for the responses pertaining to various demographic attributes. The critical impacts of environmental and social aspects were obtained based on the observed variations in weightage. Further, the study highlights the key aspects of changing socio-economic structure influencing the formation and representation of common

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opinion regarding futuristic wind energy adoption plans. Based on this, a conceptual framework is proposed for social inclusion as a critical measure for decision making.

Keywords: energy environment and economics, public hearing, public perception, questionnaire survey, social inclusion, wind energy farm

Introduction

The renewable energy sector is facing a complex paradox while dealing with the ever-increasing rate of energy demand despite its pursuits to combat the adverse environmental impacts from the non-conventional resources utilization practices. Among the available renewable energy sources (solar, wind, biomass, tidal, microbial fuel cells etc.), wind energy proves to be promising for large-scale applications due to its technical maturity, commercial readiness, environment-friendliness, ease of availability and accessibility [1-3]. It is also considered as the energy source for green technology due to its minimal negative environmental effects. That is to say, the net environmental impacts of wind energy plants (wind farms) are preferably articulated towards a positive campaigning with the scope of achieving emission-free, low cost and socially acceptable solutions capable of reframing the energy business infrastructure for the future [4].

Some of the commonly reported problems associated with wind farms include noise produced from the rotor blades [5-6], death of birds [7], obstruction to bats [8] and other visual impacts [8-9]. In some cases, the avian mortality incidents were also correlated with the impacts of lightning, weather and wind tower design [10-13]. Birol et al. [14] have reported that even small wind-farm fatalities can pose a considerable extinction threat on the long-living species. However, apart from the ecological perspective, these problems seem to have serious social impacts for a highly populated and agriculture-based country like India where public perception can be quite diversified and unleash towards command on social, economic and political supports. Putting together, it is evident that there are some throbbing social elements which have been undermined or missed in the feasibility studies and policy frameworks for the installation and operation of wind farms in lively areas.

One major drawback in the prevailing environmental impact assessment methodology is the limited scope for timely intervention and the enforcement to adhere to the recommendations as mandatory, not as optional. The recent policy decisions to promote extensive extraction of wind energy in the state of Tamil Nadu, India have shown remarkable implications illustrating socio-cultural responsiveness through the underlying industry-government collaborations [15-17]. Unlike in the Western countries, the reluctance to accept a major shift in transformational processes has got limited scope in India based on the non-converging nature of personal/ individual responses. Therefore, although the feedback survey studies generally indicate a socio-cultural spirit of welcoming and accepting the developmental activities of public interest without doubting the intention, it cannot deny any evidence/ remark of so-called NIMBYism (not in my backyard) [4, 18]. Therefore, an expression of fear about the impact and dissatisfaction among the public can be considered as an unavoidable consequence of lack of participation and recognition in the decision-making process. This 'social gap' is expected to have a diverse representation in the Indian context owing to the co-existing socio-cultural and other demographic variations. Therefore, we feel that there must be a serious revisit on the successful aspects of the public hearing process being conducted as a mandatory step in environmental impact assessment [19-20]. This is quite important in the case of renewable energy projects where the public hearing has to be conducted not as an official necessity for environmental clearance by convincing the public about the futuristic benefits, but with a focus on addressing the socio-economic concerns [21-22] of necessity.

The major limitations of public hearing as part of environmental impact assessment (EIA) observed in the Indian context are, (i) lately announced interactions preventing the public from being involved in the scoping stage and (ii) presentation of scanty and inaccurate data [23]. The lack of education and awareness of the public to understand the detailed implications of the project proposals eventually result in failure of such approaches. There is quite a lot of evidence in India that the petitioners (usually individuals or their association) could not arguably justify the prominent environmental degradation caused by the misuse of sanctioned authorities by the multinational companies in front of the court for a fair jurisdiction (Table 1). Therefore, many non-government organizations are appointed as conveners for conducting such meetings by promoting the public notifications and intervening legally to intensify the guidance and follow-up [24-34]. There is, of course, evidence that conducting a proper public hearing can provide more favorable weightage to the environmental concerns during the final verdict. However, many serious petitions were outwardly dismissed due to lack of technical support in the absence of proper public hearing. The information provided in Table 1 can fairly give a justification for our hypothesis that early social inclusion in an enforced or customary practice may be more effective and appreciative than striving against the administrative and economic powers to recover the missed justice.

Table 1. Typical responses to the public hearing process carried out for a few socially significant projects in India.

S. No.	Obligatory reason	Evidence of public involvement	Outcome of petitions	Document title	Reference
1	Wind energy tariff revision, Tamil Nadu	Notice on 27.04.2011 & 08.09.2011 and meeting on 08.06.2012	Comments were noted and action taken against the revised tariff	Beta Wind Farm (P) Limited vs Tamil Nadu State Commission on 24 May, 2013	[24]
2	Wind energy tariff revision, Karnataka	Order on 10.10.2013	The levelled tariff was re-determined for the useful life of the project	Guttaseema Wind Energy Company Pvt. Limited vs Karnataka State Commission on 25 November, 2014	[25]
3	Mini Hydro Electric Project of 15 MW, Karnataka	Order on 28.06.2017 and meeting on 12.07.2017	Writ petitions on retail supply and wheeling tariff were dismissed	Graphite India Limited vs Karnataka State Commission on 21 June, 2018	[26]
4	Purchase obligations from renewable energy sources, Rajasthan	Order on 07.03.2007; no mention of public hearing	Dismissed petitions about the impugned regulations with the prevailing state acts	M/S Dcm Shriram Consolidated L vs State Of Rajasthan And Odisha on 31 August, 2012	[27]
5	Revision of tariff order from biomass based power projects, Madhya Pradesh	Order on 07.08.2007; no mention of public hearing date	Redirected the State Commission to modify the tariff	M/S. Harvest Energy Private Ltd vs Madhya Pradesh Electricity Board on 18 February, 2013	[28]
6	Mangalore Super Thermal Power Station as well as Ash Pond	Agreement on 12.09.1989; no public hearing	Complains dismissed due to lack of violation of fundamental rights	Jana Jagruthi Samithi vs Union Of India (UoI) on 6 August, 1991	[29]
7	Thermal power plant in Dakshina Kannada, Karnataka	Scheduled on 12.08.1995; no meeting	Objections dismissed due to lack of evidence	Indian Council for Enviro-Legal Action vs Union Of India (UoI) on 29 August, 1997	[30]
8	Wind farm erections, Karnataka	No public hearing was conducted	Writ petitions are dismissed due to lack of challenge on the policy or process	Mr R Bhasham vs Government Of Karnataka on 26 September, 2013	[31]
9	Greenfield international airport, Goa	Order on 20.10.2014; meeting on 01.02.2015	Redirected EAC to revisit the project before sanction	Hanuman Laxman Aroskar vs Union Of India on 29 March, 2019	[32]
10	Hazardous waste handling, Kudamkulam	First meeting 10.01.2003; no meeting is mandatory for expansion	All petitions dismissed due to lack of clarity and evidence	Vedanta Limited vs State Of Tamil Nadu on 18 August, 2020	[33]
11	Salem-Chennai Eight Lane Highway Green Field Project	Need for public hearing is highly recommended	Land acquisition notification was quashed and the writ petitions were allowed	P.V.Krishnamoorthy vs The Government Of India on 8 April, 2019	[34]

Another concern for getting a realistic feedback is the limited scope of questions used in public hearing/ surveys. On the other hand, social media can provide a massive open access platform for public responses with anticipated fair data processing and retrieval options. With this background, the common factors affecting the public acceptance of wind energy projects can be identified as social, environmental, economic, technical, institutional, health and contextual [35]. In the post-COVID-19 global socio-economic scenario, it is essential to revisit these impacts in a more intrinsic and inclusive manner. It is observed that studies analyzing people's perception and attitude towards renewable energy in the Indian context are highly missing [36-37]. From a survey-based study in the USA, Thomson and Willett [38] reported that people near the wind power installations had favorable opinions compared to people residing near the thermal power plants. However, there were severe protests against the installation of wind turbines in Frankfurt, Germany indicating that renewable energy projects may not gather easy social acceptance despite the advantages in cutting down greenhouse emissions and combating climate change [39]. Lack of similar studies in this context limits further comparison of these claims. Nonetheless, the emerging trends in people's awareness and social reunion through digital media have instigated the chance for a major massive opinion irrespective of the political outcomes.

In these aspects, the present study attempts to understand the social-cultural and environmental gaps persisting in the contemporary rural Indian scenario while instigating ambitious wind energy projects towards achieving sustainable energy infrastructure. To the best of the authors' knowledge, there is no study reported on the scope of reconsidering the public hearing mechanisms in the rural/suburban Indian context on renewable energy projects expressed through public surveys. Therefore, the study primarily comprises three components: (i) data collection through a questionnaire survey, (ii) quantitative evaluation of the criticality of responses and (iii) a conceptual framework for redirecting public opinions into decisive representations. The motivation for this study is to critically evaluate the public responses towards decision-making for implementation of wind energy projects, and to provide an integrated framework for addressing some of the deep-rooted socio-cultural issues for improving public participation in such ambitious projects.

Methodology

Study Area

The state of Tamil Nadu located in the southern peninsular region is always blessed with sufficient wind flow patterns originating from the ocean currents throughout the year. During the last two decades, many prospective captivators have ventured to establish small, medium or high wind farms in Tamil Nadu with government support [40]. The study area is located in Gudimangalam which is a revenue block (total geographical area of 22.24 km^2) consisting of a total of 23 panchayat villages in the district of Tiruppur in the state of Tamil Nadu, India (10.690N and 77.270E). It has been identified as a potential location for wind energy production having a wind farm established in 2011 with 15 turbines (each having a rated power of 1250 kW) and it presently contributes about 21.0 MW [41]. The location map of Gudimangalam highlighting the presence of wind turbines is shown in Fig. 1.

The social picture of Gudimangalam has been evaluated as part of this study to depict the current status of developmental activities and their visible impacts

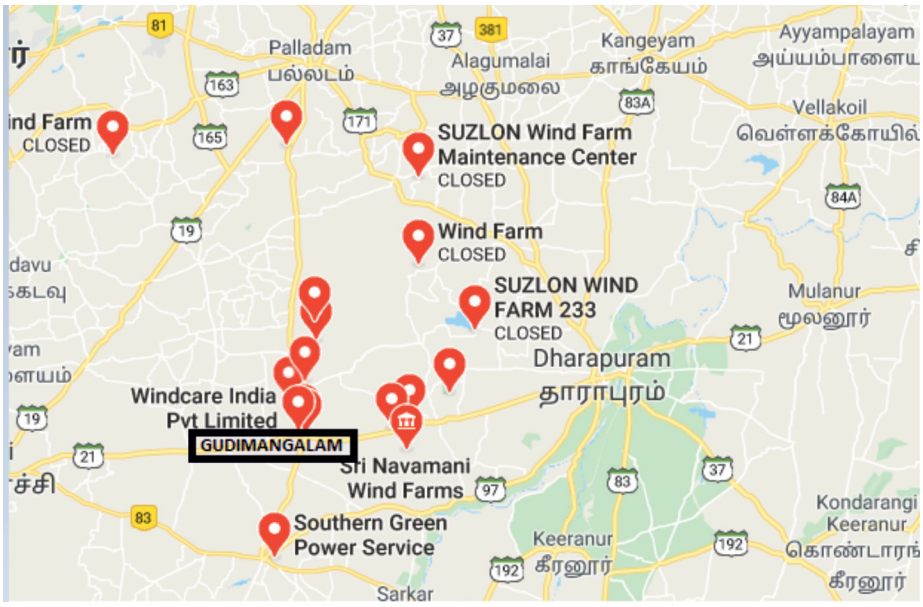

Fig. 1. Location map of Gudimangalam showing the wind turbines.

over the years. Based on the latest available population census data, the Gudimangalam block has about 5000 persons with an almost equal male-female distribution (49.12% and 50.88%) living in 1430 households with a population density of 220 per km^2. Though the district is highly industrialized, poor literacy rate (65%) and high unemployment rate (42.26%) have resulted in an unstable work profile with low income occupations. Out of the total population, about 51% of the workers are engaged in agriculture-related occupations. The human development index of Gudimangalam is comparatively much lower (0.45 in a scale of 0 to 1) to the average values of the district and the state where 44% people live below poverty lines as per the state records [42-43]. As per the existing scenario, it is necessary to evaluate whether the developmental activities of the wind farm in Gudimangalam can bring any remarkable socio-economic benefits to the people in general. In order to get a consensus of the public perception of the overall impact of the wind farm in their locality, it is necessary to collect the direct concerns of affected people, though as a case study, without a formal public address format. Therefore, a typical questionnaire survey has been conducted with the persons located in 8 nearby villages as indicated in Fig. 2.

Development of Questionnaire Framework

It is quite essential to identify the relevant questions that could be the critical loop-holes, to reinstate a win-win situation for all the stakeholders who might have been separated with some unknown vested interests deposited on them. To analyze the perception of the people on the installation and operation of the wind farm, a questionnaire was prepared in English as well as the native language Tamil based on the demographic information (age, gender, literacy level, location). The questionnaire consisted of 14 questions related to impact on human health, environment, agriculture and social aspects. The questions were framed as a combination of multiple choice, assertive types and open-ended so that the ambiguity in collecting and interpreting the direct responses can be eliminated. The template of the questionnaire is provided in Fig. 3. The responses were collected through direct interviews, hard copy forms and soft copy forms circulated through emails.

Social Aspects of the Survey

The questionnaire was distributed to the rural community living in different localities in and around the study area, namely, Kamanaikenpalayam, Kethanur, Krishnapuram, Mallegoundenpalayam, Manasipalayam, Metrathi, Puliyampatti and Thungavi. The participants in the questionnaire survey typically belong to various age groups having different levels of formal education and occupational engagements. As mentioned above, age, gender, literacy and location were specifically chosen as important parameters for the response analysis. The summary of distributions of the people based on these parameters is shown in Fig. 4. It is observed that, among the total of 113 participants, there were no participants below 10 years of age, and

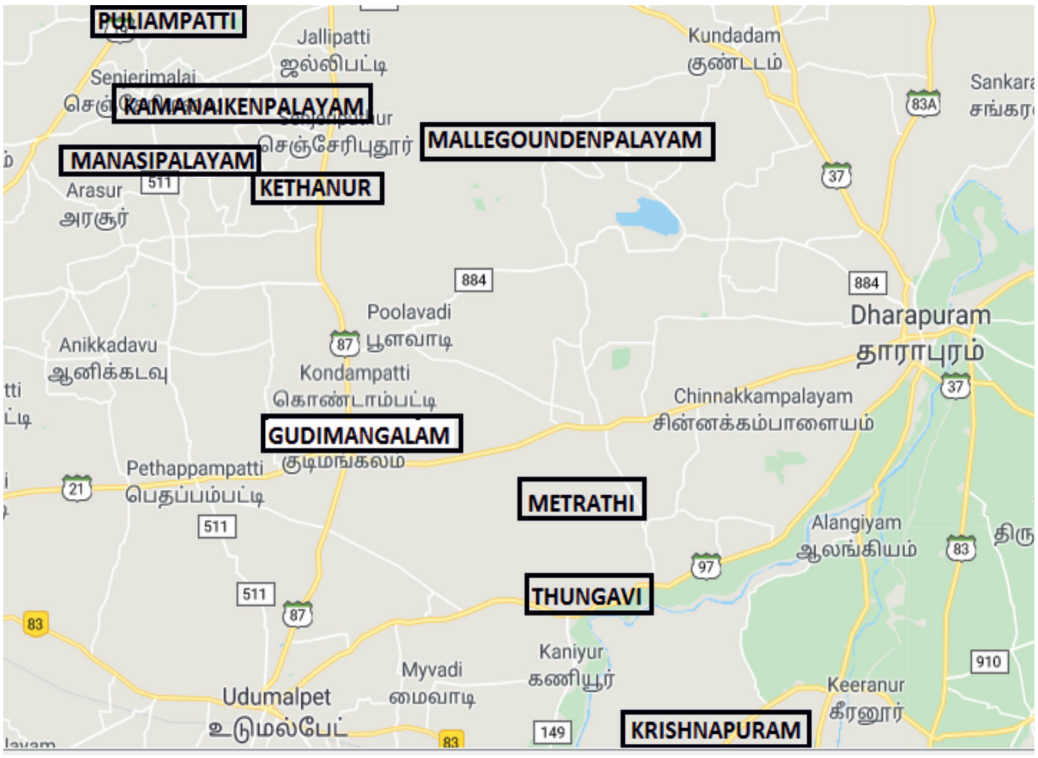

Fig. 2. Location map of Gudimangalam showing the survey spots.

Fig. 3. Questionnaire survey sample in a) English and b) native language (Tamil).

only 3 were in the age group of 61-70. The majority of the people who took part in the survey belong to the middle-aged group (41 people in the age group of 31-40 and 44 people in the age group of 41-50). There were 8 participants each in the age groups of 11-20 and 21-30, and 9 in the age group of 51-60. It is also observed that the gender ratio (female/male) is greater than one (1.17) which is a good sign of equality in their participation. Majority of the people (23 participants) who took part in the survey belong to the central portion of Gudimangalam where the wind farm is situated. Out of the remaining participants, 22 were from Metrathi, 18 from Kamanaikenpalayam, 17 from Manasipalayam, 15 from Thungavi, 15 from Kethanur, 1 from Puliampatti, 1 from Mallegoundenpalayam and 1 from Krishnapuram. As far as the educational background

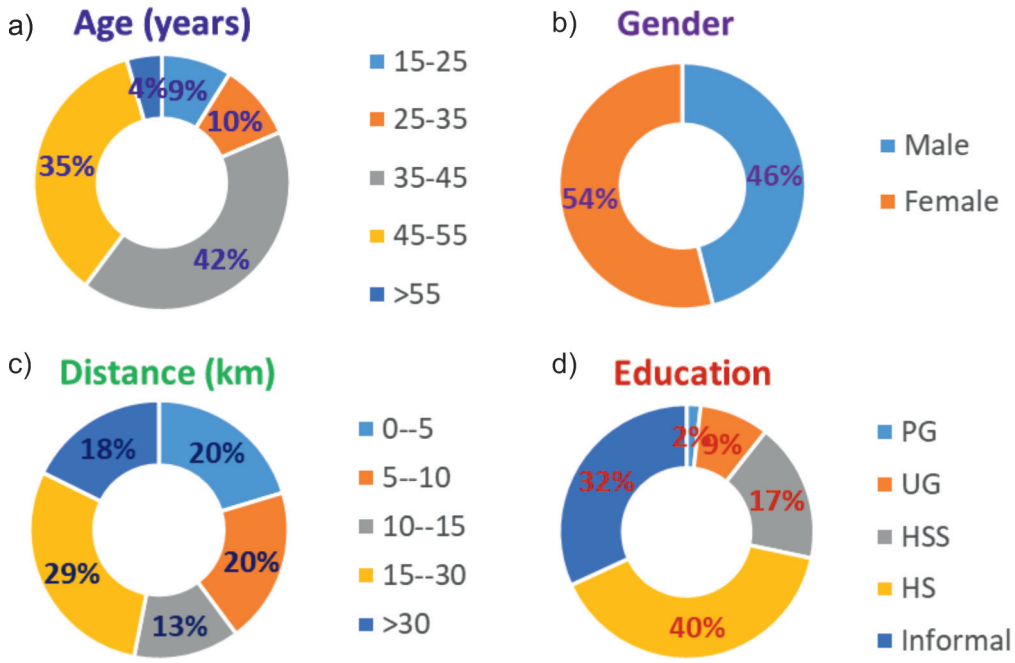

Fig. 4. Distributions of the people based on the survey attributes a) age, b) gender, c) distance and d) education.

is concerned, among the total of 113 participants, 2 were post-graduate, 19 graduates, 5 diploma holders, 60 completed schooling and the remaining 36 were without any formal education history.

Methodology for Evaluating the Perceptions

In order to ascertain the possibility of successful representation of people's perceptions in the decision making process, we felt that there must be a mechanism to ensure the proper implementation of the public hearing process to be moderated by the local administrative bodies. It is also important to ensure the participation of all representatives in such gatherings to share their impactful views of various aspects of the planned project. In this perspective, we have attempted to qualitatively evaluate the responses from the questionnaire survey based on the classifications in the question type (health, environment, agriculture and social). A weighted average method is employed to calculate the response score under each category of the questions since the representations are only indicative of the total strength of population. The weightage is assigned for the selected attributes of the population (age, gender, distance and education) based on their representation in a particular class as shown in Fig. 4. Further, the representations of responses with significance to the criticality of each question were also calculated by defining a response score for the critically impacting responses ('Yes' type or 'High' type responses). Finally, a comprehensive weighted average response score (CWARS) is computed for each question to compare the perceptions of the people among the selected categories (Eq. 1-3).

$$W_{i,g} = \frac{P_{i,g}}{P_{Li,g}} \tag{1}$$

$$WARS_{g,q} = \frac{\sum (W_{i,g} \times R_{i,g,q})}{\sum W_{i,g}} \tag{2}$$

$$CWARS_q = \frac{\sum WARS_{g,q}}{N_g} \tag{3}$$

Where $W_{i,g}$ is the weightage for class 'i' in the attribute 'g', $P_{i,g}$ is the percentage of people shown critical response to a particular question under each class, $P_{Li,g}$ is the percentage of people who belong to the lowest response class, $WARS_{g,q}$ is the weighted average response score for a particular question 'q' under the attribute 'g', $R_{i,g,q}$ is the actual count of the response under the class 'i' for a particular attribute 'g' for the given question 'q', $CWARS_q$ is the comprehensive weighted average responses score for a particular question and N_g is the number of attributes considered (which is 4 in our study).

In order to confirm the characteristics of the average responsiveness, a statistical analysis is also performed by comparing the variances among the social attributes and the questionnaire categories. The analysis is done using the two-dimensional ANOVA (analysis of variance) tool package available in the Microsoft Excel spreadsheet.

Further, in order to address the need for a comprehensive framework for normalizing the adopted

methodology, a two-dimensional conceptual mapping is projected to compare the different aspects of public perceptions in view of the anticipated impacts as well as administrative overrules under prevailing socio-economic considerations. The analysis is aimed to prioritize the key concepts of public concerns in the dynamically changing post COVID-19 scenario where the administrative and business priorities have shown a wide transformation plan towards overcoming the losses happened during the pandemic time.

Results and Discussion

As far as the industrial-administrative collaborations are concerned, there are timely updates in the state-level policies to support the industries and addressing their concerns as the major share of the state's financial expenses which are to be met from the industrial revenues. Despite the favorable atmosphere for the industries to operate without any social disturbances, it is not reasonable to assume that some of the stakeholders might have opted out in framing the general operating strategies as well as for sanctioning the new projects on the ground of economic feasibility. However, the results from this study, in essence, indicate the missing connection while promoting industrial activities without actually addressing the real 'social well-being'.

Comparison of Concerns Based on Reported Impacts

As an initial step, the perceptions of the people about the wind farm located in Gudimangalam were critically assessed with respect to its impacts on the environment and human health. For this, the results from the questionnaire survey were analyzed in terms of the perceived impacts to various segments of life as listed below.

Perceived Impacts on Health

Among the participants surveyed, 40 of them said that the wind farm is affecting their health negatively while 70 of them represented a positive attitude. On the basis of gender, 16 out of 52 males (30.76%) and 24 out of 61 females (39.34%) believe that the wind farm had an adverse impact on their lifestyle. On account of the prevailing social structure, though estimated locally, it is quite reasonable to infer that females perceive more of adverse impacts than males. Based on age groups, only 4 people indicated negative impacts in the age groups of 11-20, 21-30 and 51-60 and 2 in the age group of 61-70. In the age group of 31-40 and 41-50, 13 of them perceived the negative impacts due to the existing wind farm. People in the middle-aged groups had more negative opinions about the impacts of the wind farm compared to lower and higher age groups. With regard to health issues, the majority of the people (about 62%) reported headache, while few others dizziness, mental stress, and lack of concentration.

Among the people with low or poor academic education, 15 out of 36 (42%) did not feel any negative impacts of the wind farm, while 30% of the people who passed schooling have different perceptions. Similarly, about 40% of the graduates and diploma holders have expressed their opinions against the wind farms. It is observed that the educational exposure is a significant attribute to form a reasonable opinion which is very critical for the participating inhabitants. Based on the locality i.e. distance to their home from the wind farm site, 39.13% of people from Gudimangalam, 11.11% from Kamanaikenpalayam, 13.33% from Kethanur, 11.76% from Manasipalayam, 63.63% from Metrathi and 60% from Thungavi have directly perceived negative impacts. It is observed that Metrathi and Thunagavi which are located very near (8.4 and 11.0 km from wind farm site, respectively) to Gudimangalam have perceived more negative impacts compared to locations situated farther off from the wind farm.

Perceived Impacts on the Environment

The aesthetic aspect of visibility of the wind farm was a major concern for about 45.13% of the people surveyed. Only 34.51% of people perceived that the wind farm was generating dust due to the spinning of the turbine blades. Among the participants from Gudimangalam, 65.21% of the people indicated that the wind farm was generating a lot of dust. Obviously, this can be attributed to their location of stay in close proximity with the wind farm. The observation was similar for the impact of the wind farm on the trees. Only 36.28% of the people observed that the wind farm is affecting the rainfall pattern in their respective localities. People from Gudimangalam also perceived the same with regard to rainfall patterns.

As far as the impact of the wind farm on birds' related accidents is concerned, 43.36% of the participants felt that the wind farm is causing a negative impact on the bird's movement. Around 45.83% people among schooling literate and illiterates feel that the wind farm is affecting the movement of the birds. Even among those who have obtained graduate or postgraduate degrees, only a few of them perceive the negative impact of the wind farm on birds. Furthermore, a majority of the people say that the wind farm does not affect the telecommunication signals in their localities.

Perceived Impacts on Social Aspects

The participants were also enquired regarding the noise being generated from the wind turbines. It is a well-known fact that the human ear can safely withstand sound vibration in the range of 0 dB to 130 dB and wind turbines generally produce about 40-45 dB [43]. Moreover, the sound produced by the

Table 2. Distribution of selected attributes of the participants and assigned weights.

Attribute	Count	Percentage	Weightage
Age group (years)			
15-25	10	9	*2.0*
25-35	11	10	*2.2*
35-45	47	42	*9.4*
45-55	40	35	*8.0*
>55	5	4	1.0
Gender group			
Male	52	46	*1.0*
Female	61	54	*1.2*
Distance group (km)			
0--5	23	20	*1.5*
5--10	22	19	1.5
10--15	15	13	*1.0*
15--30	33	29	*2.2*
>30	20	18	*1.3*
Education group			
Post Graduate (PG)	2	2	*1.0*
Under Graduate (UG)	10	9	*5.0*
Higher Secondary School (HSS)	20	18	*10.0*
High School (HS)	45	40	*22.5*
Informal	36	32	*18.0*

wind turbines tends to persist till about 38 dB within 0.5 to 1 km from the wind turbine location. Though the wind farm may not apparently create any disturbance to people living far-off, the critical concerns of the affected people (about 10 persons) cannot be neglected. The remaining people perceived only medium (50 persons) or low (53 persons) noise from the wind farm. As mentioned earlier, the wind blows only in certain specific directions in Gudimangalam, thus creating an uneven distribution of the noise generated from the wind turbines.

Furthermore, about 30% of the people feel that the vibrations produced by the wind farm are significant though a majority of the people felt otherwise. As far as the impact of the wind farm on the sleep disturbance is concerned, 86.95% of people from Gudimangalam felt that the wind farm is affecting their sleep from moderate to high level of inconvenience. Most middle-aged people have reportedly been critically affected compared to people of other age groups. However, only a few people from distant localities have reported any notable disturbances to their sleep.

Perceived Impacts on Agriculture

People were enquired about the impact of the wind farm on the land and crop productivity though there is no direct evidence to prove it technically. About 24% of the people carry the impression that the wind farm is causing a negative impact on crop productivity. Similarly, about 25% of the participants including people from Gudimangalam feel that the wind farm will affect the land fertility as well. The changes in perception of the people with various educational backgrounds and age groups were clearly observed through this survey. Even though participatory attempts like questionnaire surveys can help in gathering public opinion about the perceivable impacts of installation and operation of wind farms, it is widely recognized that the public perception can be highly diverse and highly influenced by location-specific details [44].

Quantitative Evaluation of People's Perceptions

As mentioned in the methodology section, the present study proposes a quantitative estimation of the criticality of impacts based on the perceptions of people while considering due weightage to their prevailing socio-economic background. The distribution of participants according to their attribute classes revealed that a scattered pattern is observed for 'age' and 'education' groups compared to the 'distance' and 'gender' groups (Table 2). In fact, the non-uniform distribution can be informative while correlating the criticality of the responses with the population attributes. Based on this, weightages were assigned corresponding to the percentage of representation as mentioned in Eq (1).

It was observed that the questions pertaining to the environmental and social categories have received higher values of significant responses compared to the agricultural and health concerns (Fig. 5). This is a crucial observation to investigate more on the factors influencing their opinion-making. While considering the representation for critical types of responses (such as Yes-type and High-type responses for the impacts), the highest score was observed under the attribute of 'gender' while the scores under other categories are more specifically related to the 'fair' categories of the questions. For example, the 'distance' has a profound significance under the categories of 'environment' and 'social' indicating the deeper impacts of directly perceived experiences. However, the 'age' and 'education' have similar response scores in all questions irrespective of the category of the question.

Based on the above analysis, the average response score for a particular category (e.g. 'social') can have diverse trends under the four categories, which is also different for each question in that particular category. Hence, a simplified representation of the criticality of the responses per category is calculated based on the average scores obtained for all the questions in

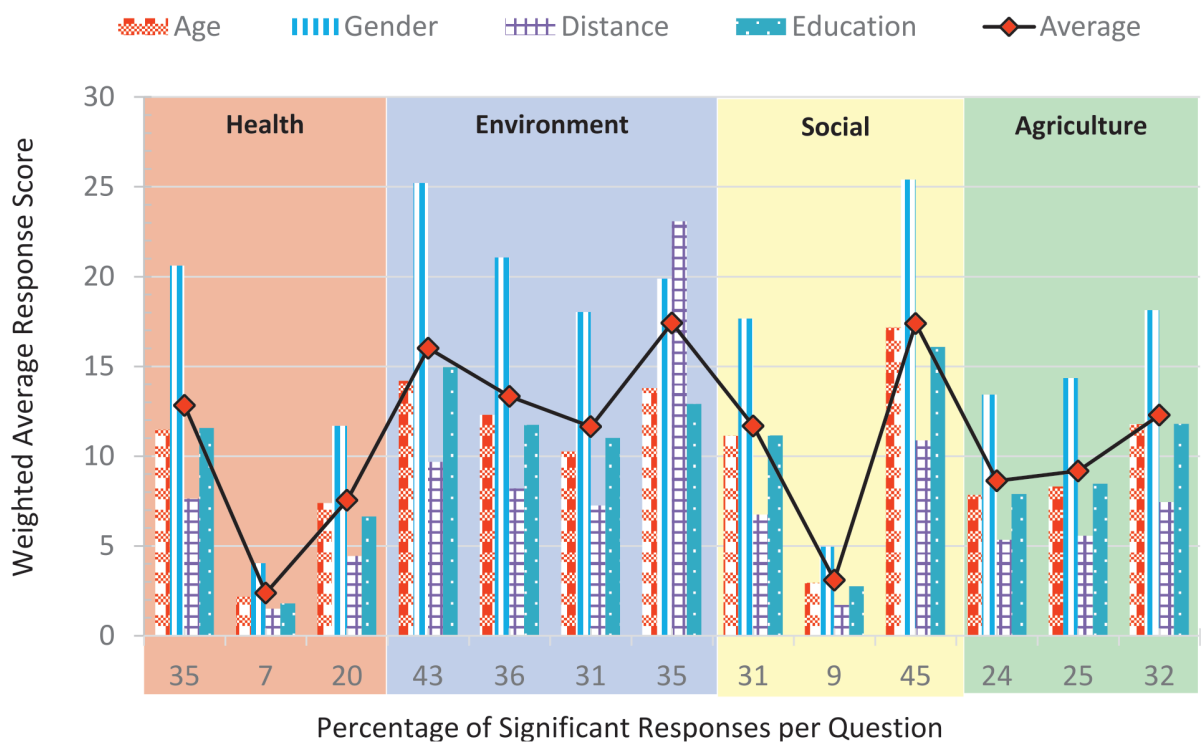

Fig. 5. Variation of weighted average response score (WARS) for each survey questions (under the selected four categories – health, environment, social and agriculture) with respect to the criticality of responses (under the selected attributes – age, gender, distance and education).

that category. It is observed that the average response score thus obtained bears a direct ratio to the percentage of critical representations received from the survey (Table 3). It is to be understood that the CWARS values are typically representatives of the combined effects of the people's attributes and question categories, and hence can effectively depict the overall concerns pertaining to the impacts of the wind farm in Gudimangalam.

Further, a statistical analysis is performed for evaluating the significance of variability in the demographic attributes versus the variability in the set of questions under each category towards the perceived responses. For this, different sets of two-factor ANOVA tables were constructed for the four social attributes (age, gender, distance and education) against each set of questions under health, environment, social and agriculture (Table 4). The hypothesis test results indicate that the variations in the demographic categories are more significant compared to the variability in the questions under all four categories. Based on the main three test statistics such as (i) difference between the p-value and the selected level of significance ($\alpha = 0.05$); (ii) F-crit and F-values and (iii) sum of squared deviations, the highest variability is observed for the questions under the set of environment, followed by social, agriculture and health sets. This is also in confirmation with the observed CWARS results as mentioned in Table 3. The overall impact of the influence of questions and demographic categories are also evaluated by using a single two-way ANOVA by considering all thirteen questions at a time. Based on the numerical values of p and F-crit, it is observed that the variations in demographic attributes are much higher for the combined set of questions compared to their separated sets.

In addition to the categorical sketching of the localized impacts, the results also highlight some of the underlying crucial factors leading to the public opinion forming process. Based on these results as

Table 3. Comparison of the representation of critical responses and average response scores under the selected question categories.

Category of Question	No. of Questions	Percentage of Critical Responses	Average Response Score
Health	3	21	8
Environment	4	36	15
Social	3	28	11
Agriculture	3	27	10

Table 4. Comparison of two-way ANOVA test results for demographic and question categories.

Question Categories	No. of Questions	Source of variation = Demographic		Source of variation = Questionnaire		Sum of Squared Deviation (SS)	Order of Significance
		p-value ($\alpha = 0.05$)	F-crit/F-stat	p-value ($\alpha = 0.05$)	F-crit/F-stat		
Health	3	0.0367	4.75/ 5.52	0.1206	5.14/ 3.07	417111.1	4
Environment	4	4.95E-08	3.86/ 152.41	0.1004	3.86/ 2.81	1162472.8	1
Social	3	0.0250	4.75/ 6.60	0.1112	5.1433/ 3.23	893962.8	2
Agriculture	3	8.11E-05	4.75/ 57.72	0.1274	5.1433/ 2.96	515401.5	3
All Questions	13	5.56E-15	2.86/ 68.82	0.0028	2.0327/ 3.27	3118397.1	

well as from the representations received for the open-ended question, we feel that a more conceptual-based evaluation of the factors affecting the social dimensions and the scope of social inclusion are to be performed to fill the gaps based on the observations.

Criticality of Forces, Factors and Their Relationships

Administrative Trades off on Energy Revenues

Due to the significant increase in the wind energy production capacity in the Indian scenario (reached to 40GW in May 2022); there is an associated reduction in the wind energy costs and tariffs which are being revised by the government from time to time [39]. However, it is to be noted that there are certain financial risks involved in relation to the changing global energy market due to climate action plans, renewable energy tradeoff plans and clean technology mission on the increased potential energy production [44-45]. As the total dependence of renewable energy in India is expected to increase from 18% to 44% within the next decade, there is ample space for balancing the expenses related to investment on land, production, conversion and storage facilities with the anticipated profit in energy production and transfer mechanisms. It is observed that very few people are actually aware of the technical details of energy trading mechanisms and policies existing for its various stakeholders [44]. As the investments on land and machines rise, people feel skeptical about the transparency in the state government administration due to the increased business happening to the private firms [45]. But most of the people are of the opinion that despite the public concerns on environmental impacts, the impact of an energy-driven economy can push the administration towards expanding the wind farm adoption plans.

Public Attitude on Energy Crisis

In general, we are prejudiced with the concept that people's concerns are at the background of any democratic decision making mechanism and, therefore, a similar response may be expected for any policy framing activity regarding renewable energy concerns [39]. However, in view of the survey questions, most of the responses were directed towards the environmental concerns, though the cost of energy at their livelihood as well as in occupation is still a major crisis. Though the dependence on thermal energy is unavoidable for at least a few more decades, people are more confident on the replacement opportunity and large-scale adaptability of renewable energy sources hoping to reduce their cost of living. Considering the scale of operation and application, there is still a lack of clarity among the public in getting confidence in wind energy as the best alternative for the current energy crisis. This survey has opened up such remarkable concerns among the people which would have missed in the regular framework of public hearing process administered for the official documentation purposes.

Business Opportunity versus Social Inclusion

As the supply chain of wind energy business has access to the educated class of the local residents at present, an increased opportunity is envisaged for the local entrepreneurs to expand vertically by providing in-house solutions for both technical and support services. Development of a local taskforce is particularly beneficial for the large-scale organizations to redistribute their immediate needs to be satisfied with minimal investments on raw materials and technical capacity building. Such business models are becoming financially promising and getting popular in the contemporary Indian manufacturing market [40]. One prominent transformation in the public opinion through such an inclusive approach can be perceived by the reduced complaints on skeptical arguments on NIMBYism and polluter-pay models. Thus adopting these strategies of social inclusiveness as one of the business targets, there is large scope in collaborative schemes with the self-help groups for directly benefiting the local community towards social empowerment and economic sustainability. Adding to the potential benefits, it is also possible to gear up and cater the public opinion towards any decision making process.

Table 5, A Conceptual framework for redirecting public opinions into decisive representations,

Perceived Impact Domain (A)	Demographic Representation Obtained (B)	Context of Critical Opinions (C)	Focal Point of Analysis (D)	Methodology to Outline the Preferences (E)	Plausible Action Plan (F)	Expected Outcome (G)
Environment	Visibility – 45.13% Dust spread – 65.21% Climate and rainfall –36.28%	• Personal experience • Site history • Exposure to awareness programs • Political influence • Cultural traits	○ Field data collection ○ Expert opinion ○ Strengthening public hearing ○ Historical survey ○ Awareness programs	➢ Select relative/ pair-wise comparison of preferred choices from (D) ➢ Compute the relative weights of parameters based on public opinion (C) ➢ Perform relative grading of parameters selected by merging (C) and (D) based on expert opinion ➢ Check the consistency of opinions using the principles of analytical hierarchy process ➢ Rank the obtained parameters in the decreasing order	❖ Exhaustive data collection ❖ Regular opinion polls ❖ Rehearsal of public hearing ❖ Education and awareness programs ❖ Provision for adequate feedback collection and follow-up ❖ Consignment of intermediate group for rapid communication	✓ Easy and transparent representation ✓ Rapid communication and hassle-free decision making ✓ Transformation of public face of industrial ecology ✓ Collaboration for renewable energy support ✓ Promotion of innovative technology with social responsibility
Health	Perceived diseases – 30-39% Sound illness – 31% Impacting sleep – 87%	• Personal medical history • Fear through media • Increasing medical cases • Emerging diseases • Changing lifestyle	○ Medical database collection ○ Health awareness programs ○ Medical insurance scheme			
Agriculture	Impacting trees – 65% Impacting crops – 24% Land fertility – 25%	• Deforestation • Decreasing land • Social reputation • Insufficient market • Lack of promotion	○ Promotion of indigenous technology ○ Agricultural promotion schemes ○ Market surety			
Social values	Animals and birds – 43.36% Signal trap – 65%	• Lack of sufficient compensation • Limited job opportunities • Aesthetic issues • Cultural traits • Lack of policy protection	○ Property values ○ Employment commitments ○ Public revenues and costs ○ Information communication management			

A Conceptual Framework for Incorporating Public Opinion in Decision Making

The increasing momentum for public involvement in the policy framing and other decision-making processes requires amalgamation of diverse and competing interests of all stakeholders in order to achieve an optimized representation. There are many analytical and data-oriented processes involving quantitative estimation of relative significance of the parameters. However, in many cases, the identification and selection of critical parameters is the most crucial step, thereby influencing the public perception of the project outcomes [6, 9, 15-17]. As discussed in the introductory section, there is a growing need to realize an effective public participation to minimize the "social gap" and to revolutionize the concept of industrial ecology [46-47]. We feel that the outcomes from the survey analysis have provoked a clear line of thought to address it in view of the generic phenomenal aspects.

In the same line of thought, a descriptive conceptual framework is presented here (Table 5) comprehending an adaptive system prioritizing both public and expert opinions through a transparent medium, thereby enabling to merge the selections through an integrated adaptive strategy, thus eliminating the chances of false claims and biased polls. Though the survey results were quantitatively low for a generic extrapolation, their categorical description has helped us to delineate the major domains of public perceptions. One peculiar advantage of this framework is the suggestion for transformational activities to promote the public welfare by progressively involving them through regular educational and awareness programs, thereby inducing the spirit of sustainability. Though controversial in terminology, it is observed that many industry giants are also getting involved in illustrating sustainable operations in renewable energy extraction systems for the welfare of the public. Another key aspect of this framework is the inclusion of an intermediate agency composed of the public-private representatives to stand as a transparent medium to timely communicate the concerns and decisions in an adaptive manner. This approach can very well result in exclusion and replacement of the existing delimiting factors such as unauthorized intermediates and local politicians who may misrepresent the concerns and take advantage of mutual agreements. Being a nation with highly diverse entities co-existing on every platform, we feel with an intuition that it is possible to check the negative tendencies in the contemporary Indian market by replacing it with a positive, inclusive approach. It is anticipated that the credit of success of an implemented renewable energy project such as the wind farm operation can be shared among the common man and thereby constituting a healthy industrial ecology in the state.

Conclusions

The existing socio-economic scenario in the wind energy market of India has many disputing issues which are less likely to be represented in the conventional mechanisms of public hearing. In addition, it is important to assess the status of public awareness on various aspects of wind energy adoption especially in suburban/rural communities. A questionnaire survey was conducted to understand the perceptions of the people living in and around the wind farm located in Gudimangalam in the state of Tamil Nadu, India. A quantitative evaluation of the perceptions was proposed in terms of a comprehensive weighted average response score (CWARS) for the selected categories of questions under various demographic attributes which were further tested using two-way ANOVA model. Results showed that the CWARS values are typical representatives of the combined effects of the people's attributes and question categories, and hence can effectively depict the overall concerns pertaining to the impacts of the wind farm in Gudimangalam. Based on qualitative analysis of the interactions between the key drivers and factors affecting the wind energy sector in the upcoming decades, a framework is prepared in this study as an adaptive strategy to represent the concerns in framing the public opinion, by incorporating the contextual elements of perceptions in terms of criticality and also by identifying suitable methodology to evaluate them in addition to the public polls or expert opinions. The framework further proposes a mechanism for implementing the outlined suggestions in order to ascertain the social inclusiveness as a positive dimension of renewable energy business in public interest.

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Conflict of Interest

The authors declare no conflict of interest.

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