

Energy Efficient Behaviour in Domestic Environment

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Abstract

Judicious use of energy sources assumes prime importance in attaining energy efficient behaviours and this also helps to achieve environmental protection. This study aims to develop the most conducive energy efficient and environment-friendly behavioural assessment framework for household energy consumers in India. The multi-grade fuzzy and Importance Performance Analysis (IPA) are applied to develop this assessment framework. The case study has been conducted with residents of XYZ residents' association in India. The results obtained from the case-study Energy Efficiency Behavioural (EEB) Index is 6.6 which belongs to 'Energy Efficient'. The IPA analysis classified the weaker attributes of the case residents' association. The appropriate suggestions are provided to improve the weaker attributes. This framework will enable energy auditors, residents' association, and government to periodically evaluate the EEB.

Keywords

Energy conservation; Efficiency behaviour; Assessment; Maintenance behaviour; Energy efficiency; Environmental protection

1. Introduction

Energy is a scarce resource available to the mankind and it can be put to different applications. Judicious use of energy and its conservation assume prime importance in life. The energy can be primary energy, which is extracted or tapped directly from nature like solar, wind, tidal, geothermal, biomass etc. (which fall in the category of renewable energy) or fossil-based fuels such as crude oil, natural gas, coal, lignite etc. (which fall under the category of non-renewable energy). Secondary energy sources are mostly Steam and Electricity which are produced by the industrial utilities from primary energy sources. Energy and Environment are closely interrelated as the production of Secondary Energy or utilisation of non-renewable energy sources in industry results in emission of oxides of Carbon, Sulphur, Nitrogen etc., other flue gases and particulate matter which pollute the environment. The global domestic electricity consumption for the year 2019 is 23104 Terra Watt-hours (TWh) and the global carbon dioxide emission for the year 2019 is 32741.42 Million tonnes of CO₂ (MtCO₂) (Enerdata, 2020). In terms of final energy consumption in India, industry accounts for 56%, the transportation sector accounts for 17% and the residential and commercial sectors account for 13% (TERI, 2019). As regards climate change, the year 2017 was the fourth warmest year on record, since 1901 (TERI, 2019). Carbon dioxide emission in India stood at 2344.2 MtCO₂ in 2017 (TERI, 2019). The energy use in high consuming industries is subjected to audit by qualified and experienced energy auditors and managers and they suggest ways and means to reduce consumption or improve efficiency, which the industry adopts.

In the case of residential consumers, it is not the case and the efficiency of utilisation of energy in domestic sector is far low, which underpins the requirement of this study. Moreover, the number of residential consumers is far more than the industrial houses and the behaviour of the members of the households affect the energy use in the residential sector. Almost five units of input electrical energy are consumed to deliver a single unit of electricity to the end-user (Padmanabhan, 2021); after allowing for all the losses in the production and supply chain which include conversion losses at the generating station and transmission & distribution losses in the network.

Globally, the growth of primary energy consumption and carbon dioxide emission from the year 2007 to 2018 is tabulated below, in Table 1, as reported in the BP Statistical Review of World Energy (2019). Both Primary Energy Consumption and carbon dioxide emission could be reduced by practicing energy conservation behaviours by the consumers of energy.

Table 1. Global Growth of Primary Energy Consumption (MTOE) and CO₂ Emission

Year	Consumption in MTOE	CO ₂ Emission in MtCO ₂
2008	11705.1	30336.7
2009	11540.3	29719.4
2010	12099.9	31057.9
2011	12403.7	31978.3
2012	12575.5	32316.7
2013	12819.4	32799.9
2014	12939.8	32844.8
2015	13045.6	32804.4
2016	13228.6	32913.5
2017	13474.6	33242.5
2018	13864.9	33890.8

Inculcating energy saving behaviours among the members of the households depends on a variety of factors such as attitudes, values, behaviours, environmental concerns of the individuals, level of awareness of individuals etc. The Consumer Energy Behaviour is complex, and it does not follow the traditional theories of decision making (Frederiks et al., 2015). Though most of the residential consumers are aware of the climate change issues and they are concerned about saving energy to save environment; such concerns do not translate into taking practical decisions entailing in reduction in consumption. Invisible nature of energy, careless attitude towards energy use, lack of trust etc. are serious barriers to efficient energy consumption in the domestic environment (Tang and Bhamra, 2008).

Domestic energy consumption and conservation encompass a wide variety of disciplines like economics, psychology, sociology, technology, consumer behaviour, organisational behaviour, environmental studies, costing, pollution control etc.; and hence is a truly interdisciplinary topic (Steg, 2008) which offers good scope for research and development and is worth-studying for the benefit of the society, mankind and the future generations to come. Such studies cover national and global interests and are incidental to providing the much-needed energy security to the whole world, though the conditions prevalent in the study are applicable for a particular region based on the culture, demography, climatic conditions, life style etc. of the region. This study aims at assessing how important are the various attributes of Energy Efficiency and Environmental Protection and how they are correlated with practices in a domestic environment by collecting responses from energy auditors and managers to assess the importance criteria and home makers in a residents' association in ABC Municipal area who manage their households for the performance levels; using fuzzy logic. Importance- Performance (IP) Analysis is then performed to identify which of the attributes require more careful management to attain the desired levels of Energy Efficient Behaviour as well as maintaining a benign environment and which among the attributes are well taken care of by the representative sample of the population which comprise of 148 residents belonging to the XYZ Residents' Association, located in ABC Municipality of the State of Kerala. The sampling method adopted is snowball sampling.

2. Literature Review

The intensity of energy use in any economy is an indicator of development and per-capita consumption of energy is normally considered as a development index of a country or region. The efficiency of energy use without giving away as waste is another significant area to be addressed to curtail wastages and to improve the effectiveness of the production or conversion processes. From the perspective of a residential consumer, there exist umpteen numbers of peculiarities for energy, as a commodity of use in comparison with other consumer goods and services that are consumed in the domestic environment. Energy is very abstract, its consumption is inconspicuous (Steg et al, 2018); compared to other consumer goods and the sources of energy like electricity or gas are really intangible, except that domestic gas is provided with an additive called Ethyl Mercaptan to give a smell of rotten cabbage upon its leakage from the gas cylinder. Consumers regard energy as a necessary and unspectacular product of which security of supply is important (Fischer, 2008). Energy consumption is not perceived as a coherent field of action (Fischer, 2008); and many unrelated activities like listening to music, cooking meals, working on the computer, washing of clothes and utensils, grinding soaked rice to make batter etc. result in energy consumption as a background activity.

There is a strong linkage between energy consumption and environmental friendliness (Urban and Scasny, 2012). The lower the energy consumed, the higher is the concern for environment. As production of energy involves burning of primary non-renewable resources, the process results in emission of gaseous waste to atmosphere which contributes to environmental pollution. Thus, as a part of eco-friendly attitude, energy consumption has to be made optimal. Also, renewable content of electricity has to be increased in production and is to be integrated in to the grid without loss of reliability to create a sustainable environment. Energy Efficiency implies using less energy to perform the same function and the benefits accruing from adopting energy efficient methods and technology are multi-pronged at consumer level, national level and global level. At consumer level- reduced cost of energy in financial terms, increased competitiveness and productivity levels are the benefits; at national levels- reduced import of crude oil, savings in foreign exchange, conservation of limited resources, improved energy security are the benefits and at global level- reduced GHG and other emissions and maintaining an eco-friendly and sustainable environment are the benefits. The main characteristics of a sustainable energy system are cost-efficiency, reliability and environmental friendliness (Alanne and Saari, 2006).

No previous study involving multi-grade fuzzy and importance- performance analysis (IPA) was observed to be made in assessing energy efficiency or environmental protection behavioural attributes in residential buildings upon survey of available literature.

3. Research Methodology

3.1 Multi-grade fuzzy

The study adopted multi-grade fuzzy logic approach (Vinodh, 2011; Vinodh and Chintha, 2011; Vinodh and Prasanna, 2011) to assess the level of energy efficiency behavioural practices of residents and IPA is used to classify the weaker attributes (Vasanthan and Suresh, 2021). The new conceptual model for EEB is shown in Table 2. The EEB index (E) is computed as the product of ratings (R) and weightage (W), as given by the experts at primary, secondary and tertiary grade.

$$E = R \times W \text{ (Suresh and Gopakumar, 2021; Anil and Suresh, 2020)}$$

Table 2. Conceptual model for EEB assessment

Enablers	Criteria	Attributes
Energy Efficiency (E1)	Efficiency Behaviour (E11)	Using energy efficient equipment/ gadgets- star rated ones (E111)
		Replacing old refrigerators/ air-conditioning units with inefficient compressor (E112)
		Replacing light fixtures with more luminous efficiency and low power consumption (E113)
		Use of occupancy sensors to turn ON/ OFF lights and fans (E114)
		Plugging leakages in water distribution lines in the house (E115)
		Frequency of washing laundry (E116)
		Using kettle when boiling water instead of electric/gas stoves (E117)
		Using energy saving option in the computer system (E118)
		Turning OFF television sets with ON/ OFFswitch (E119)
		Washing textiles/ dishes only when full machine capacity is attained (E1110)
		Use of electric iron (E1111)
		Putting lids on pots during cooking (E1112)
		Curtailment Behaviour (E12)
	Avoiding rinsing dishes before putting them to dish washer (E122)	

		Use of showers instead of bathing tub (E123)
		Turning OFF lights and fans when leaving a room (E124)
		Covering windows at night using curtains/ blind and uncovering during day time (E125)
		Reducing frequency of opening refrigerators (E126)
		Cleaning air filters in air-conditioning units occasionally (E127)
		Replacing old motor-pump sets in domestic water pump sets (E128)
		Rewinding old motor in domestic water pump sets (E129)
		Repairing houses in an energy saving direction/ orientation to admit natural light or changing building envelope etc. (E1210)
		Frequency of use of Electric Iron_ Daily Vs once in a week (E1211)
Environmental Protection (E2)	Altruistic or Eco-Friendly Behaviour (E21)	Reduced emission of CO ₂ and other Green House Gases (E211)
		More restraint on fossil-fuel based energy consumption (E212)
		More reliance on Renewable Energy Sources (E213)
		Proper disposal of food wastes and other bio-wastes (E214)
		Prevention of burning of plastics, thermocoal, rubber etc. (E215)
		Use of solar water heaters to source hot water (E216)
		Use of solar air-conditioners and inverters (E217)
		Use of solar photo-voltaic generation on roof tops (E218)
	Fuel Use Curtailment (E22)	Less use of hydrocarbon based gasoline/ HSD for cars (E221)
		Putting lids on pots during cooking (E222)
		Completion of cooking in quick succession to prevent fuel wastage (E223)
		Setting standards for emission limits from vehicles and adherence to such standards (E224)
		Use of bumps/ dips on roads to regulate speed of vehicles for better fuel efficiency (E225)

The scale of assessment of EEB Index was graded into five levels, as per principles of fuzzy determination of the index $E = \{10, 8, 6, 4, 2\}$. The value between 8 and 10 representing “Extremely Energy Efficient”, between 6 to 8 representing “Energy Efficient”, between 4 and 6 representing “Fairly Energy Efficient”, between 2 to 4 representing “Energy Inefficient” and between 0 and 2 representing “Extremely Energy Inefficient”.

Energy Efficient Behaviours: Household energy conservation has been identified as a very effective and efficient means of reducing emissions. Recently, the Government of India has stressed the need for bringing in e-mobility by establishing Electric Vehicle Charging Stations (EVCS) across the length and breadth of the country to shift the transportation sector from crude oil-based gasoline fuel to electricity thereby entailing in savings in foreign exchange by way of savings in import of crude oil and to make the environment more benign and pollution-free. India imports 85% of its crude oil requirement (5 million barrels per day) on an average; the total crude oil imports in 2021-22 being 212.2 million tonnes spending US \$119 billion (Petroleum, 2022). The State Governments have identified nodal agencies to establish EVCS within the geographical boundaries of the states to promote e-mobility. At a later stage, battery swapping stations are also in the offing to reduce the time required for charging electric vehicles in the charging stations.

The various energy efficiency behaviours ask us to spend money or give up comforts and are a trade-off between suffering on one hand and spending on the other (Karlin et al, 2014). Energy conservation behaviour varies by frequency of adoption and cost involved. Efficiency Behaviour is infrequent and involves high cost whereas curtailment behaviour is more frequent and low-cost behaviour. Maintenance behaviours are also important, which are essentially inexpensive and non-frequent. Saving of energy is attained by better maintenance of household appliances to improve their performance and efficiency.

Environmental concerns and altruistic eco-friendly behaviour have a great influence on curtailment behaviour than efficiency behaviour. The behaviour of leaving lights/ fans on is a highly visible behaviour and is source of conflict amongst the members of the household, where the enforcing partner runs after the others and keeps the switches off. Efficiency Behaviours often lead to larger energy savings than curtailment behaviour (van der Werff et al, 2018), but the cost involved in engaging in efficiency behaviour is more than that in curtailment behaviour. Adoption of solar panels on roof-tops of houses, modification of houses to admit more sunlight in an energy saving direction or changing the building envelope of the house with a material of less Solar Heat Gain Co-efficient (SHGC) to reduce the *R*-value of the building etc. are examples of efficiency behaviour. Standards and Labelling Programme (SLP) of the Bureau of Energy Efficiency as per the Energy Conservation Act, 2001 is a good indicator to the purchaser when household consumer durables are procured from the market. Star ratings affixed on appliances by accredited laboratories of the Bureau of Energy Efficiency offer decision heuristics for the purchasing consumer to procure energy efficient appliances from the market. Examples of curtailment behaviour can be switching off the television set, instead of being left on standby mode; avoiding laundry by removing stains and airing, especially during winter and rainy seasons; using of showers instead of bathtub; reducing frequency of opening of household refrigerators; reducing frequency of operating electric iron etc. An example of maintenance behaviour can be cleaning air filters in air-conditioning units occasionally to reduce the load on its compressor unit.

Environmental Protection: The driver environmental protection is identified with two criteria in the study viz. altruistic or eco-friendly behaviour and fuel use curtailment. The Intergovernmental Panel for Climate Change (IPCC) proposed to reduce greenhouse gas (GHG) emissions in the energy sector by 90%, compared to 2010 emission levels, between the years 2040 and 2070 (van der Werff et al, 2018). Curtailing energy consumption by domestic users worldwide shall entail in reduction of carbon emission levels to atmosphere, thus helping to attain the recommendations of IPCC. The attributes corresponding to altruistic or eco-friendly behaviour are reduced emission of CO₂ and other GH Gases, more reliance on renewable sources of energy by substituting energy generated by burning fossil-based fuels, prevention of burning of plastics in the home environment to prevent emission of harmful, carcinogens gases to the atmosphere, use of solar photo-voltaic panels on roof-tops and using them in a grid-tied configuration etc. The attributes for fuel use curtailment are less use of gasoline-based fuels for household cars, more utilisation of electric vehicles (battery electric vehicles, BEVs and fuel cell electric vehicles, FCEVs) instead of IC engine-based cars for domestic transportation etc.

Theoretical Framework for the Study: The theoretical support for the study is provided by the theory of planned behaviour (Ajzen and Fishbein, 2005). The behavioural intention has three antecedents viz. attitudes towards behaviour, subjective norms and degree of perceived behavioural control. Actual behavioural control moderates perceived behavioural control and the manifested behaviour. The theory of planned behaviour proposed by Ajzen and Fishbein (2005) states that attitude, subjective norms and perceived behavioural control together shape an individual's behavioural intention and behaviour.

4. Case Study

The study is made for about 148 households residing in XYZ Residents' Association in ABC Municipal town of the state of Kerala. This locality is situated very near to Lake, where there are plenty of tourist boats in operation in the back waters. The place is characterized by the presence of e-coli bacteria in the freshwater lake due to uncontrolled waste disposal from the tourists' boats and the adjoining residential areas. There exist Municipal drinking water supply to the area and the residents boil the water supplied through pipelines before drinking. Well water exists only in limited old houses in the habitat and the well water also is required to be boiled for drinking. Majority of the households use RO water (purified by Reverse Osmosis), but so far, no mineral deficiencies was reported in such users of RO water. The Municipality collects solid wastes generated in the households, which are segregated at source into plastic and food wastes. Plastic waste is collected once in a week after levying a fee of INR. ₹ 50/- per month per

household. Most of the households have pipe composting for effective disposal of bio-degradable and food wastes, but no bio-gas plant exists in any of the household. Solar air-conditioners and solar inverters exist in some of the houses. Rainwater harvesting is necessary in the newly built houses, as per statute and charging occurs to the ground level sump tank. A few of the houses in this habitat has solar PV generating plants on their roof tops and the energy so generated is utilized in the household in grid connected mode.

The case study has been carried out by personally interviewing five prominent decision makers in five households belonging to XYZ residents’ association and ratings against each attribute were collected. Weights were provided from interviewing well-experienced energy auditors who are energy efficiency practitioners and holding the energy auditor certification from the Bureau of Energy Efficiency, India. For the positive attribute’s (maximum is best) ratings, we used a questionnaire with a 10-point Likert scale, representing extremely high (10 points) to extremely low (1 point). The reverse scale is used to capture ratings for negative attributes (minimum is best). For the weightage, we used 10-point Likert scale that represents extremely high importance (10 points) to extremely low importance (1 point). The normalized mean weightages are captured in Table 3. After primary, secondary and tertiary assessment of the ratings with the weights obtained from experts, the overall EEB index was obtained to be 6.66, which indicates “Energy Efficient”, as the value belongs to the range between 6 and 8.

Table 3. Enabler, Criteria and attributes weights and attributes performance rating from experts

Ei	Eij	Eijk	R1	R2	R3	R4	R5	Wij	Wi	W
E1	E11	E111	10	10	7	8	8	0.088	0.524	0.5
		E112	8	8	6	7	7	0.102		
		E113	8	10	8	10	10	0.090		
		E114	1	5	5	3	3	0.076		
		E115	10	10	7	8	7	0.090		
		E116	2	5	5	5	8	0.052		
		E117	3	2	2	2	3	0.088		
		E118	8	6	7	8	8	0.074		
		E119	9	1	9	3	9	0.090		
		E1110	10	9	5	9	6	0.090		
		E1111	5	5	6	6	9	0.062		
	E1112	10	10	7	9	7	0.090			
	E12	E121	2	1	4	1	1	0.083	0.475	
		E122	9	8	5	5	3	0.091		
		E123	9	9	9	9	9	0.096		
		E124	9	10	9	7	7	0.112		
		E125	9	10	7	8	9	0.099		
		E126	5	5	5	5	9	0.107		
		E127	8	8	9	9	5	0.109		
		E128	7	8	9	9	7	0.102		
		E129	2	3	2	8	2	0.028		
		E1210	2	8	2	8	6	0.062		
E1211	5	5	9	9	8	0.104				
E2	E21	E211	3	5	6	3	3	0.136	0.5	0.5
		E212	8	5	5	5	5	0.123		
		E213	5	5	5	5	6	0.133		
		E214	10	10	5	7	6	0.12		
		E215	8	10	10	10	10	0.133		
		E216	5	5	10	5	4	0.116		
		E217	3	3	3	4	3	0.113		
		E218	3	2	2	2	4	0.123		
	E22	E221	8	5	5	5	4	0.228	0.5	
		E222	10	10	10	10	8	0.228		

		E223	9	9	9	9	9	0.222		
		E224	8	8	8	8	8	0.228		
		E225	4	3	2	2	2	0.092		

5. Calculation

The first-grade calculation is done for the “Efficiency behaviour (E11)” is given below.

Weights concerning to “Efficiency behaviour” criterion is $W_{11} = [0.088, 0.102, 0.090, 0.076, 0.09, 0.052, 0.088, 0.074, 0.09, 0.09, 0.062, 0.09]$

Assessment for the practice of “Efficiency behaviour” criterion is given below as

$$R_{11} = \begin{bmatrix} 10 & 10 & 7 & 8 & 8 \\ 8 & 8 & 6 & 7 & 7 \\ 8 & 10 & 8 & 10 & 10 \\ 1 & 5 & 5 & 3 & 3 \\ 10 & 10 & 7 & 8 & 7 \\ 2 & 5 & 5 & 5 & 8 \\ 3 & 2 & 2 & 2 & 3 \\ 8 & 6 & 7 & 8 & 8 \\ 9 & 1 & 9 & 3 & 9 \\ 10 & 9 & 5 & 9 & 6 \\ 5 & 5 & 6 & 6 & 9 \\ 10 & 10 & 7 & 9 & 7 \end{bmatrix}$$

Index concerning of “Efficiency behaviour” criterion is given by

$$E_{11} = W_{11} \times R_{11} \quad (\text{Subramanian and Suresh, 2022})$$

$$E_{11} = [7.332, 6.923, 6.224, 6.610, 7.043]$$

Similarly,

$$E_{12} = [6.609, 7.154, 6.945, 7.117, 6.416]$$

Second-grade calculation

The calculation concerning to enabler of “Energy efficiency (E1)” is given below as

Weights concerning to “Energy efficiency” enabler given as $W_1 = [0.524, 0.475]$

Assessment of “Energy efficiency” enabler is given as below

$$E_1 = \begin{bmatrix} 7.332 & 6.923 & 6.224 & 6.610 & 7.043 \\ 6.609 & 7.154 & 6.945 & 7.117 & 6.416 \end{bmatrix}$$

Index concerning of “Energy efficiency” enabler is given by

$$E_1 = W_1 \times R_1$$

$$E_1 = [6.988, 7.033, 6.567, 6.851, 6.774]$$

Similarly,

$$E_2 = [6.965, 6.600, 6.614, 6.294, 5.966]$$

Third-grade calculation

The energy efficiency behavioural assessment value of case residents’ association has been calculated as follows

Complete weight $W = [0.5, 0.5]$

$$\text{Complete assessment vector } R = \begin{bmatrix} 6.988 & 7.033 & 6.567 & 6.851 & 6.774 \\ 6.965 & 6.600 & 6.614 & 6.294 & 5.966 \end{bmatrix}$$

Energy efficiency behavioural index $E = W \times R$

$$E = [6.977, 6.816, 6.590, 6.572, 6.355]$$

The final energy efficiency behavioural index is the average of $E = 6.66 \in (6 \text{ to } 8)$. \therefore ‘Energy Efficient’

6. Importance- Performance Analysis (IPA)

IPA was done with the attributes with values of importance and performance (Deng, 2008). With respect to the mean values of attribute importance and attribute performance, the plot area is divided into four quadrants (Martilla and James, 1977). Table 4 shows the IPA plot.

Table 4. Attributes classification using IPA

	8.6	Quadrant -I										E112	E127	E124	Quadrant -II		
	8.2				E211	E213	E126			E1211						E215	
	7.8								E119		E1110	E115,E128	E1112,E125	E113			
	7.4		E117	E218			E221	E212				E214	E224	E111,E123	E222,E223		
	7				E217				E122, E216								
Importance ↑	6.6	E121			E114												
	6.2											E118					
	5.8																
	5.4								E1111								
	5						E1210										
	4.6						E116										
	4.2																
	3.8																
	3.4																
	3			E225													
	2.6																
	2.2	Quadrant -IV			E129										Quadrant -III		
		1.8	2.4	3	3.6	4.2	4.8	5.4	6	6.6	7.2	7.8	8.4	9	9.6		
		Performance Rating →															

Quadrant I (Concentrate here): The attributes in this quadrant need to be paid attention (Thomas and Suresh, 2022). by the case-residents' association managers to increase their energy efficiency behavioural practices. The attributes are "Using kettle when boiling water instead of electric/gas stoves, turning off television sets with on/ off switch, reducing frequency of opening refrigerators, reduced emission of CO₂ and other greenhouse gases, more restraint on fossil-fuel based energy consumption, more reliance on renewable energy sources, use of solar photo-voltaic generation on roof tops, less use of hydrocarbon-based gasoline/ HSD for cars.

Quadrant II (Keep up the good work): The attributes in this quadrant need to be maintained as the same (Chacko et al., 2021) and the attributes are "Using energy efficient equipment/ gadgets- star rated ones, replacing old refrigerators/ air-conditioning units with inefficient compressor, replacing light fixtures with more luminous efficiency and low power consumption, plugging leakages in water distribution lines in the house, washing textiles/ dishes only when full machine capacity is attained, putting lids on pots during cooking, use of showers instead of bathing tub, turning off lights and fans when leaving a room, covering windows at night using curtains/ blind and uncovering during day time, cleaning air filters in air-conditioning units occasionally, replacing old motor-pump sets in domestic water pump sets, frequency of use of electric iron daily Vs once in a week, proper disposal of food wastes and other bio-wastes, prevention of burning of plastics, thermocoal, rubber etc., putting lids on pots during cooking, completion of cooking in quick succession to prevent fuel wastage, setting standards for emission limits from vehicles and adherence to such standards."

Quadrant III (Possible overkill): The attributes in this quadrant are of low importance but high-performance (Sreedharshini et al., 2021). The performance of these attributes should be minimized. The attributes are "Using energy saving option in the computer system". In the modern laptops and desktops, energy saving option is automatically invoked after a few minutes or seconds, if no key stroke or mouse movement is made.

Quadrant IV (Low priority): The attributes in this quadrant are of low importance and low performance (Vaishnavi and Suresh, 2021). The attributes are “Use of occupancy sensors to turn on/ off lights and fans, frequency of washing laundry, use of electric iron, avoiding laundry by removing stains and airing, avoiding rinsing dishes before putting them to dish washer, rewinding old motor in domestic water pump sets, repairing houses in an energy saving direction/ orientation to admit natural light or changing building envelope etc., use of solar water heaters to source hot water, use of solar air-conditioners and inverters, use of bumps/ dips on roads to regulate speed of vehicles for better fuel efficiency”.

The suggestions for the improvement of performance of weaker attributes are given in Table 5.

Table 5. Suggestions for weaker attributes

Weaker attributes	Suggestions for improvement
Using kettle when boiling water instead of electric/gas stoves	Impart training to the homemakers to bring about a behavioural change as electric kettle usage is: <ul style="list-style-type: none"> • More fuel efficient • More environmental friendly • Direct heat transfer in kettle is more process efficient than heat transfer by conduction and convection in electric/ gas stove.
Turning OFF television sets with ON/ OFF switch	Impart training for behavioural change to the members of the households to: <ul style="list-style-type: none"> • Switch off television with control power switch to save power consumption as television will consume certain amount of power in sleep mode. • Reduce the frequency of opening of refrigerator, thereby reducing its power consumption and enhancing the operational efficiency.
Reducing frequency of opening refrigerators	
Reduced emission of CO ₂ and other Green House Gases	<ul style="list-style-type: none"> • Renewable Energy (RE) Sources do not pollute the environment and hence are sustainable. • Burning of coal, oil, natural gas etc. results in emission of greenhouse gases and particulate matter to the atmosphere and is to be curtailed. • All new houses are to be equipped with solar photo-voltaic (SPV) generation and is to be ensured by stipulating standards for building construction. • Policy support to be extended to all existing houses by the Government to establish RE generation to reduce fossil fuel-based energy consumption. • Grants and subsidies can be instituted by the Government to promote RE generation to make the world sustainable. • Building tax concession and purchase tax concession for solar PV panels could be considered as nudges to reinforce pro-environmental behaviour.
More restraint on fossil-fuel based energy consumption	
More reliance on Renewable Energy Sources	
Use of solar photo-voltaic generation on roof tops	
Less use of hydrocarbon-based gasoline/ HSD for cars	<ul style="list-style-type: none"> • The proposed shift from hydrocarbon economy to hydrogen economy has to be sped up to mitigate climate change issues and to save the environment. • Governments to offer grants & subsidies for accelerating the change over from IC Engine-based cars and vans to BEVs & FCEVs. • More fast charging infrastructure & battery swapping facilities for EVs & renewable hydrogen outlets for FCEVs must be deployed.

	<ul style="list-style-type: none">• Conducive policy support must be ensured by the federal and the State Governments.
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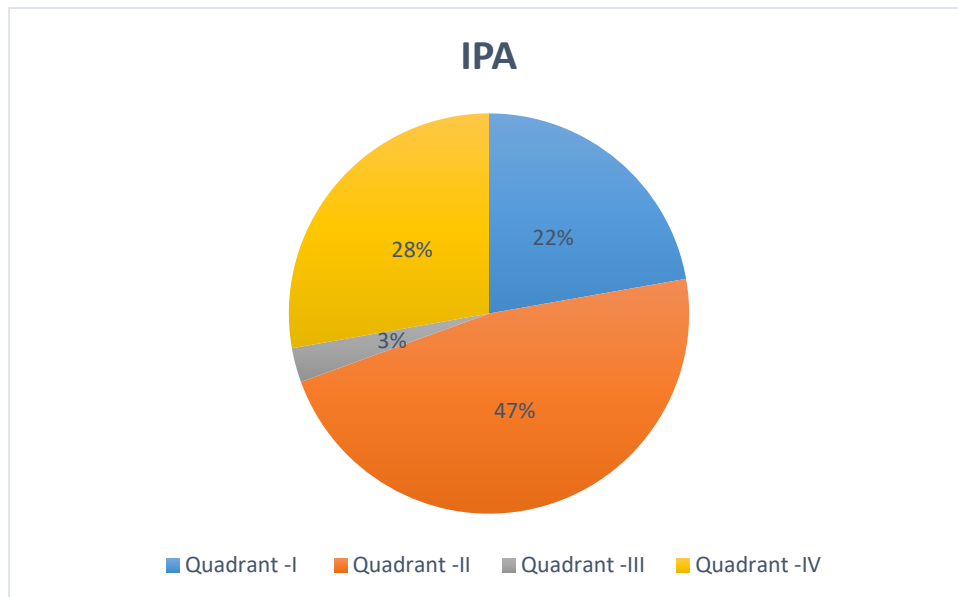


Figure 1. Graphical representation of IPA

Figure 1 shows the graphical representation of IPA. 22% of the factors in quadrant I need concentration and the management should take appropriate actions to improve it.

7. Conclusion

In the current study, the energy efficiency behaviour and environmental behaviour of a Residents' Association, located in ABC Municipality in the state of Kerala were studied and the EEB index was assessed, using multi-grade fuzzy. The focus was obviously on the household consumers of energy. In other classes of consumers of energy viz. commercial, industrial and agricultural sectors; study could be conducted with different sets of attributes concerning consumers' behaviour in the related sectors using multi-grade fuzzy. In this study, we identified total 36 attributes of which 23 attributes are belonging to energy efficiency behaviour and the remaining 13 attributes are behaviours contributing to environmental protection.

Reducing energy intensity, wastages in energy; utilizing energy with a conservative mentality coupled with lower dependence on fossil-based fuels result from higher adoption of energy efficiency behaviours which in turn contribute to environmental protection. The learning from this study can be replicated to other communities in the region with the same socio-cultural norms and extended to promote energy efficiency and environmental protection behaviours for the benefit of the nation and the world.

Development of the state-of-the-art technology in grid management and metering gave an impetus to area of research related to efficiency behaviours in using the secondary energy source viz. electricity. In smart grid environment, each of the devices in the system is enabled with a sensor and could be addressed and the decision heuristics to switch on a device is taken based on the availability of power, cost of energy per unit at a given slot of time etc. Hence the not-so-important loads could be switched on when the tariff is the least in a time-of-day scenario. The study could also be extended in a smart grid environment enabled with advanced metering infrastructure.

References

Ajzen, I., & Fishbein, M., The influence of attitudes on behavior. The handbook of attitudes. *Red. D. Albarracin, BT Johnson & MP Zanna. Mahwah: Erlbaum, 173-221, 2005.*

- Alanne, K., & Saari, A., Distributed energy generation and sustainable development. *Renewable and sustainable energy reviews*, 10(6), 539-558, 2006.
- Anil, M., & Suresh, M., Assessment of Service Agility in Power Distribution Company. In *IOP Conference Series: Materials Science and Engineering*, 954(1), 012010, 2020.
- BP Statistical Review of World Energy, United Kingdom, 68th Edition, 2019.
- Chacko, E., Suresh, M., & Priyadarsini, S. L., Start-Up Leagility Assessment Using Multi-grade Fuzzy and Importance Performance Analysis. In *Data Intelligence and Cognitive Informatics*, pp. 397-407, 2021.
- Deng, W. J., Fuzzy importance-performance analysis for determining critical service attributes. *International Journal of Service Industry Management*. 19(2), 252-270, 2008.
- Enerdata, *Energy Statistical Yearbook*, 2020 [data set]
- Fischer, C., Feedback on household electricity consumption: a tool for saving energy?. *Energy efficiency*, 1(1), 79-104, 2008.
- Frederiks, E. R., Stenner, K., & Hobman, E. V., Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, 41, 1385-1394, 2015.
- Karlin, B., Davis, N., Sanguinetti, A., Gamble, K., Kirkby, D., & Stokols, D., Dimensions of conservation: Exploring differences among energy behaviors. *Environment and Behavior*, 46(4), 423-452, 2014.
- Martilla, J. A., & James, J. C., Importance-performance analysis. *Journal of Marketing*, 41(1), 77-79, 1977.
- Padmanabhan, P., First Fuel- India's Energy Efficiency Journey and a Radical Vision for Sustainability, Macmillan, 2021.
- Petroleum, <http://petroleum.nic.in>, (accessed on 28th April, 2022), 2022.
- Sreedharshini, S., Suresh, M., & Priyadarsini, S. L., Workplace Stress Assessment of Software Employees Using Multi-grade Fuzzy and Importance Performance Analysis. In *Data Intelligence and Cognitive Informatics*, pp. 433-443, 2021.
- Steg, L., Promoting household energy conservation. *Energy policy*, 36(12), 4449-4453, 2008.
- Steg, L., Shwom, R., & Dietz, T., What drives energy consumers?: Engaging people in a sustainable energy transition. *IEEE Power and Energy Magazine*, 16(1), 20-28, 2018.
- Subramanian, N., & Suresh, M., Assessment Framework for Agile HRM Practices. *Global Journal of Flexible Systems Management*, 23, 135-149, 2022.
- Suresh, M., & Gopakumar, K., Multi-grade fuzzy assessment framework for software professionals in work-from-home mode during and post-COVID-19 era. *Future Business Journal*, 7(1), 1-9, 2021.
- Tang, T., & Bhamra, T., Changing energy consumption behaviour through sustainable product design. In *DS 48: Proceedings DESIGN 2008, the 10th International Design Conference, Dubrovnik, Croatia*, 2008.
- TERI, *TERI Energy & Environment Data Diary & Year Book 2017/18*, The Energy and Resources Institute, April, 2019. New Delhi, India, 2008.
- Thomas, A., & Suresh, M., Assessment of COVID-19 prevention and protection measures in hospitals. *Cleaner Engineering and Technology*, 7, 100440, 2022.
- Urban, J., & Ščasný, M., Exploring domestic energy-saving: The role of environmental concern and background variables. *Energy policy*, 47, 69-80, 2012.
- Vaishnavi, V., & Suresh, M., Assessment of Leagility in Healthcare Organization Using Multi-grade Fuzzy Approach. In *Data Intelligence and Cognitive Informatics*, pp. 409-421, 2021.
- van der Werff, E., Thøgersen, J., & de Bruin, W. B., Changing household energy usage: the downsides of incentives and how to overcome them. *IEEE Power and Energy Magazine*, 16(1), 42-48, 2018.
- Vasanthan, P., & Suresh, M., Assessment of organizational agility in response to disruptive innovation: a case of an engineering services firm. *International Journal of Organizational Analysis*. <https://doi.org/10.1108/IJOA-09-2020-2431>, 2021.
- Vinodh, S., Assessment of sustainability using multi-grade fuzzy approach. *Clean Technologies and Environmental Policy*, 13(3), 509-515, 2011.
- Vinodh, S., & Chintla, S. K., Leanness assessment using multi-grade fuzzy approach. *International Journal of Production Research*, 49(2), 431-445, 2011.
- Vinodh, S., & Prasanna, M., Evaluation of agility in supply chains using multi-grade fuzzy approach. *International Journal of Production Research*, 49(17), 5263-5276, 2011.

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