Multi Criteria Evaluation of Parabolic Solar Cooker as a Domestic Cooking Device

THESIS

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By

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Under the Supervision of
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CERTIFICATE

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This is to certify that the thesis entitled **'Multi Criteria Evaluation of Parabolic Solar Cooker as a Domestic Cooking Device'** and submitted by **Sanjay D. Pohekar** ID No **1999PHXF407** for award of Ph.D. Degree of the Institute, embodies original work done by him under my supervision.

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ABSTRACT

Energy requirements for cooking account for 36 % of total primary energy consumption in India and non-commercial energy sources are utilized for meeting most of the cooking energy demands. It is observed that India follows income-based ladder starting with fuel-wood and ending with sophisticated fuels like liquefied petroleum gas (LPG) and electricity. The diffusion of renewable energy devices is observed far below their estimated potential.

Though the renewable energy technologies have proved their techno-economic feasibilities from time to time, the diffusion of these technologies is still fairly low. Therefore it is felt that, in the changed socio-economic scenario, dissemination strategies for renewable energy devices may be devised by the energy planners and decision makers based on a different conception of energy planning procedure involving multiple criteria. The purpose of present research is to evaluate parabolic solar cooker (PSC), a recent innovation in solar cooking technology on techno-economic, social, behavioral and commercial criteria in the present Indian context in comparison with other contemporary cooking energy devices with a view to devise strategies for its further commercialization.

To know the perceptions of different actors in the decision making process (primary data); a survey was conducted to evaluate nine cooking energy devices available in India. The data for quantitative criteria was taken from secondary source, mainly published literature. Energy technology issues, economics, environmental/social, behavioral and commercial issues are considered for the evaluation. Thirty sub-criteria

are considered under these five aspects for comparison of the devices. The identified decision making groups were policy makers (Officers of the Ministry, State Nodal Agency Officers and Manufacturers), Researchers, Educators and Actual Users. The evaluation has been made using three multi criteria evaluation techniques viz. Outranking (PROMETHEE), Priority (AHP) and Utility (MAUT). Spearman rank correlation test is used to assess the correlation between the various evaluation techniques used.

It is found that Liquefied Petroleum Gas (LPG) stove is the most preferred device, followed by Microwave Oven, Electric Oven. Parabolic Solar Cooker has occupied fifth to sixth rank amongst the identified devices. Sensitivity analyses are also carried out for identifying potential areas for improvement for PSC following all these evaluations. On the basis of results, strategies for promoting wide spread use of PSC are suggested.

More importance is given to identifying the criteria and policy issues related to dissemination of PSC. The study uses time tasted multi criteria evaluation techniques. The conclusions mainly relate to the policy issues in commercialization of PSC which can be followed for other similar renewable energy devices waiting for their successful commercialization.

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List of Symbols and Abbreviations

Symbol/ Abbreviations	Description
(a, b)	Pair of alternatives/devices
AHP	Analytical Hierarchy Process
A_i	Number assigned to devices
AIHSHEW	Institute of Home Sciences and Higher Education for Women
ARI	Acute Respiratory Infection
BIS	Bureau of Indian Standards
BITS	Birla Institute of Technology and Science
CI	Consistency Index
CMIE	Center for Monitoring Indian Economy
CP	Compromise Programming
CR	Consistency Ratio
d_j	Difference between pair of alternatives a and b for criteria j
EIU	Economist Intelligence Unit
ELECTRE	The Elimination and Choice Translating Reality
ESMAP	Energy Management Assistance Program
$f(a)$	Value of alternative a for criteria j
$f(b)$	Value of alternative b for criteria j
FAO	Food and Agriculture Organization
GEDA	Gujarat Energy Development Agency
I	Matrix of unity

List of Symbols and Abbreviations (Contd...)

Symbol/ Abbreviations	Description
IEA	International Energy Annual
iff	If and only if
IREDA	Indian Renewable Energy Development Agency Ltd.
IRP	Integrated Resource Planning
j	Number of criteria factors
k	Overall scaling constant
k_j	Overall scaling constant for criteria j
LPG	Liquefied Petroleum Gas
MADM	Multi Attribute Decision Making
MCDM	Multi Criteria Decision Making
MCPE	Monthly Per Capita Expenditure
MCPI	Multi Criteria Preference Index
MNES	Ministry of Non-conventional Energy Sources
MODM	Multi Objective Decision Making
MoPNG	Ministry of Petroleum and Natural Gas
MT	Million Tonnes
MTOE	Million Tonnes of Oil Equivalent
N	Total number of respondents
N_j	Number of respondents for j^{th} criteria
N'	Size of the matrix
NCAER	National Council of Applied Economic Research

List of Symbols and Abbreviations (Contd...)

Symbol/ Abbreviations	Description
NGO	Non Government Organization
NPBD	National Programme on Biogas Development
NPIC	National Programme on Improved *Chulhas*
NSSO	National Sample Survey Organization
p	Preference threshold
PDS	Public Distribution System
$P_j(a, b)$	Preference function of alternative a over b for j^{th} criteria
PROMETHEE	Preference Ranking Organization METHod for Enrichment Evaluations
PSC	Parabolic Solar Cooker
q	Indifference threshold
Quads	Quadrillions
R	Spearman rank correlation coefficient
RWEDP	Regional Wood Energy Development Programme
SBC	Solar Box Cooker
SNA	State Nodal Agency
TBU	Technical Backup Unit
TERI	The Energy and Resources Institute
TOPSIS	The Technique for Order Preference by Similarity to Ideal Solutions
u (.)	Overall utility function operator (between 0 and 1)
U_A	Rank given by an evaluator to device A
u_j (.)	Overall utility function operator for each attribute j

List of Symbols and Abbreviations (Contd...)

Symbol/ Abbreviations	Description
V_A	Rank given by another evaluator to device *A*
VITA	Volunteers in Technical Assistance
W_j	Weight assigned to criteria *j*
WPM	Weighted Product Method
WSM	Weighted Sum Method
λ_{max}	Maximum Eigen value
π (a, b)	Multi criteria preference index of alternative *a* over *b*
σ	Standard deviation
$\Phi(a)$	Net ranking of *a* in the alternative set A
$\Phi^-(a)$	Outranked character of *a* in the alternative set A
$\Phi^+(a)$	Outranking character of *a* in the alternative set A

Energy is at the heart of the contemporary living and the standards of living are therefore closely associated with the per capita energy consumption. On the other hand, depleting conventional energy resources warrant energy substitution by renewables. Though the renewable energy technologies have proved their techno-economic feasibilities from time to time, the diffusion of these technologies is still fairly low. Therefore it is felt that, in the changed socio-economic scenario, dissemination strategies for renewable energy devices may be devised by the energy planners and decision makers based on a different conception of energy planning procedure involving multiple criteria.

The purpose of present research is to evaluate parabolic solar cooker (PSC), a recent innovation in solar cooking technology on techno-economic, social, behavioral and commercial criteria in the present Indian context in comparison with other contemporary cooking energy device, with a view to devise strategies for its further commercialization.

This chapter introduces the topic based on brief background of cooking energy scenario in India and prevailing devices used in Indian households. This is followed by the need of multi criteria evaluation of PSC, objectives, scope of the research and chapter wise overview.

1.1. Background

Presently, 70% of India's population lives in rural areas distributed over 580,000 villages. Domestic sector accounts for 40% of total primary energy consumption. A large share of this is met by non-commercial fuels such as fuel-wood, dung, etc. The energy requirements for cooking are 90% of total domestic consumption (TERI, 2003).

Since cooking is carried out using both renewable and non-renewable fuels, a large variety of devices are used in India. Major cooking energy source in rural areas is biomass. Around 168 Million Tonnes (MT) of biomass is used every year for cooking (RWEDP, 2003). Traditional low cost devices like *chulhas* (cook-stoves) are widely used by rural masses. However, they have very low thermal efficiencies of 10-15% and higher emissions (Patel and Raiyani, 1997). With the increasing scarcity of fuel-wood, women have to walk up to 10 km and spend 3-4 hours a day for its collection. Improved *chulhas* have durability of 2-4 years and require fuel-wood in lesser quantity. Out of 23 Million improved *chulhas* installed in India, only 6 Million are functional (Neudoerfler *et al*, 2001). Biogas needs higher initial investment and trained manpower for installation. Many biogas plants are non-functional due to non-availability of water throughout the year. The problems identified for limited use of improved *chulhas* and biogas stoves are operational, social and behavioral leading to non-participation of masses (Malhotra *et al*, 2004). Kerosene stoves have good thermal efficiency and benefits of simplicity and availability due to good market network. Due to high costs and weak supply chain in rural India, only 1.3% of rural houses use liquefied petroleum gas (LPG) as against 27.2% in urban (TERI, 2003). There is pressure to increase the subsidy on kerosene and LPG to further reduce the prices leading to heavy burden on overall economy of the country. Modern alternatives such as micro-wave and electric ovens are not affordable to masses due to high capital and operating costs and intermittent electric supply.

A significant portion of cooking energy is required at low temperatures. Solar cookers thus offer an alternative solution for supplementing such thermal energy requirements in addition to health, nutrition safety and economy on micro level for the users. Solar cookers have a high potential for diffusion in the country (Vipradas and Mathur, 2001).

From the above discussion it is clear that fuel shortages for the increased population, over exploitation of fuel-wood resources, poor distribution network of petroleum products in rural areas, dependence on oil producing countries, associated pollution hazards and good availability solar radiation (Mani and Rangarajan, 1982) have compelled the government to promote solar cookers as sustainable energy technologies for decentralized population in India.

However, the users are having different perceptions about the usefulness of these devices. There are many conflicting issues in the preference selection of any cooking device in general and solar cookers in particular. Table 1.1 presents perceptions of Indian populaces for various cooking sources.

Table 1.1 Users' Perspective of Various Cooking Energy Sources

Alternative	*Advantages*	*Drawbacks*
Fuel-wood	Provides more heat/heavy heat Good for cooking in bulk Tasty cooking for all dishes Free and ready availability No price fluctuations Little initial investment	Poor aesthetics Produces smoke, dust, soot etc Needs spacious and aerated kitchen
Kerosene	Easy to extinguish fire Little initial investment Heat and flame are controllable Economical for most of the dishes	Blackens utensils and produces smoke Price fluctuations are high Black market supplies

Alternative	*Advantages*	*Drawbacks*
LPG	Very sophisticated and trendy Good for fixed amount of cooking Easy to extinguish flame and light up	Limited availability More investment for connection Fear of blasts and leakage
Biogas	Suitable for farmers and cattle owners	Season dependant production Requires water in high quantity Requires high maintenance
Electricity	Suitable for modern kitchens Models are trendy Controls are s~~upplicated~~ sophisticated	Interrupted supply of electricity Hazardous
Solar Heat	Fuel is free of cost Suitable for rural masses	Cooking outside in the Sun Not suitable for all dishes Not available at doorstep Unfamiliar technology

(Source: Joshi, 1999)

From the Table 1.1, it is clear that dissemination of any cooking source is governed by many factors which not necessarily are technical and economic but social, behavioral and commercial in nature. Solar cookers will have to meet the needs of end user for its successful dissemination in the masses.

Figure 1.1 shows the increasing affluence of technology in cooking energy based on data collected on efficiency and cost from various literature sources.

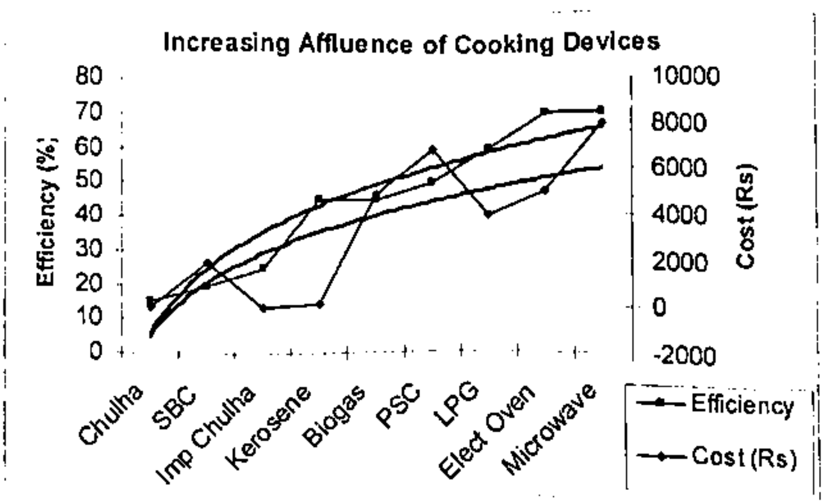


Figure 1.1 Affluence of Technology in Cooking Energy

It is observed that, as families gain socioeconomic status, they abandon technologies that are inefficient, less costly, and more polluting (Smith and Ramakrishna, 1990; Ravindranath and Ramakrishna, 1997). An increase in available income allows them to leave these fuels behind, and purchase technologies that are usually more efficient and costly, but require fewer inputs of labor and fuel, and produce less pollution per unit of fuel.

The Indian programme of solar cookers started in 1982-83 (Rao, 1998). However, it has met with limited success. Against the total potential of 10 Million, only 0.5 Million solar cookers have been sold (MNES, 2003). The initiatives have largely been in from of the national level rural and renewable energy programmes. A majority of the solar cookers sold are in cities, a few in rural areas where women suffer most from indoor air pollution from cooking. The estimates show that only 10% are being used or are in working order, the reasons being quality and reliability of product, poor after sales service etc (Jagadeesh, 2000). Though technical quality is necessary and is emphasized; it is not the only criteria for efficacy of solar cooker programme.

The problem of dissemination of solar cookers compels the planners and decision makers to identify the barriers for penetration and suggest interventions to overcome them. It is therefore felt that, along with the necessary policy measures, the wide exploitation of solar cookers should be based on a completely different conception of energy planning procedure. There are various issues like technology up gradation, economics, behavioral and commercial aspects. Thus role of different actors in decision making thus becomes important, which warrants the planning based on multi criteria evaluations. Moreover, the efficacy of dissemination of solar cookers in general and PSC in particular in present Indian context should not be considered in isolation but in contrast with the other cooking energy options available to the users. This implies that the technology has to compete with conventional cooking energy technologies. To devise strategies for better dissemination of PSC, one of the important aids required by planners, decision-makers is to have a comprehensive yardstick to compare solar cookers with other cookers. In view of the above, the objectives of present research work are given below.

1.2. Objectives

i. To study the present cooking energy situation in India to understand the need of disseminating renewable energy devices;
ii. To identify various criteria governing the usefulness of various cooking energy devices with special reference to PSC;
iii. To assess the relative strengths, weaknesses and constraints of prevailing cooking devices;
iv. To model the comprehensive usefulness of PSC on technical, economic, social, behavioral and commercial criteria in the present Indian context;
v. To compare the performance of PSC with other domestic cooking devices on selected multiple criteria;
vi. To carry out sensitivity analyses of PSC to investigate its performance with possible techno-economic and policy interventions ; and
vii. To identify the barriers and suggest suitable strategies for further commercialization of PSC in India.

1.3. Scope of the Study

In this study, multi criteria evaluation of nine prevailing cooking devices indicative of all the domestic cooking energy devices has been attempted on thirty criteria. The entire gamut of criteria selected contains nine quantitative and twenty one qualitative criteria. The data for quantitative criteria is taken from secondary sources mainly from published literature. Primary data has been collected for qualitative criteria by conducting a survey of four different decision making groups. The study uses convenient sampling for primary data. Any study of this nature is also subjected to uncertainty in the input data.

Three methods viz. outranking, priority and utility assessment have been used for multi criteria evaluations. Though Brans *et al.* (1986) have offered six generalized criteria functions the evaluation by outranking is mainly carried out using usual criterion function. Evaluation by priority model uses compromising scale for pair-wise comparison. Utility assessment is also carried out based on linear utility functions.

1.4. Organization of the Thesis

Chapter -1 (this chapter) gives an overview of the present research work, discussing the advantages and limitations of prevailing cooking energy devices from the user's perspectives. A brief introduction to the problem under study is followed by the need of renewable energy planning using multi criteria evaluations. It also discusses objectives, scope and organization of the work.

Chapter-2 discusses cooking energy scenario in the country with an objective to understand the underlying socio-economic factors governing the utilization of various fuels/energy carriers in cooking. The trends in household energy consumption for urban and rural areas are presented with dissemination of various fuel-device combinations including both renewable and non-renewable devices. It also discusses the initiatives by the government for technology dissemination of solar cookers in India. The chapter concludes with need of renewable energy devices like PSCs, its potential benefits and a few insights into the dissemination strategies adopted till date.

Chapter -3 presents a review of literature for the present thesis. A brief overview of literature highlighting methods and trends in energy planning is presented. The chapter discusses applications of various multi criteria evaluations reported for energy planning. A review of earlier evaluations of solar cookers is presented with a view to identify the research gaps in the present literature as well as the needs of multi criteria evaluations with special reference to PSC. The chapter leads to identification of criteria.

Chapter -4 discusses the methodology adopted and the analytical framework for the research work. The chapter identifies and discusses the criteria for the present evaluation study. Detailed report on methodology adopted for survey, analysis of data collected and computation of weightages for all the decision making groups is discussed in the chapter. The chapter also discusses various evaluation methodologies adopted for the study viz. outranking (PROMETHEE), priority (AHP) and utility assessment (MAUT) techniques. The chapter emphasizes on the actual evaluation of PSC using the said techniques.

Chapter-5 discusses the results of the present research work. It discusses the ranking of PSC for various decision making groups as well as rankings obtained by various evaluation methodologies. The correlation coefficients between the ranks obtained from Spearman test are also presented. Sensitivity analyses have been carried out in this chapter to devise alternative strategies for improving the ranking of PSC amongst the selected devices.

Chapter-6 examines the issues in commercialization of PSC under the current dissemination framework and suggests suitable measures to overcome the identified parameters perceived as barriers based on the results of present research work.

Chapter-7 presents conclusions of the research. General conclusions are followed by specific contributions of the research work. Areas that require further exploration are identified, and the implications of the results for further dissemination are presented.

There are four appendices included in the thesis. It includes techno-economic evaluation carried out at BITS, Pilani; the response sheets used for the survey, list of respondents. List of publications and presentations based on present investigations is also appended to the thesis.

Chapter 2: Cooking Energy Issues in India

Most of the Indian population lives in villages and depend upon non-commercial fuels to meet their energy needs. Diverse urban growth patterns have led to structural changes in economy and these have important ramifications on energy consumption in households sector. This chapter discusses cooking energy needs in India, trends in dissemination conventional energy devices/fuels and dissemination of renewable energy devices with a view to understand the underlying socio-economic factors governing the utilization. A special emphasis has been given on the dissemination of solar cooker technology in the country.

2.1. Cooking Energy Consumption in Indian Households

World's primary energy consumption in 2000-01 was 403.92 Quads against a production of 403.44 Quads (IEA, 2003). This situation is worse in developing countries like India. Though the primary energy consumption in India was 3% of the world energy consumption during 2000-2001, increasing population at a rate of 2.1% per annum has resulted in increasing gap between demand and supply of energy (TERI, 2003). India mainly depends on coal, oil and fuel -wood for most of its energy needs. After the first oil shock in 1973, the renewable energy sector emerged as a crucial and dynamic component of the Indian economy (Naidu, 1996; Gupta, 2000).

The domestic sector is one of the largest consumers of primary energy (nearly 40% of total energy demand) in India and traditional sources still dominate the sector. 90% of the household energy consumption is for cooking alone. The demand for cooking energy is increasing annually at a rate of 8.1%. Though the population of

India can be divided into rural and urban areas, India follows an income based cooking energy ladder starting from fuel-wood and ending at sophisticated fuels like LPG and electricity (Reddy, 2003; Reddy and Painuly, 2004). In the household sector, 75% of energy requirements are met by fuel-wood and agriculture waste; the rest are met through kerosene and LPG. Historical trends in household energy consumption for the period 1950-2000 are shown in Table 2.1.

Table 2.1 Energy Consumption by Indian Households (MTOE) (1950-2000)

Fuel	*1950 (%)*	*1960*	*1970*	*1980*	*1990*	*2000 (%)*	*Annual Growth rate (%)*
Fuel-wood	54.08 (82.65)	67.10	84.65	88.10	84.43	114 (75.60)	3.7
Coal/ Charcoal	0.77 (1.18)	1.08	1.36	2.12	2.03	2.5 (1.66)	6.7
Kerosene	1.12 (1.71)	2.76	3.48	5.24	5.02	12.5 (8.29)	11.5
LPG	NA	NA	NA	1.20	1.15	6.4 (4.24)	35.8
Electricity	0.06 (0.09)	0.13	0.16	0.79	0.76	9.2 (6.10)	23.8
Others	9.40 (14.37)	8.20	10.34	6.90	6.61	6.2 (4.11)	-2.3
Total	65.43 (100)	79.27	100	104.35	100	151.8 (100)	3.9

(MTOE- Million Tonnes of Oil Equivalent. Source: CMIE, 2001)

Table 2.1 indicates decline in share of non- commercial fuels which, in 1950 accounting for 97% of the total, declined to about 80% in 2000. The data demonstrates the increased share of LPG and electricity as the main fuels from 0.06 % in 1950 to 10.34% in 2000. The growth of kerosene however remained steady over the 50-year period.

Eventhough the difference between the shares of commercial and non-commercial fuels/energy carriers decreased substantially, it remains to be considerable. This higher share of fuel wood and other biomass resources is a consequence of lower energy efficiency utilization. The demand for modern fuels has also increased with the changes in economy. Many households that used to depend on fuel-wood fuels have shifted to modern energy carriers like LPG and electricity. Major factors contributing to these shifts are the levels of urbanization, economic development, and living standards. This has resulted in lower growth rate of fuel- wood (3.7% per annum) while increase in growth rates of LPG (35.8%) and electricity (23.8%).

The pattern of household energy consumption is region specific, depends on the income of the household, availability of local resources, alternative fuels and price of fuels, etc. There is a variation in the contribution of different energy carriers in the energy mix of different income groups. Low-income households use fuel-wood, charcoal, agricultural wastes, etc., whereas the high-income households use LPG and electricity. Figure 2.1 indicates the share of rural households using particular fuel/energy for cooking application.

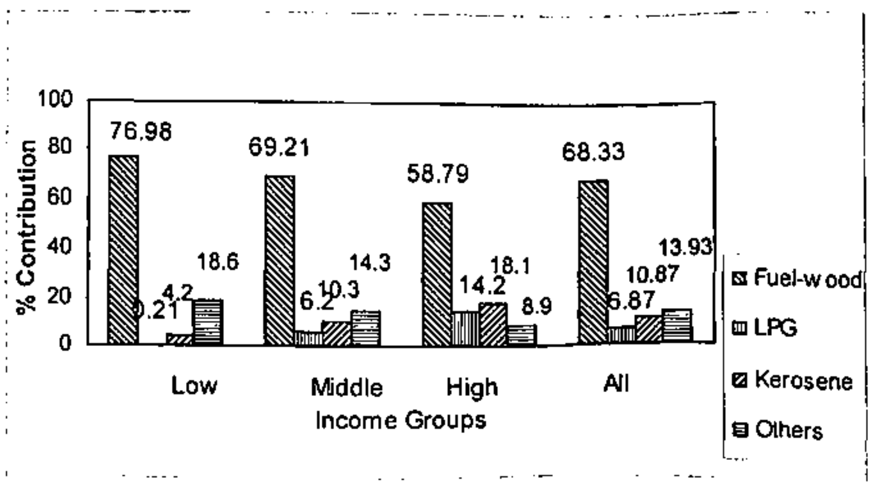


Figure 2.1 Share of Rural Households using Particular Fuel/Energy for Cooking
(Source: TERI, 2003)

Figure 2.2 indicates the share of urban households using particular fuel/energy for cooking application.

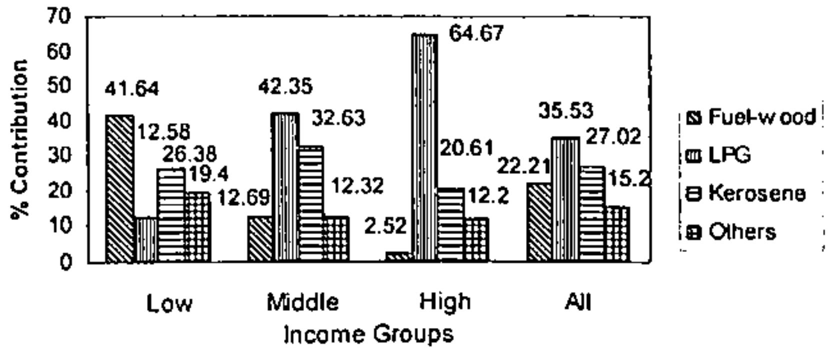


Figure 2.2 Share of Urban Households using Particular Fuel/Energy for Cooking
(Source: TERI, 2003)

The above figures indicate that middle and high income urban consumers use LPG whereas lower income people use fuel-wood and kerosene. This trend is discernible for both rural as well as urban areas. The contribution of various fuels/energy carriers in each income group across rural and urban households is shown in Table 2.2.

Table 2.2 Households using Particular Fuel/Energy Carrier for Cooking (%)

Income Class	*Fuel-wood*	*LPG*	*Dung*	*Kerosene*	*Coal*	*Biogas*	*Electricity*	*Others*	*Total*
				Rural Households					
Low	29.24	0.16	3.85	0.24	0.61	0.01	0.00	1.37	35.5
Middle	39.36	2.14	5.59	1.35	0.72	0.15	0.04	1.66	51.0
High	6.95	3.10	1.18	1.12	0.23	0.16	0.04	0.73	13.5
Total	**75.54**	**5.40**	**10.62**	**2.71**	**1.56**	**0.32**	**0.08**	**3.77**	**100.0**
				Urban Households					
Low	15.24	5.04	1.26	7.13	2.08	0.01	0.08	1.92	32.8
Middle	6.81	28.16	0.76	13.11	2.07	0.04	0.25	1.98	53.2
High	0.25	11.01	0.04	1.50	0.10	0.00	0.08	1.09	14.1
Total	**22.29**	**44.21**	**2.06**	**21.74**	**4.25**	**0.05**	**0.40**	**4.99**	**100.0**

(Source: Reddy, 2003)

As the data shows, in rural areas, 75.5% of households use fuel-wood while the rest depend on dung, LPG and kerosene. The estimated annual consumption of fuel-wood is much higher than the recorded production in country. It is estimated that the annual sustainable production of fuel-wood from different sources is about 122 MT which is much less than the estimated consumption of fuel-wood of 168 MT. This gap between sustainable production and consumption of fuel-wood emphasizes the fuel-wood problem in India. Fuel-wood energy use in India is 13-23 MJ per capita per day (RWEDP, 2003). Among those households which depend on fuel-wood, nearly 90% are from the low income and middle-income groups. In the case of urban regions, the major fuel is LPG (accounting for 44.2%) followed by fuel-wood and kerosene (about 22% each). One of the main reasons for this trend is the high initial cost of devices (LPG and electric stoves) to the consumer, particularly relative to the low cash incomes in many rural areas. Other factors include shortages of particular fuels, lack of a distribution network, and failures of distribution system. With increasing disposable income and changes in lifestyles, households tend to move from the cheapest and the least convenient fuels (fuel-wood, dung, etc.) to more convenient and normally more expensive ones (kerosene) and eventually to the most convenient and usually most expensive types (LPG, and electricity).

Statistics derived from the series of National Sample Survey Organization (NSSO) provide information on the use of various fuels in different classes of expenditure. Figures 2.3 and 2.4 explain the distribution of household by primary source of energy used for cooking in urban and rural areas respectively based on the NSSO data.

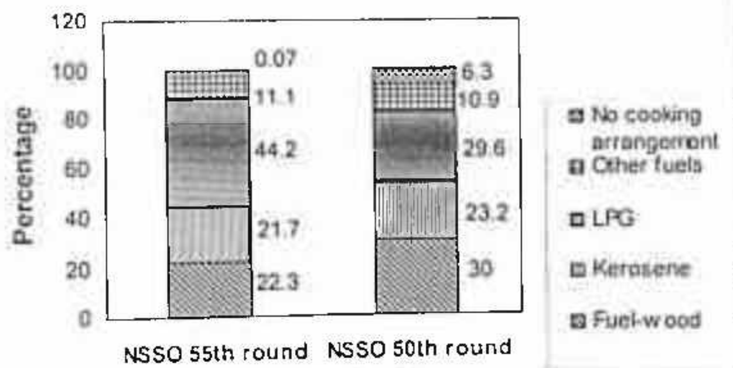


Figure 2.3 Distribution of Households by Primary Source of Energy used for Cooking in Urban Areas (Source: NSSO, 1998; 2001)

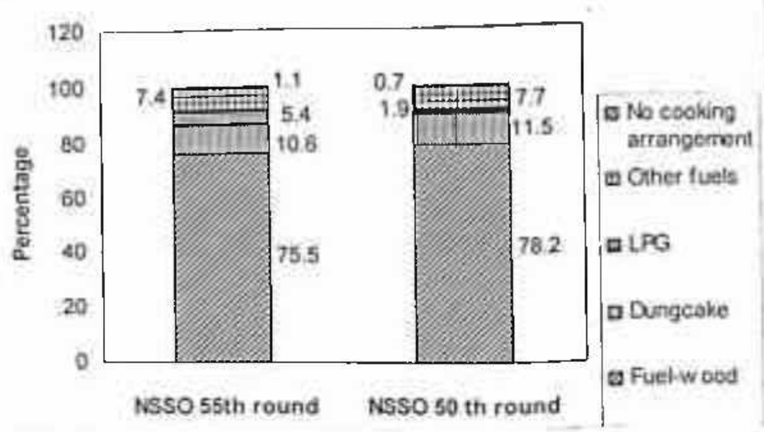


Figure 2.4 Distribution of Households by Primary Source of Energy used for Cooking in Rural Areas (Source: NSSO, 1998; 2001)

The above figures indicate that the expenditure on cooking energy has increased between 50^{th} and the 55^{th} rounds of the NSSO.

The information derived from subsequent NSSO rounds also indicates similar trends. The average monthly per capita consumer expenditure (MCPE) was Rs. 495 for rural areas and Rs. 914 for urban areas according to the 56^{th} round of data collection by NSSO conducted during 1999-2000 (NSSO, 2001). The average MPCE for urban areas on all-India level is 85% higher than that of rural areas. An increasing trend has been observed in the MPCE of households on fuel and light. The total MPCE for fuel and light in rural areas was Rs 22 according to the 51 [st] round of NSSO conducted during 1995-1996 (NSSO, 1998) and this increased to Rs 41 according to the 56[th] round conducted during 1999-2000 (NSSO, 2001). In urban areas, the corresponding figures were Rs 34 in the 51[st] round and Rs 77 for the 56[th] round.

Figure 2.5 shows a slight increase in the monthly per capita energy consumption of fuel-wood from 1993/94 to 1999/2000 and increase in consumption of electricity.

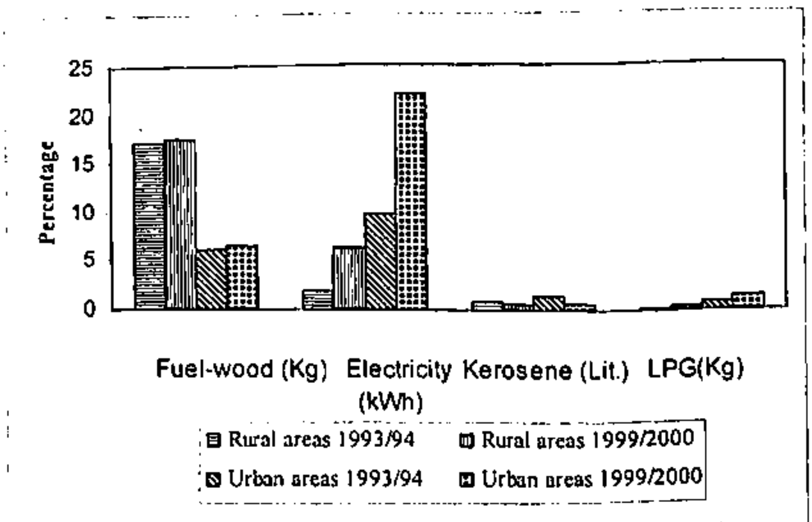


Figure 2.5 Monthly Per Capita Consumption of Energy Sources (Source: TERI, 2003)

The above figures indicate that compared to the urban households, rural households allocate a higher proportion of their expenditure to meet their energy needs. Therefore it is probable that the poor not only use smoky and inconvenient fuels leading to poor health but also pay relatively higher price for reaching comparable levels of energy use. The prices of energy products have increased faster compared to other commodities. This is especially hard on the poor as energy forms the bulk of their household expenditure. The price of kerosene is subsidized with a view to protect consumers, but the benefits of the subsidy are not directed to the poor in particular. As a result, the subsidy is often misdirected and the relatively cheap kerosene is often used for adulteration in the transport and industrial sector. Poor consumers are unable to fulfill their total requirement of kerosene from ration shops and depend in part on supplies from outside sources for which they pay higher prices.

Thus the accessibility and availability of cooking fuels at affordable prices is becoming more difficult day by day for poor people, many of whom are outside the modern energy system. The use of these bio-fuels causes, especially to women, much hardship (Parikh and Laxmi, 2000; Ramana, 1999), which in economic terms are negative externalities. In the case of bio-fuel use, time spent and hardship suffered in fuel collection, health impact suffered from air pollution, increased burden of cleaning utensils and ecological changes are negative externalities. Unavailability of clean cooking fuels leads to many such problems. More over the energy transition from dung to electricity is possible in areas where alternatives exist. The economic and environmental impacts associated with energy transition in both urban and rural areas represent a potent area of opportunity for individual consumers as well as to the society (Jain, 1995). Hence there is need to explore alternative cooking options for domestic sector.

2.2. Dissemination of Conventional Energy Technologies

There are large varieties of conventional cooking technologies available to the Indian households. The households either use commercially available fuel-device combinations or use traditional (non-commercial) options or both depending upon their income, the availability of fuel and the price (Reddy, 1996; Kishore 1989).

It is also important to consider fuel-device combinations as the same fuel; can be used more efficiently (Gupta and Ravindranath, 1997). The same is related with pollution levels (Mande and Lata, 2001). Table 2.3 gives percentage of heat utilization /efficiency and life of various devices.

Table 2.3 Efficiency and Average Life of Different Fuel-Device Combinations

Sr No	*Fuel-device*	*Efficiency (%)*	*Life (Years)*
1.	Wood- 3 Stone	15. 7	3
2.	Wood- Traditional -3 pan	14.2	3
3.	Biogas-KVIC Burner	45.1	3
4.	Kerosene-Nutan	60.2	7
5.	Kerosene –Perfect	40.4	7
6.	LPG-Super Flame	60.4	20
7.	Electricity-Hotplate	71.3	7

(Source: Gupta and Ravindranath, 1997)

Indoor air pollution from domestic cooking devices using coal, kerosene and LPG, wood, dung and their processed fuels have indicated higher levels of carbon monoxide emissions as reported in the literature (Kandpal *et al* 1995a; 1995b; Srivastava, 1997).

2.2.1. Traditional *Chulhas* (Cook-Stoves)

In rural households, food is generally cooked on clay or three stone stoves, called *chulhas*. Both single pot and multiple pot *chulhas* are used by masses. The *chulhas* use biomass as fuel and have a maximum life of 3 years. A family of 5 to 6 persons requires about 8 kg of fuel every day. The *chulhas* use only 10% of the total heating potential of the fuel burnt in them. Another disadvantage of the traditional *chulhas* is that they produce a lot of smoke, soot and un-burnt volatile organic matter, which not only blacken the pots and the walls of the kitchen, but also pollute the indoor air and adversely affect the health of the householders (Rajvanshi, 2003). Housewives and infants are affected the most by these pollutants, because they are maximally exposed to the smoke. Several respiratory and chronic diseases in kitchens of developing countries have been attributed to higher levels of indoor pollution. Acute Respiratory Infection (ARI) is one such disease responsible for death of 5 Million children below the age of 5 years worldwide every year (Vishwanathan and Kumar, 2004).

Normally, the domestic fuel consists of dung supplemented by wood. The former is generated in the family farm, while the latter, consisting mainly of branches of trees, is collected in the neighborhood. The agricultural wastes like wheat stalks, sugarcane leaves, cotton roots and stalks, wheat husk, stalks of pigeon pea, lops and tops of fruit trees etc. are used as fuel in rural areas. Even families who can afford modern fuels, prefer to use biomass because it is available free of cost. In forested regions, the fuel consists almost exclusively of wood. The use of fuel-wood is associated with drudgery in gathering and in its use leading to low quality of life apart from adverse impact on forest and village tree resources.

2.2.2. Kerosene Stoves

Kerosene is used for cooking using a kerosene stove either using the pressurized or the wick stoves. Kerosene stoves occupy a place between *chullhas* and LPG in the cooking energy ladder. Kerosene is much easier to burn cleanly than coal, wood or agricultural residues. Kerosene stoves are popular due to their efficient, quick, easily controllable, convenient features as compared to other rural cooking devices. The equipment cost is lower and maintenance cost is very less. Lighting kerosene stove is but tedious. On the other hand, kerosene stoves give off an unpleasant smell. The safety of kerosene stoves is also questionable.

Kerosene is a liquid fossil fuel which comes from the refinement of crude oil. It is trendy fuel with a specific gravity of 0.8 and flash point temperature of 38 °C. Kerosene is distributed through Public Distribution System (PDS) and mostly used by low-income and middle-income group families. The nominal price of kerosene has increased from US $ 12 (Rs. 555) per barrel to US $ 41 (Rs.1900) per barrel between 1999 and 2000. The consumers are protected from these fluctuations by giving subsidy which increases the burden on foreign exchange economy of the country. Government is providing flat subsidy of Rs. 2.45 on every liter of PDS kerosene. The total kerosene consumption in India during 2000/01 was estimated at around 10.5 MT out of which about 60% of the total consumption was for rural areas and the rest for urban areas. Non availability of kerosene for the households is a major issue. Kerosene sales increased at a rate of 4.6% per annum. Kerosene stove has a major share of 22% in urban area and only 3% in rural area; the reason being poor distribution network (TERI, 2003). The allocation of subsidized kerosene by the central government varies from state to state and is based on historical patterns rather than on actual demand or on consideration of relative poverty levels. The allocation within a state depends on whether the household is in a rural or urban area, and typically on whether or not the household has taken up LPG. The lowest allocation quantity typically is set aside for those with double-cylinder connection.

2.2.3. LPG Stoves

These stoves are trendy, easy to ignite and switch off and hence used widely across the world. It has relatively fewer components; it is easy to achieve the correct fuel to air mix ratio that allows the complete combustion of the product. This gives LPG its clean burning characteristics. These characteristics lead to making LPG a substitute for indigenous fuels such as wood, coal, and other organic matter. This provides a solution to de-forestation and the reduction of particulate matter in the atmosphere (haze). What distinguishes LPG from others is cylinder arrangement which can store high amount of fuel in a small cylinder. The average efficiency of LPG stove is estimated to be 60%. Liquefied Petroleum Gas is a general description of Propane (C_3H_8) and Butane (C_4H_{10}), either stored separately or together as a mix. They are so called because these gases can be liquefied at normal temperature by application of a moderate pressure increase, or at normal pressure by application of cooling using refrigeration. Since LPG tends to vaporize easily, it is a flammable gas and higher safety is a must. The accidents are fatal.

In spite of a significant increase in the supply of commercial energy, the consumption of commercial fuels such as LPG is still negligible in rural areas with only 1.3% of households using it for cooking (TERI, 2003). The penetration of LPG is very low in rural areas due to a variety of reasons. The main reason being its poor distribution network and increasing cost. The beneficiary is supposed to deposit lump sum amount as deposit and have two cylinders to manage his cooking function. In a deregulated market, prices of LPG and kerosene are linked with international prices. Significant fluctuations in these prices are observed recently. The nominal price of LPG has increased from US $ 93 per MT to US $ 370 MT between 1997 and 2003. The consumers are protected from these fluctuations by giving subsidy which increases the burden on foreign exchange economy of the country. Out of total population of India, predominant users of LPG are from middle class and above. Since its introduction as a domestic fuel in mid-50s, LPG consumers are increasing at an average rate of 13% per year (Table 2.4) with current rate as 12% per year. The number of customers of LPG was 43.6 Million till 2000 (MoPNG, 2000).

Table 2.4 Year-wise LPG Consumption in India (Past and Projected)

Period	*Consumption (x 000 Tonnes)*	*Annual Increase (%)*
1985-86	1241	41
1990-91	2415	19
1992-93	2866	09
1994-95	3434	06
1995-96	3849	12
1996-97	4198	09
1997-98	4660	11
1998-99	5027	08
1999-00	5902	17
2000-01	6500	10
2001-02	7300	12
2006-07	10148	08
2010-11	12325	05

(Source: Indiastat, 2003)

2.2.4. Electric Hot Plates/Ovens

These are trendy and sophisticated kitchen equipments which use electricity. A typical hot plate is normally having 1000-2000 Wattage and thus will be consuming 1-2 kWh of energy per hour. So is the case with ovens. The ovens require good amount of electricity for pre-heating. The door opening will loose 25 to 50 degrees or more of the thermal energy. Any breakage in the door of oven also leads to a loss of energy.

Due to erratic supply of electricity and higher prices of ovens, hazards and Indian cooking habits only 2% of households having access to electricity use electric ovens for cooking (ESMAP, 2002). A study in Karnataka has shown that the households use electric ovens/hot plates as standby which turns out to be not more than one hour occasionally. With the increase in usage of LPG, the electric ovens usage has come down by 20%. A majority (90%) of the households use it as only standby. Only 0.5% of urban households reportedly use electric ovens for cooking (Murthy *et al*, 2001).

2.2.5. Microwave Ovens

These are trendy and sophisticated kitchen equipments which use 50% of electricity as compared to electric ovens/hot plates. Microwave ovens are popular in higher income groups because they cook food incredibly quickly. They are also extremely efficient in their use of electricity because a microwave oven heats only the food. A microwave oven uses microwaves radio waves of frequency 2,500 Megahertz to heat food. Radio waves in this frequency range have an interesting property that they are absorbed by water, fats and sugars and not absorbed by most plastics, glass or ceramics. When they are absorbed they are converted directly into atomic motion - heat. Metal reflects microwaves, which is why metal pans do not work well in a microwave oven. Microwaves are not utilized much in India, the reason being the requirement of Indian cooking habits requiring deep frying and baking. Microwave prices were very high when they were first launched in the 1990s. This was due to imported parts and high import duties. During 2002/03 about 215,000 microwave ovens were sold compared to 25,000 in 1995. Indian women are increasingly accepting the convenience offered by microwave ovens and their ability to cook many Indian dishes quickly. A sharp drop in prices helped by local manufacturing has made the device affordable to Indian middle and higher income people (EIU, 2004). The ovens however kill fiber contents in the food and it may lead to cancerous diseases with its continuous use (Nexusmagazine, 2003).

2.3. Dissemination of Renewable Energy Technologies

In the above scenario one should be looking for the smooth and sustainable energy supply for meeting the basic need of domestic cooking. Efforts have been made in India to develop and disseminate renewable energy technologies such as improved *chulhas*, biogas, solar box cookers (SBCs) and PSCs for domestic cooking sector.

2.3.1. Improved *Chulhas*

The low and middle income masses would like to have a cook-stove which produces blue flame, is easy to light and reduces their burden of collecting biomass fuel. Thus the biggest challenge to scientists is to provide a fuel and cooking stove technology, which gives complete combustion based blue flame for cooking. Improved *chulhas* aimed at enhancing the energy efficiency of biomass burning and eliminating the smoke from the kitchen environment, have been in vogue in India since the late 1940 (Karve *et al* , 2001; Ramana, 2001). Installation of chimneys leading to smoke removal is seen as a remarkable plus point of this device which does not mean that the efficiency has been increased.

To this effect Government of India initiated a National Program on Improved *Chulhas* (NPIC) in 1985, through MNES. There are basically of two types fixed mud *chulhas* (with chimney) and portable metal *chulhas* (without chimney). Within these two categories, there are a number of different models and designs available in different parts of the country. Around 30 models of *chulhas* were developed and distributed all over the country (Usretery *et al*, 1995; Kishore and Ramana, 2002). The cost of *chulhas* varies from Indian Rs 100–300. A minimum thermal efficiency of 20% and 25% has been prescribed for fixed and portable *chulhas* respectively by MNES under NPIC. Improved *chulhas* have not been disseminated in India much; their number of installation being 35.2 Million (MNES, 2003). A recent evaluation by National Council of Applied Economic Research (NCAER) termed the program as a failure which led to its shelving by MNES after spending almost Rs. 150 Crores (Kishore and Ramana, 2002).

Figure 2.6 indicates the year wise installation of improved *chulhas* in India.

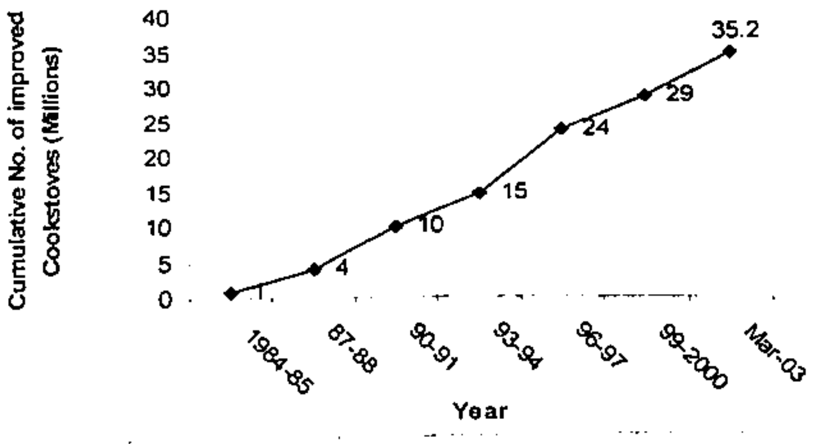


Figure 2.6 Year-wise Installation of Improved *chulhas* in India
(Source: Purohit *et al*, 2002; MNES, 2003)

2.3.2. Biogas Stoves/Plants

The gaseous fuel can be produced as biogas from the existing biomass sources. The biogas is a mixture of methane and carbon dioxide. It is produced in fixed and floating drum digesters which are locally built up by the farm and cattle owners. There are six designs of biogas digesters in use. However, the oldest design is still in use. The biogas plant requires considerable amount of cow-dung and other nitrogenous material. The biogas stoves inside the kitchen are connected to biogas digesters outside the kitchens via pipelines. Biogas cannot be liquefied and requires very high pressure (> 100 atmospheres) to compress it so that it can be used over extended periods. The development of extremely efficient biogas reactors and appropriate storage materials which could store biogas at low pressures are the challenges before scientists. This will lead to the production/unit of biomass inputs and its extended use.

The biogas is produced very inefficiently in fixed and floating dome systems and is not suitable for a household with less than 3-4 cattle. Besides there are problems of improper mixing inputs like biomass, night soil, cow-dung etc and gas production during winter.

Biogas is used extensively in rural areas of India. Though the use of biogas is increasing at a brisk rate, it is not been able to replace traditional *chulhas*. According to a survey conducted by United Nations' Food and Agriculture Organization-Regional Wood Energy Development Programme (FAO-RWEDP), increase in biogas energy consumption in India during 1981 to 1991 was 30.4% (RWEDP, 2003). Government has been supporting biogas use since 1981, through National Programme on Biogas Development (NBPD) and the number of installed biogas plants at the end of March 2003 was 3.5 Million (MNES, 2003). Figure 2.7 shows the dissemination of biogas plants in India.

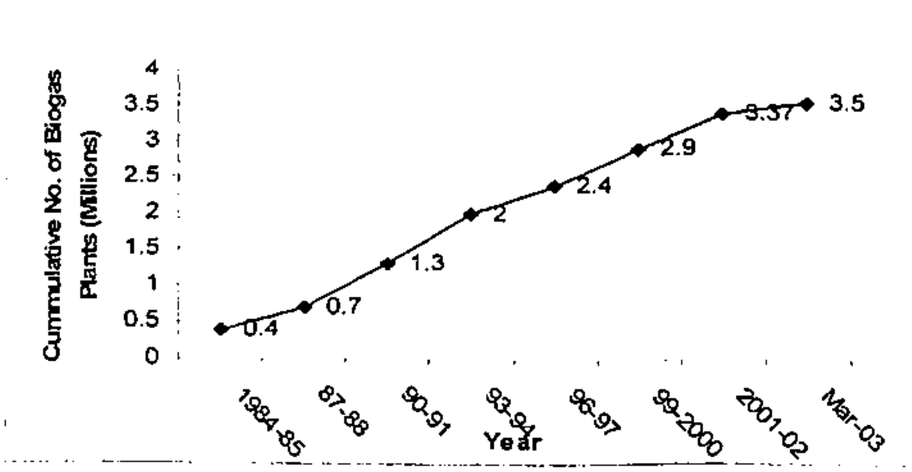


Figure 2.7 Year-wise Installation of Biogas Plants in India
(Source: Purohit *et al*, 2002; MNES, 2003)

2.4. Solar Cooker Programmes in India

One more option to meet the cooking energy crises is to use renewable energy based gadgets such as SBCs and PSCs. India has a solar radiation of 700 watts per square meter and 250 sunny days in a year. This makes a unique destination for a good potential for energy substitution (Mani and Rangarjan, 1982). Cooking for centuries has been carried out using fire. But side-by-side partial cooking of food using the Sun was also successfully carried out in India. With the successful application of solar energy for cooking food, a new era began in the early fifties in India. The history of solar cooking dates back to 18^{th} century when Nicholas de Saussare firstly used it. Several models have been developed to suit to variety of people. It is estimated that out of the entire solar cookers sold worldwide about $2/3^{rd}$ are box type and rest are concentrating type (Kundapur, 1998).

Ministry of Non-conventional Energy Sources is a primary agency promoting SBCs through State Nodal Agencies (SNAs) since 1983-84. Different types of solar cookers developed so far include SBCs, solar cooker with electrical back-up, domestic and community PSCs steam cooker, solar meal maker with heat storage, bowl type, heat pipe and solar steam cooking system etc. The primary focus however has been the SBC programme due to its various advantages over the others. Financing through local banks, co-operative societies and Indian Renewable Energy Development Agency Ltd. (IREDA) are also features of the solar cookers programme of government of India (Bakthavatsalam, 2001; Majumdar, 2000; Natarajan, 2000).

In spite of significant success reported in case of biogas plants, improved *chulhas*, solar cookers dissemination level is far below the estimated potential of 10 Million (MNES, 2003). With low educational levels and poor purchasing power, the dissemination of these devices remains a tough task (Kumar *et al*, 2003; Peter *et al*, 2002). But purchasing power need not be the only criterion for choice/selection/preference of cooking device.

2.4.1. Box Solar Cookers

A SBC is an insulated container with a multiple or single glass (or other transparent material) cover. Solar cooker works on the principle of greenhouse effect. In this, the transparent glazing permits passage of shorter wavelength solar radiation inside the cooker. But the glazing is opaque to most of the longer wavelength radiation coming from relatively low temperature heated objects, i.e. walls of the container. Mirrors may be used to reflect additional solar radiation into the cooking chamber. The inner part of the box is painted black. Up to four black painted vessels are placed inside the box with the food to be cooked. The cooker takes 1½ to 2 hours to cook items such as rice, split pea and vegetables. The cooker has also been used to prepare simple cakes, roast cashew nuts, dry grapes, etc. It is an ideal device for domestic cooking during most of the year except the monsoon season and cloudy days. It however cannot be used for frying or baking. Aluminium and fiber reinforced plastic SBCs are available in 60 x 60 cm, 50 x 50 cm and other sizes. The SBC can save about 25% of yearly cooking energy budget if used continuously.

Some manufacturers have come up with new models of solar cookers with electrical backup and various other added features. Salient features of these cookers are light weight adding to convenience, very nominal electricity consumption, and good aesthetics with inbuilt thermostat, light indicators and seamless steel vessels. Cooker with an electrical back up has the advantage of cooking food during non-sunshine hours/cloudy days with very nominal consumption of electricity. The cost of the cooker varies from Rs. 1000 to 2500 depending on its size and features. A normal size family cooker is sufficient for a family of 4 to 5 members. It has a life of 15 to 20 years has a pay back period of 3 to 4 years (MNES, 2003).

To maintain the quality of solar cookers manufactured, standard specifications are developed and provided to all manufacturers and these are now approved by the Bureau of Indian Standards (BIS, 2003). Six Regional Test Centers were also established in various parts of the country apart from the Solar Energy Centre, Gurgaon as National Referral Centre for certifying the product of various manufacturers as per ISI specifications (Kumar *et al*, 1995). The manufacturers are asked to get their product tested from these test centers before supplying solar cookers to various SNAs and only those manufacturers are who get their product certified from these test centers are eligible for subsidy if any.

Solar box cooker is an alternative food cooking device used by 5,41,000 users in India. It is being disseminated in India since last 20 years. The basic objective of SBC programme is market development and commercialization of these cookers for meeting substantial cooking energy needs of rural and urban people. To promote these cookers initially an amount of Rs. 150 was provided as central subsidy by the Ministry on sale of each unit to the user which continued till the end of March 1994. In addition to this subsidy many states provided an additional subsidy of an equivalent amount or more. The SBCs were therefore available to the users at the price between Rs. 450 to Rs. 600 in the beginning which increased to Rs. 850 to Rs. 1250 in due course of time after withdrawal of central subsidy. The state subsidy (though reduced) is still continued in many of the states without which the cost of the cooker would have been more. The sale of SBC was made by the nodal agencies through their district network. In order to give market orientation to the programme, the central subsidy on solar cookers is withdrawn from April 1994. A new strategy aiming at adoption and speedy commercialization of solar cookers is now adopted. Under this strategy, manufactures are allowed to make modifications in the cooker design to be more attractive and user-friendly. The sale can be made both through SNAs and directly by manufacturer through their own network. The idea is to develop the market force to come up with different models of solar cookers suitable to various groups of people living in different regions of the country with varying food habits and sell them through their own network like other consumer durable products. For this, financial assistance is being provided to SNAs for promotional activities on solar cookers such as publicity awareness, cooking demonstration/competitions, training, developing market network and repair/servicing facilities, sales outlets etc. This support is further being extended to manufacturers and NGO's for these activities through SNAs. To manufacturers, the support is, being provided on 50 % cost sharing basis. Around 40 manufacturers are involved in fabrication of solar cookers having a production capacity of about 1,00,000 cookers per annum. In addition to this, under an interest subsidy scheme of MNES, interest free loans are made available through IREDA to bulk users for supplying cookers to their employees and to the intermediaries for offering loans to individuals/providing cookers to hire-purchase basis. Soft loans at lower interest rate are also made available to manufacturers for purchase of equipments/machinery for the purpose of manufacturing and testing of solar cookers. Arrangements have been made with commercial banks to provide interest free loans to individuals for purchase of solar cookers which could be repaid on monthly installment basis in the year's time. With these arrangements around 5,41,000 SBCs, 630 PSCs and 6 solar steam cooking systems have been sold/ installed in the country till March 2003 (MNES, 2003). The dissemination of various solar cookers till 2002 is as shown in Figure 2.8.

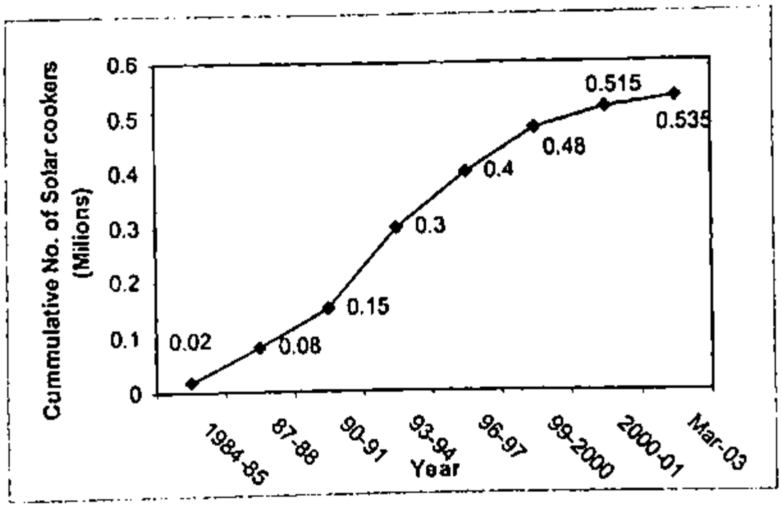


Figure 2.8 Year-wise Installation of Solar Cookers in India
(Source: Purohit *et al*, 2002; MNES, 2003)

2.4.2. Parabolic Solar Cookers

There are technological limitations for achieving high temperature without concentration of solar radiation. With the concentration of solar radiation at a point, the total energy flux can be increased beyond 1 kW/m^2 (Duffie and Beckman 1991). Parabolic Solar Cooker is used for concentrating solar radiation on the pot. Thus PSCs can cook food in much shorter duration as compared to SBC. However, it needs continuous tracking of the Sun to focus light on the cooking pot which adds to the cost. The beneficiary has to stand in the sun while food is cooked with solar cooker. Also only one item can be cooked with solar cooker at a time unlike SBC .

The device under consideration in the present thesis is PSC with aperture diameter of 1.4 meter and focal length 0.28 meter. The reflecting material used for fabrication of this cooker is anodized aluminum sheet, which has a reflectivity of over 75%. The tracking of the cooker is manual and thus has to be adjusted in 15 to 20 minutes during cooking time. These cookers can deliver 0.6 kW of thermal power with a thermal efficiency of 55-60% and stagnation temperature (vessel bottom temperature without any foodstuff) of 350-400° C. The cooker is thus useful for boiling, roasting, frying, baking etc. operations. The cooker is user friendly, portable, convenient and can meet the needs of around 15 people (Ramachandran and Vardhan, 1999). The cooker can be easily dismantled and assembled by anybody and thus may be nicely packed and transported anywhere in the country. The cooker is user friendly as the place of vessel to be kept for cooking is at a level, which is convenient for the people to use. The technology has been tested in India at the Technical Back Up (TBUs) units of MNES across the country and few universities and premier institutions (Singhal, 1998). Appendix I describe techno-economic evaluation carried out at BITS, Pilani.

The cost of PSC may vary from Rs. 3,500 to Rs. 7,000 depending on the type of reflectors used and the salient features provided by the manufacturers. The cookers with imported reflectors having a reflectivity of over 90% will have a higher cost. This cost includes the cost of accessories like pressure cooker, cap, hand gloves, goggles, cooker manual, packing etc. These cookers have average life of 20 years for the metallic parts and 5 years for the reflector material. More than 100 domestic PSC of this kind been sold and the growth is exponential (Gadhia, 2001). The said device is shown in Figure 2.9.

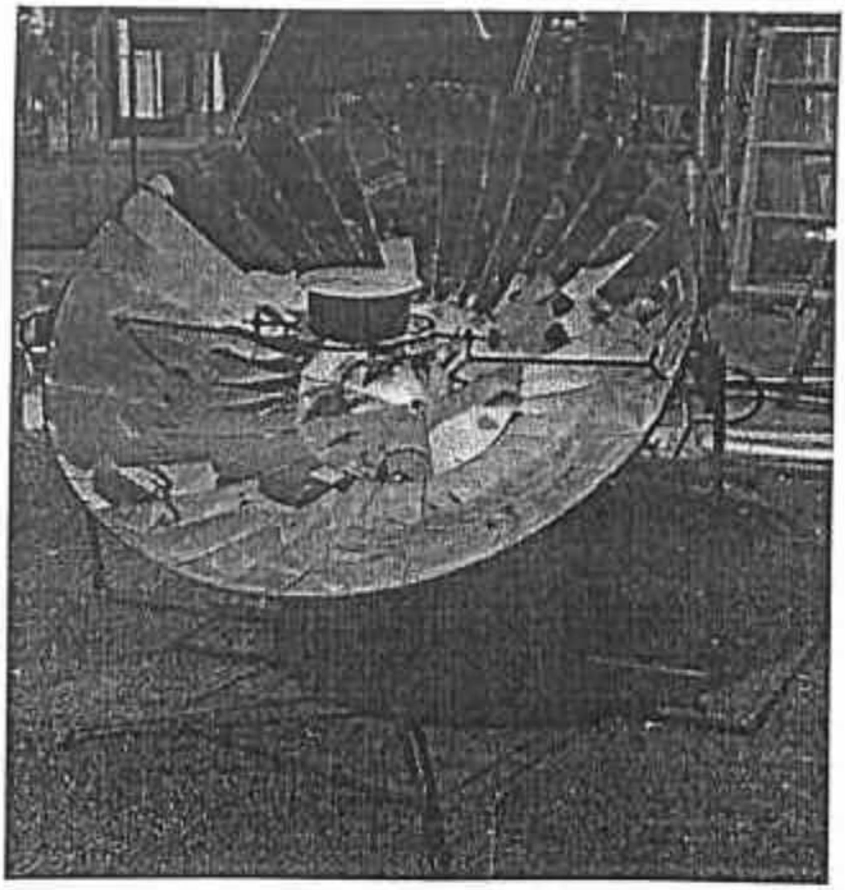


Figure 2.9 Domestic Model of Parabolic Solar Cooker

2.4.3. Community Solar Cookers

The unique feature of these cookers is that it is possible to cook using solar energy within the kitchen itself. The typical system consists of a large (7-8 m^2) reflector made of small pieces of acrylic mirror sheets fixed outside the kitchen tracking automatically the Sun and sending the reflected solar rays in the kitchen (focal length 3 m) through a small window in the wall and the secondary reflector made of aluminum foil concentrating the rays on the bottom of the cooking pot painted black. The reflectance of main reflector and secondary reflector is 0.75 and 0.65 respectively. The stagnation temperature attained is as high as 650 °C which ensures that the food is cooked in a shorter time unlike SBC. It therefore acts like a conventional cooking device with the difference that instead of conventional cooking fuel like gas, electricity or firewood, the food is cooked with the help of solar energy. The salient features are suitability of cooking for about 40 to 50 persons twice a day where radiation is available in plenty, automatic & simplified tracking using clock mechanism, manual seasonal adjustments of tracking and multiple uses. These cookers are also called Scheffler Cookers.

Presently about 230 Scheffler reflectors are in use all over the world for mainly cooking (Gadhia, 2004). Like SBC, reflectors are made from locally available materials. Mobile solar kitchen is used as an energetically self-sufficient catering unit for parties, fairs, etc. Its capacity is sufficient for about 30 meals. More than 70 such community solar cookers are put in the field for testing/demonstration/use in India. There are 15 manufactures of these solar cookers in India (MNES, 2003). Table 2.5 shows the cost economics of PSCs.

Table 2.5 Economics of Parabolic Solar Cookers

Particulars	*Domestic Model(PSC)*	*Community Model (Scheffler)*
Useful for	Small establishments and homes	Community Kitchens
Savings potential	10 Cylinders/Year	30-40 Cylinders/Year
Approximate cost	Rs. 7000	Rs 50,000
Life	20 years	20 Years
Payback period	1.5 –3 Years	5-6 Years

(Source: MNES, 2003)

2.4.4. Solar Steam Cooking Systems

The solar steam cooking system comprises of automatically tracked parabolic (Scheffler) concentrators, steam header assemblies with receivers, steam pipelines, feed water piping, steel structures and civil works, instrumentation like pressure gauges and temperature indicators, steam separators, steam traps etc. It is generally hooked up with conventional steam generating system already available with the user to make it reliable under all climatic conditions. There are nine such systems installed till date. Table 2.6 gives the details of such installations in the country.

Table 2.6 Details of Solar Steam Cooking Systems in India

Sr No	*Location*	*No of Collectors*	*Cooking Capacity (People /day)*	*Approx Cost (Lac Rs)*
1	Tirumalla Tirupati Devasthanam, Tirupati A. P.	106	15,000	109
2	Shri Sai Baba Sansthan,Shirdi, M S	40	3000	32
3	Brahmakumari's Hubli, Karnataka	NA	600	9.40
4	Brahmakumari's Gurgaon, Haryana	NA	2000	23.97
5	Brahmakumari's Talleti, Rajasthan	24	1000	25
6	Brahmakumari's Talleti, Rajasthan	84	10,000	55
7	Rishi Valley School, Chittoor, A. P.	NA	500	9
8	Sangi Industries , Hyderabad, A. P.	NA	500	NA
9	Rishi Sanskriti Vidya Kendra, Bangalore, Karnataka	NA	500	NA

(Source: Gadhia, 2004)

The above discussion reveals the role of cooking energy in sustainable energy management in the Indian households. There are various options to meet the end user needs using both commercial and non-commercial energies. Traditional fuel-wood utilization must be minimized with better dissemination of improved *chulhas*, biomass and biogas development. India with a large decentralized population is an ideal location for disseminating renewable energy technologies. However, the dissemination has been far below the potential and there is need to think of energy planning with a different conception. Better dissemination will have economic impacts on individual consumers as well as to the society and will reduce human drudgery. A considerable amount of socio-economic gains can be reaped with better dissemination of various cooking energy alternatives such as solar cookers.

This chapter presents an overview of literature on two major issues for the present research work. A review of literature on multi criteria evaluation techniques and their applications to energy planning is presented here with a view to identify the trends in energy planning and to ensure the applicability of these multi criteria evaluations to the present problem. A review of solar cooker evaluations reported so far is also presented to identify the attributes for multi criteria evaluation of PSC and suggest suitable strategies for its further commercialization.

3.1. Introduction to Multi Criteria Decision Process

Multi Criteria Decision Making (MCDM) is the process of making decisions in the presence of multiple objectives. A decision-maker is often required to choose among quantifiable or non-quantifiable and multiple criteria. The objectives are usually conflicting and therefore, the solution is highly dependent on the preferences of the decision-maker and must be a compromise. In most of the cases, different groups of decision-makers are involved in the process. Each group brings along different criteria and points of view, which must be resolved within a framework of understanding and mutual compromise. These methods are superior to traditional single criteria decision making which are normally aimed at maximization of benefits with minimization of costs. The basic multi criteria decision process is as shown in Figure 3.1.

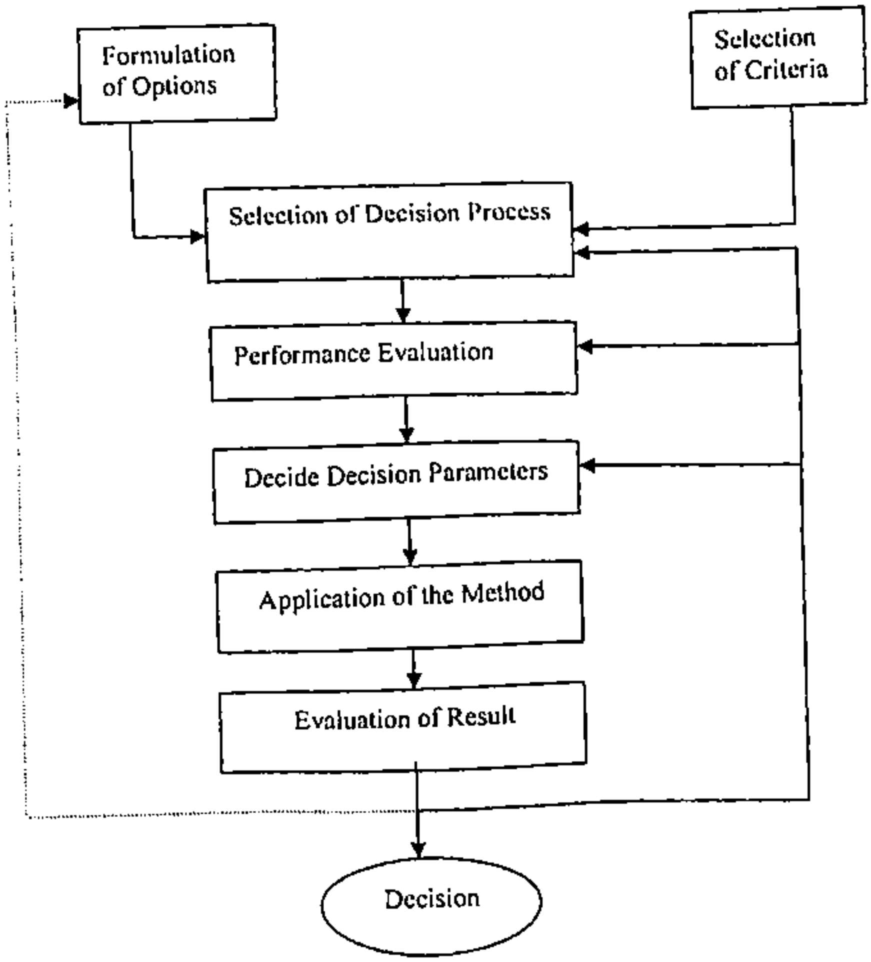


Figure 3.1 Multi Criteria Decision Process

As shown in the Figure 3.1, a decision maker is supposed to select an alternative course of action amongst the available options. The options are formulated either by using one or more techniques of operations research or are predefined. The decision process selection involving different stakeholders is followed by performance evaluation of the options which are often called as alternatives. The performance evaluation exercise requires selection of criteria and decides the importance (weightages) of the criteria termed as decision parameters. In the days of corporate decision making a lot of multi criteria evaluation methods based on scientific principles have come to the rescue of the decision makers. Once the ranking of options has been carried out the decision maker will be evaluating his decision by sensitizing the options to variation in decision parameters before the final decision is taken. These methods are more beneficial because they....

i. provide better understanding of inherent features of decision problem involving conflicting and multi dimensional objectives;

ii. promote the role of participants in decision making process;

iii. facilitate compromise and collective decisions;

iv. provide a good platform to understand the perception of models' and analysts' in a realistic scenario;

v. improve quality of decisions by making them more explicit, rational and efficient; and

vi. help in negotiating, quantifying and communicating the priorities.

The methods however have disadvantages of 'information pollution', if the decision making groups are not representatives of community, inconsistencies in data, tedious computations etc. These demerits can be overcome by validating the results by a few more methods, tactically identifying the decision making groups for eliminating bias and the use of computers.

Applications of these evaluations include a wide variety of areas such as integrated manufacturing systems (Putrus, 1990), evaluations of technology investment (Boucher and McStravic, 1991), water and agriculture management (Ozelkan and Duckstein, 1996; Raju and Pillai, 2000) in addition to energy planning (Huang and Poh, 1995).

3.2. Overview of Multi Criteria Evaluation Techniques

Multi Criteria Decision Making is a branch of a general class of operations research models which deal with decision problems under the presence of a number of decision criteria. This class is further divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) or multi-criteria decision making (MCDM) (Climaco, 1997; Triantaphyllou *et al*, 1998). There are several methods in each of the above categories. Priority based, outranking, distance based and mixed methods are also applied to various problems. Each method has its own characteristics and the methods can also be classified as deterministic, stochastic and fuzzy methods. There may be combinations of the above methods. Depending upon the number of decision makers the methods can be classified as single or group decision making methods. Decision making under uncertainty and decision support systems (DSS) are also prominent decision making techniques (Gal and Hanne, 1999).

In MODM, the alternatives are not predetermined but instead a set of objective functions is optimized subject to a set of constraints. In MCDM, a small number of alternatives are to be evaluated against a set of attributes which are often hard to quantify. The best alternative is usually selected by making comparisons between alternatives with respect to each attribute. Different multi criteria evaluation techniques are described below.

Weighted Sum Method (WSM) is the most commonly used approach, in single dimensional problems. The total value of each alternative is equal to the addition of products. Difficulty with this method emerges when it is applied to multi-dimensional problems (Solnes, 2003). **Weighted Product Method (WPM)** takes into account the multiplication instead of addition. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. In maximization case the ratio has to be more than unity. The best alternative is the one that is better than or at least equal to all the other alternatives (Chang and Yeh, 2001).

Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) is based on outranking principle where an attempt is made to find the relative strengths of one alternative over all the other alternatives. It computes Multi Criteria Preference Index (MCPI) which indicates aggregate strengths of the alternative over its weaknesses (Brans *et al.* 1984; 1986; 1990). Detailed discussion of this method is presented in section 4.5 (evaluation by outranking).

The Elimination and Choice Translating Reality (ELECTRE) method belonging to outranking class of multi criteria evaluations is capable of handling discrete criteria of both quantitative and qualitative in nature and provides complete ordering of the alternatives. The problem is to be so formulated that it chooses alternatives those are preferred over most of the criteria and that do not cause an unacceptable level of discontent for any of the criteria. The concordance, discordance indices and threshold values are used in this technique. Based on these indices, graphs for strong and weak relationships are developed. These graphs are used in an iterative procedure to obtain the ranking of alternatives (Roy, 1985). It only produces a core of leading alternatives. This method has a clearer view of alternatives by eliminating less favorable ones, especially convenient while encountering a few criteria with large number of alternatives in a decision making problem (Goicoechea *et al*, 1982).

The Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) developed by Huang and Yoon (1981) as an alternative to ELECTRE. The basic concept of this method is that, the selected alternative should have the shortest distance from negative ideal solution in geometrical sense. The method assumes that each attribute has a monotonically increasing or decreasing utility. This makes it easy to locate the ideal and negative–ideal solutions. Thus, the preference order of alternatives is yielded through comparing the Euclidean distances. The best alternative is one which has the shortest distance to the ideal solution and longest distance to negative ideal solution.

Analytical Hierarchy Process (AHP) decomposes a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy (Saaty, 1980; 1992). Elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The method computes and aggregates their Eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of hierarchy. Decision maker may use this vector due to his particular needs and interests. Detailed discussion on the method is presented in section 4.6 (evaluation by priority).

Compromise Programming (CP) defines the best solution as the one in the set of efficient solutions whose point is at the least distance from an ideal point. The aim is to obtain a solution that is as closed as possible to ideal (Zeleny, 1982).

Multi-attribute Utility Theory (MAUT) takes into consideration the decision maker's preferences in the form of utility function which is defined over a set of attributes. The utility value can be computed by determination of single attribute utility functions followed by verification of preferential and utility independent conditions and derivation of multi-attribute utility functions. The utility functions can be of either additively separable or multiplicatively separable with respect to single attribute utility (Keeny and Raiffa, 1976; 1993). Detailed discussion on the method is presented in section 4.7 (multi attribute utility assessment).

3.3. Review of Multi Criteria Evaluations in Energy Planning

3.3.1 Trends in Energy Planning

A look at energy planning during the seventies reveals that the efforts were directed primarily towards energy models exploring the energy-economy relationships established in the energy sector. The main objectives followed were to accurately estimate future energy demand. Single criteria approach aimed at identifying the most efficient energy supply options at a low cost was popular (Samouilidis and Mitropoulos, 1982; Meirer and Mubayi, 1983). Multi-objective linear programming was also popular in energy planning with conventional fuels in seventies. It was used for illustrating trade-off between environmental and economic parameters and for assisting in the selection of compromise solutions (Kavrakoglu, 1983; Schulz and Stefest, 1984). After the oil shock of 1973, a thought was given for energy conservation and energy substitution. In the eighties, the growing environmental awareness has slightly modified the above decision framework (Nijcamp and Volwahsen, 1990).

The need to incorporate environmental and social considerations in energy planning resulted in the increasing use of multi criteria approaches. Energy substitution by renewables has been given a thought worldwide. Despite of considerable technological development and their increasing competitiveness with respect to conventional fuels, the contribution of these sources is very low. This compels the planners and decision makers to identify the barriers for penetration and suggest interventions to overcome them. It is therefore felt that, along with the necessary policy measures, the wide exploitation of sustainable energy should be based on a completely different conception of energy planning procedure. Since the promotion of renewable energy sources involve multiple actors such as policy makers, researchers, investors and actual users, their role in decision making becomes important which warrant methods of group decision making.

3.3.2 Review of Applications Areas

Multi criteria evaluations have been applied to a variety of application areas in energy planning such as renewable energy planning, energy resource allocation, planning for energy projects, building energy management, transportation energy management, electric utility planning and other areas. Classical review by Hobbs and Meirer (1994) presents the comparison of different multi criteria evaluations applicable to energy planning reported in the literature. Huang and Poh (1995) discussed the methods used in energy and environmental modeling under uncertainties on similar lines. The commonly applied multi criteria evaluation methods out of the above discussed methods are AHP, PROMETHEE, ELECTRE, and MAUT. Applications using fuzzy methods and multi-objective optimization are also reported in energy planning. Validation of alternative strategies using one or more methods is commonly reported in the literature (Karni *et al*, 1992; Mirasgedis and Diakoulaki, 1997; Salminen *et al*, 1998).

The application areas presented in this chapter have common features of minimization of cost benefit ratios, high degrees of uncertainties in formulating the problems, incommensurable units and need to handle socio-economic aspects.

3.3.2.1. Renewable Energy Planning

The multi criteria evaluations have been widely used in renewable energy planning. The features of applications reported for renewable energy planning are compilation of feasible energy plan, dissemination of various renewable energy options and evaluation of alternative energies.

Evaluation of new energy systems in Taiwan has been attempted by Tzeng *et al* (1992) using PROMETHEE II outranking technique to evolve pre-ordering of the alternatives. The entire evaluation was based on 14 decision makers selected from four groups such as Energy Committee of Taiwan, Taipower Company, Chinese Petroleum Corporation and educators at Energy Research Institute. Georgopoulou *et al* (2003) have developed DSS for group decision making for renewable energy based on PROMETHEE II framework of outranking method. Georgopoulou *et al* (1997, 1998) and Cormico *et al* (2003) are of the opinion that regional energy planning is a multi actor and multi criteria problem especially for power generating systems. The authors have proposed ELECTRE III outranking framework for renewable energy planning for Greek islands. The actors involved in decision making are government top officials, project interveners, shadow actors as public and intermediaries. A comparison of fuzzy set theory and ELECTRE III for energy planning has been attempted by Beccali *et al* (1998, 2003). The study however has indicated that both the methods can give consistent results and non-quantifiable parameters can also be taken care by the outranking method.

Psarras *et al* (1990) have used multi objective programming method for large scale energy planning model. The authors have used hierarchical decision process for ranking the alternative courses of action. Analytical hierarchy process has been also employed for rural energy planning for China (Xiaohua and Zhenmin, 2002), domestic solar hot water heating and desalination system evaluations in Jordon (Mamlook *et al*, 2001, Mohsen and Akash, 1997; Akash *et al*, 1997; Elkarni and Mustafa, 1998). Mamlook *et al* (2001) compared different power generating options for Jordon by using neuro-fuzzy programming approach. The authors have considered fossil fuel power plants, solar, wind and hydro power plants for their analysis. Ramanathan and Ganesh (1994) have done multi objective analysis of cooking energy alternatives. Fifteen cooking energy sources have been considered using nine objectives representing energy-economy-environment system. The authors have suggested alternative strategies for national level energy issues. The study however has considered certain hypothetical options like solar photovoltaic electricity, fuel-electricity, biogas-electricity, diesel-electricity as cooking energy alternatives.

Skikos and Machias (1992) have presented an innovative fuzzy multi criteria evaluation approach to evaluation of wind sites. Fuzzy Site Index has been developed by the authors to evaluate and classify the potential wind sites. Mamlook *et al* (2001) have evaluated various solar system applications using fuzzy set methodology. The study considers cost benefit analysis for evaluating the solar systems. Efficiency, reliability, social benefits, safety and various costs like hardware, maintenance, auxiliary stems etc are considered in the evaluation. Hierarchical evaluations have been commonly applied to renewable energy planning applications, followed by outranking evaluations. A few utility assessment applications have been also reported.

3.3.2.2. Energy Resource Allocation

The features of energy resource allocation are need of investment planning, energy capacity expansion etc.

Lootsma *et al* (1990) used multi criteria evaluations for long term energy planning and allocation. The authors have evolved multiple scenarios but proved that preferences for certain strategies do not depend upon scenarios. The experts identified for the evaluation were authors themselves and working group on energy scenario analysis. Jones *et al* (1990) developed a multiattribute utility value model to study various energy options for UK. Their model was adopted from the simple multi attribute rating technique for multiattribute utility measurement. This consists of ten steps, such as identification of stakeholders, options for action, attributes, empirical indicators, ranking of attributes, rating of attributes in importance-preserving ratios, scaling of ratings, scoring options on each attribute, calculation of utilities and finally the decision. Sustainability indicators for economic and environmental resources problems have been devised by Afgan and Carvalho (2002). The authors have used multi-objective optimization followed by multi criteria assessment of power plants. Sustainability assessment for desalination of solar distillation has been attempted by Afgan *et al* (2000) by developing a multi criteria sustainability index for such type of plants considering all quantifiable criteria. Energy resource allocation by multi objective programming has been attempted by Ramanathan and Ganesh (1990, 1995) and Iniyan and Sumathy (2000) for Madras (India) to suggest an optimal mix of renewable and conventional energy for the said city. Sinha and Kandpal (1991) have devised optimal mix of energy technologies for cooking sector of India by employing multi objective optimization. Mezher *et al* (1998) have applied multi objective goal programming for energy resource allocation in Lebanon. The allocation has been analyzed for energy-economy-environment point of view to give a thought to costs, efficiencies, and energy conservation and eco-friendly energy options. Japan's power generating mix has been analyzed by Amagai and Leung (1989) using these methods. Similar approach has been presented by Psaras *et al* (1990) have developed large scale energy supply linear programming model using multi objective techniques using multiple criteria. A progressively efficient solution to energy planning has been proposed for Greece. Chedid *et al* (1999) have used fuzzy multi objective linear programming approach to energy resource allocation problems. Nine resources and six household end uses are considered for evaluation in the study. The fuzzy techniques provide decision makers with more flexibility in dynamic environment.

Multi objective linear programming and fuzzy methods have been extensively used in energy resource allocation. Hierarchical evaluations are normally used once the alternatives are generated in the said area. Very few applications of outranking and other methods are reported.

3.3.2.3. Building Energy Management

Applications reported for building energy management normally include quantitative criteria. Design, selection, and installation of building energy management systems are addressed in a multi criteria context. Multi-objective optimization also finds applications in building energy management (Blondeau and

Allard, 2000). The issues identified are building material design (Wright *et al*, 2002), building performance design (D'Cruz and Radford, 1987; Flourentzou and Roulet, 2002), building arrangement design (Klemm *et al*, 2000), and building shape design (Marks, 1997; Jedrzejuk and Marks, 2002).

Decision support systems (DSS) are also used for building energy management. However basic methodology was found to be multi -objective optimization in the reported literature.

3.3.2.4. Transportation Energy Management

Pollution control, elimination of old polluting vehicles, choosing between private and public transport featuring high concerns for socio-economic reasons are the key features of transportation system applications. Tzeng and Tsaur (1990) have applied combine hierarchical and outranking approach to old vehicle elimination in Taiwan. In this study the weight factors have been calculate by using pair-wise comparisons based on AHP. The decision makers were from environment protection field, energy field, implementers of the project and five representatives from the population. Tzeng and Shiau (1987) analyzed energy conservation strategies for transportation sector of Taiwan using ELECTRE III approach. Bowman and Mall (2002) have compared various passenger transportation systems using multi criteria evaluation considering space, time, cost etc. Analytical hierarchy process has been also employed for rural energy planning for China (Xiaohua and Zhenmin, 2002), transportation energy planning for Delhi (Yedla and Shrestha, 2003).

The transportation system applications have either used hierarchical methods or used outranking methods for their analyses of alternative strategies (Brand *et al*, 2002).

3.3.2.5. Project Planning

The objectives of arriving at a Pareto optimal solution for technology selection, sizing, execution, and investment planning and site selection are normally addressed by decision makers in project planning (Gandibleux, 1999). The application areas have common features of higher investment costs, higher project durations, conflicting objectives and uncertainty. Energy security and social benefits are prominent objectives in energy planning with these methods. Group decision making framework by assessing multi criteria analysis has been attempted by Harlambopoulos and Polatidis (2003). The authors have used PROMETHEE II outranking approach to exploitation of geothermal energy resource. Goumas *et al* (1999) have used multi criteria evaluations for planning, designing an evaluating geothermal energy projects on technical, economic, social and environmental criteria using the PROMETHEE I framework. Fuzzy PROMETHEE II has been applied by Goumas and Lygerou (2000) for ranking of alternative exploitation projects. The approach has been found to be more realistic and capable of producing more reliable results. In both the cases three categories of decision makers were identified which were stakeholders in the projects. Barda *et al* (1990) have considered technical, economic and environmental criteria for location of thermal power plants. The role of multiple actors in choosing the plant location has been proven by ELECTRE III outranking method. The problem considered expert opinion of general management board of projects, engineering and production management functions and planning management stakeholders. Golabi *et al* (1981) used MAUT to select a portfolio of a solar energy project for the US Department of Energy. The reasons for choosing MAUT being logical procedures handling multiple criteria, explicitly uses the experience and knowledge of the R&D

manager and handling non-monetary aspects. The quantification of techno-economic-environment gains have been attempted by Susilk and Furtado (2001) to improve the quality of investment decision in petroleum exploration using MAUT. The approach has advantages of combination of various objectives by additive utility functions. Mills *et al* (1996) developed a computer-based DSS to help electricity supply planners to meet future power demands. Their approach is based on a planning methodology known as integrated resource planning (IRP), which was developed to allow supply technologies to be compared with various demand-side management options. The decision criteria were presented in hierarchical order and the authors' achievement function was used to weigh achievements on each of the multiple objectives. This allowed the decision-maker to assess options against two reference points; a level of achievement, which is desired, and a minimum level for acceptability. Christensen and Vidal (1990) have developed a DSS for project evaluation for energy supply in rural areas of developing countries. The aspects considered in planning are socio-economic, cultural and political ones.

Methods of group decision making have been mostly applied in project planning. The applications reported for project planning have used outranking methods, DSS as well as MAUT in a few cases.

3.3.2.6. Electric Utility Planning

Optimal electrical dispatch scheduling, deciding power generation mix, optimum electricity supply planning are the applications of electric utility planning using multi criteria evaluations (Chattopadhyay and Ramanathan, 1998). Rahman and Frair (1984), Akash *et al* (1999) and Brar *et al* (2002) have applied hierarchical approach to electric utility planning considering different actors in energy management such as public, investors etc. The objectives of cost-benefits, adequacy of supply and alternative scenarios such as addition of generation capacity, supply side management and load management etc. have been discussed in the studies. Ramanathan and Ganesh (1995) have evaluated lighting energy alternatives in India against twelve objectives representing energy-economy-environment relationships using integrated goal programming followed by hierarchical evaluation. Environmental impacts of electric utilities have been analyzed using MAUT framework by McDaniels (1996). Expansion decisions of electric power systems have been attempted by Voropai and Ivanova (2002) based on the fundamental concepts of additive utility theory. Hobbs and Horn (1997) used a multi-method multi criteria evaluation to build public confidence in energy planning. The main reason for using these different multi criteria evaluation methods is that decision makers feel manipulated by a single multi criteria evaluation method. In order to eliminate this effect, it was suggested that each person should be allowed to use different multi criteria evaluation methods to build understanding. The result was that no single method was best for each person. The study stresses the use of multiple methods. Hierarchical and MAUT methods are used in this area of energy planning.

3.3.2.7. Other Areas

These methods are used for planning for climate change (Ramanathan, 1998; 1999). In addition to these several applications, desalination plant selection, solid waste management etc are addressed in a multi criteria context by various researchers.

Other application areas are impact analysis of energy alternatives (Siskos and Hubert, 1983; Tzeng *et al*, 1992), small hydro site selection (Mladineo *et al*, 1987 and building product designs (Teno and Marseschal, 1998). Hokkanen and

Salminen (1997) used an ELECTRE III decision-aid method to choose a waste management system in the Oulu region of Finland. ELECTRE III was selected as the decision aid mainly because the available environmental data tended to be as imprecise and incomplete to that they had collected in their own study. Lathrop and Watson (1982) used decision analysis, in order to evaluate risk and the construction of evaluation indices involving the regulation of nuclear waste management.

3.4. Review of Earlier Evaluations of Solar Cookers

Various studies have been reported in the literature on technical evaluations of different versions of solar cookers from time to time. A classical review of designs and their evaluations by Kundapur (1998) highlights more than 50 major designs with 59 types of variations. In past, Volunteers for Technical Assistance (VITA) brought out a very detailed review of solar cooker projects (VITA, 1961). Studies of solar cookers from various perspectives have been brought out by Garg (1978), Bowman and Blatt (1978) in the past. Harnessing solar, the primary source of energy had been a never ending illusion. The major classification of solar cookers suggested by the various authors is concentrating type, box type and indirect type. The best design is still elusive. The researchers have primarily concentrated on performance evaluations followed by cost-economic analyses.

The concentrating solar cooker had been the major focus of evaluators. A review of patents on solar concentrators by Imadojemu (1995) highlights a progress in the area of solar concentrators for various end uses including solar cooking. More than 60 concentrator designs have been patented worldwide. However, the most of the claims of efficiency have never been realized and numbers of commercially viable collectors are a few.

The first multi criteria evaluation attempt by VITA considered cooking performance, durability, cost, weight, portability, ease of operation, ease of manufacture etc as criteria for usefulness of various versions of solar cookers. Bowman and Blatt (1978) presented detailed review of the then available versions of solar cookers considering time of cooking, maximum temperature, energy storage, cooking capacity, versatility, cooking effectiveness, ease of use, ease of maintenance, durability, wind stability, portability, material cost, imported items, ease of manufacture and transportability. He however admitted that the parameters have Haitian bias and the weightages selected were arbitrary. The entire evaluation was based on weighted sums. The authors have also suggested that conventional devices like cook-stoves, LPG stoves should form a basis of comparison for solar cookers as well.

Technical evaluation of SBCs have been reported by many authors (Das *et al*, 1994; Buddhi and Sahoo, 1997; Funk and Larson, 1998; Nahar, 2003; Rao, 2003; Sonune and Philip, 2003). The criteria considered for these evaluations are stagnation temperature, water boiling/cooking time, efficiency, weight, heat storage capacity etc. The stress on standardization of performance evaluation was also felt by many researchers. The need of proper technical evaluation and reporting performance was fulfilled by Mullick *et al* (1991) and Funk (2000) where standard test procedures were developed and appropriately modified. Patel and Philip (2000) have studied three concentrating solar cookers using the standard testing procedures. The accuracy of focusing, convenience, type of dishes cooked, portability aspects of Philippine, Chinese and IME model has been discussed by the authors. The domestic model of

PSC discussed in the thesis was also tested as per standard procedures by many researchers across the country (Arya, 1999; McGiligan, 1999; Ramachandran and Vardhan, 1999; Saha *et al*, 1999; Shukla *et al*, 1999). Innovations in existing models of concentrating solar cookers have been reported by various researchers (Habeebullah *et al*, 1995; Sharma *et al*, 2000) by varying either of the above reported technical criteria.

The dissemination of solar cookers had been also an area of wide concern in most of the evaluations. Most of the studies reviewed earlier have discussed the usefulness of their suggested modifications with a few thoughts on diffusion of efficient solar cookers. The studies highlight possible causes of disuse of solar cookers by masses and suggest strategies to overcome the barriers of penetration at times. Many studies have been reported for Gujarat, (India) on the dissemination of solar cookers. Moulik (1985) and Sharan and Naik (1997) have studied the socio-economic factors necessary for dissemination of SBC in Gujarat. Ahmad (2000) has discussed the problem of users and disusers for solar cookers in urban India. He studied 28 families in urban Gujarat have to identify the problem of space, adjustment of daily routines etc. His study stresses the involvement of potential users in the project development process. He has explained cultural aspects associated with food, climatic issues, prices, quality and quantity, access to purchase and maintenance as major problems for cooker dissemination projects. The diagnostic analysis study of SBC in Gujarat has been attempted by Moorthy (1991). He has evaluated SBC programme of Gujarat Energy Development Agency (GEDA) on several aspects which include manufacturing, research and development target market etc. Another evaluation of SBC programme of GEDA by Mahajan (1991) highlights the disadvantages of urban bias of the programme and its failure to address rural masses.

He has suggested alternative marketing strategies with agricultural households as target market segment. Evaluation by Satia (1991) highlights long day periods and termed the solar cooker programme as a drop in the bucket. He has suggested future strategies for marketing. Joshi (1991) has given certain guidelines for promoting SBCs. She has stressed on product specifications, product relevance in the existing set up of cooking systems. Her study concludes with the need to improve the performance of the product and making it consumer oriented. Philip *et al* (1987) have studied the frequency of use of solar cookers and their role in fuel savings in Gujarat. They have also reported the frequency of occurrence of defects on SBCs. Quality of product and servicing of product have emerged as major findings of their study. Gore *et al* (1990) have studied the solar cookers in Pune (India) by taking samples from selected parts of the city. They have reported the use, disuse and problems of solar cookers. The quality of black coating on the utensils and bulk (size/weight) of product has been identified as major problems. Kumar *et al* (1997) have reported the acceptance in Delhi. Rana *et al* (1997) have reported the substitution potential for cooking and lighting in rural areas of Madhya Pradesh (India) and their life cycle costing. Jagadeesh (2000) has reported solar cookers dissemination in India as a behavioral problem. Though his study points our certain technical limitations his study concludes with solar cookers as 'technology push' type of device rather then 'demand pull' type of device. Saucer (2000) has also reported similar opinion about the solar cooker programme of India. Though solar cookers are best suitable for rural households, most of the dissemination had taken place in urban areas. He concludes his study highlighting limited potential of solar cookers. Quadir *et al* (1995) have studied the barriers for dissemination of renewable energy technologies in India. Their study classifies the barriers on technical, economic, institutional and socio-cultural aspects.

Studies on acceptance of SBCs have been reported by many homemakers. Acceptance studies in Kanpur, Trivandrum, Palakkad, Bhubaneshwar, and Agra have highlighted the features of solar box and concentrating solar cookers perceived by the homemakers of that locale (AIHSHEW, 1997). Usretey *et al* (1996) have investigated on the nutrient contents of cooked food in different cooking devices including biogas stoves, SBCs. The authors have suggested procedures for cooking food with minimum reduction in protein contents with solar cookers.

Grupp (1991) has discussed the experiences with solar cookers with a view to identify the lacunae in the management of technology. He has identified the need of adapting to natural and social environment, overcoming technical shortcomings of product; overcoming the poor quality and complicated use of the product. Wareham (1997) has highlighted the parameters for successful solar cooker programme. He has discussed quality, quantity, price, financing, manufacturing, transportation, user friendliness and government support as major parameters. Experiences in South Africa (Biermaann *et al*, 1999) and Nepal (Shreshtha, 1998) have recorded similar opinions.

3.5. Limitations of Earlier Evaluations of Solar Cookers and Need of Multi Criteria Evaluation of Solar Cookers

The literature review of multi criteria evaluations in energy planning and the earlier evaluations of solar cookers combined has put forth a few limitations and scope for further investigations. The major findings of the literature on both the issues are as follows.

1. The paradigm shift in energy planning procedures stresses on considerations of multiple criteria in renewable energy planning and dissemination involving various actors in decision process.
2. The studies on evaluations of solar cookers separately considering technical, economic criteria are reported but no comprehensive study is yet reported. The literature review of various evaluations of solar cookers signifies the role of multiple criteria in the evaluations.
3. The earlier studies on solar cookers on various issues viz. efficiency, costs, user perceptions, commercialization, have indicated that the dissemination strategies of solar cookers in present Indian context should not be considered in isolation but in contrast with the other cooking energy options available to the users.
4. The applicability of multi criteria evaluations have been proved in many energy planning domains but no study is reported for solar cooker evaluations in general and PSC in particular.
5. Though more than 60 designs of solar cookers have been patented, it is very difficult to profess on their commercialization. Very often costs are identified as the only barrier for diffusion of the technology which may not be true. Technical improvements in the device seem to be necessary but not sufficient for the successful commercialization.
6. Under the above circumstances, the government has to revisit renewable energy programmmes to overcome consumer's inertia and/or deliver optimal services which requires investigation. Such a kind of study may be helpful for formulating strategies for commercialization of PSC which has proved its techno -economic capabilities.

7. The present stalemate in disseminating the solar cooking technology may be due to its comprehensive usefulness. Thus a quantification of comprehensive usefulness of PSC may be helpful in knowing the *locus standi* of PSC on multiple criteria in the present Indian energy ladder.

The present research work pursues all the above issues with special reference to PSC as a domestic cooking device in India. The tools developed in this work may be useful for other renewable devices which are not disseminated to their fullest potential. The details of the methodology adopted for investigations are presented in the next chapter.

Chapter 4: Multi Criteria Evaluation Studies

This chapter explains the methodology adopted for multi criteria evaluation of PSC vis-à-vis other domestic cooking energy devices. Selection of criteria based on the earlier evaluations and selection of prevailing domestic cooking devices is discussed. A detailed discussion of the instrument adopted for knowing importance of criteria and comparison of devices is followed by analyses of responses, development of tools for data analysis and computation of weightages. Three multi criteria evaluation methods have been applied to evaluate and validate the results. The methodology adopted for the research is given in Figure 4.1.

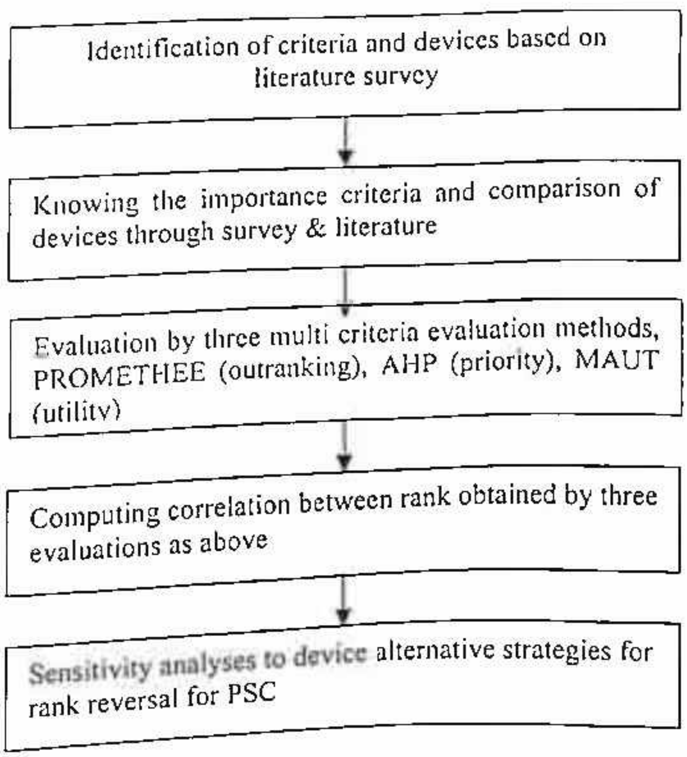


Figure 4.1 Methodology of the Present Work

4.1. Selection of Criteria

Though the better dissemination of PSC will conserve fuel-wood and help in protecting the environment, the objective of dissemination programme should address adequate energy supply to the households to satisfy their basic needs of cooking energy in a socially acceptable manner. This objective is governed by a wide variety of criteria. To comprehensively analyze PSC in the present Indian context the importance of each of the criterion should also be known. The identified devices can be compared on these criteria to deduce final rankings.

Considering the earlier evaluations carried out by various researchers, perceptions of actual users of PSC, various studies reported by homemakers in different parts of the country, a list of 55 criteria is prepared. It is also observed that the performance of a cooking device can be represented by grouping some of these criteria, eliminating some of them etc e.g. Stagnation temperature is an indicator of fuel consumption and cooking time. Quality of various spare parts, black paints; utensils are clubbed into quality and reliability of the product. Thirty criteria relevant to the present planning problem are selected after extensive discussions with the decision makers. The criteria consist of five main groups as technical, economic, social, behavioral and commercial.

4.1.1. Technical Criteria

Type of fuel, amount of fuel consumed and its availability primarily decide the selection of a cooking energy device. All these issues are associated with monthly fuel cost. Time required for cooking is also important in deciding the choice of device. Though slower cooking helps in retaining the nutrient content in the food, growing urban lifestyle and availability of time warrants faster cooking. All these criteria are desired to be minimized. The users also want durability of devices; higher quality/reliability and ruggedness due to its implications in minimizing the maintenance costs and requirement of spares and after sales service. Sophistication in terms of temperature control, heat storage facility etc. is also desirable. Even though seasonal independence and continuity of use is desirable for a device it may not be possible for SBC and PSC due to its dependence on sunshine requiring tracking as well as for biogas stoves due to scarcity of water in summer. Higher nutrition value of cooked is also desirable which may not be possible in micro-wave cooking technology (Nexusmagazine, 2003). Table 4.1a presents the definitions of identified technical criteria governing the comprehensive usefulness of any cooking device in general and PSC in particular.

Table 4.1a Definitions of Technical Criteria

Criteria No	*Criteria*	*Definitions*
CR 1.	Fuel consumption	Quantity of fuel consumed by the device in kg/person/ day as an indicator of efficiency
CR 2.	Cooking time	Time required cooking the food for a family of 4 persons
CR 3.	Durability	Maximum useful life of device considered
CR 4.	Quality/reliability	The quality of various spare parts used in the device as an indicator of consistent performance & reduced failures
CR 5.	Sophistication level	Facilities for heat rate control, storage, automation
CR 6.	Size/Weight	Overall bulk of the product as an indicator of portability
CR 7.	Ruggedness	Robustness of the device
CR 8.	Continuity of use	Seasonal dependence of the fuel-device combination throughout the year
CR 9.	Need for tracking	Need of focusing Sunrays, applicable to SBC& PSC only
CR 10.	Nutrition value of food	Level of nutrient content in the cooked food as a indicator of healthy cooking

4.1.2. Economic Criteria

These criteria are at the heart of any product selection by the user and cooking devices can not be away from the same. Lower initial cost helps in overcoming the inertia of purchase decision which must be supplemented lower fuel costs, lower maintenance costs etc. Lower rate of interests and easy availability of finance have proven its usefulness in automotive market and may be replicated in domestic sector as well. Higher subsidies desired by users, have resulted in poor quality of products and services very often. In addition to the above criteria burden on foreign exchange economy by the fuel is also given a thought which is analogues to available subsidy considered in the economic criteria. Table 4.1b presents the definitions of identified economic criteria governing the comprehensive usefulness in the present planning problem.

Table 4.1b Definitions of Economic Criteria

Criteria No	*Criteria*	*Definitions*
CR 11.	Initial cost	The price to be paid for purchase of the device in Rupees
CR 12.	Fuel cost per month	The price to be paid for purchasing fuel per month for a family of 4 persons in Rupees
CR 13.	Maintenance cost per year	Price to be paid per annum for minor repairs, servicing etc in Rupees
CR 14.	Available subsidy	Amount of discount/cost bared by the government on actual cost of the device
CR 15.	Rate of interest on loan	Rate of interest on loan for purchase of device towards a bank/ finance agency if any

4.1.3. Social/ Environmental Criteria

With an increasing population and higher rate of deforestation, the fuel-wood resource has become scarce. The utilization of other biomass fuels lead to higher emissions. Lower emissions by fuel burning/utilization, lower human drudgery in fuel collection and utilization and higher overall safety are essential social issues in cooking energy selection. Table 4.1c presents the definitions of identified social and environmental criteria applicable to the problem under study.

Table 4.1c Definitions of Social /Environmental Criteria

Criteria No	*Criteria*	*Definitions*
CR 16.	Pollution hazards	Environmental degradation in actual usage of the fuel-device combination
CR 17.	Human drudgery	Amount of human efforts to be in fuel collection and its usage
CR 18.	Overall safety	Level of safety in handling fuel-device combination in terms of fire, lost education opportunities etc.

4.1.4. Behavioral Criteria

It is also observed that better aesthetics, improvement in models, better after sales service motivate the users. The selection of a device may also be decided by type and taste of cooked food, cleanliness of utensils etc. Convenience leading to ease of operation, lower dependence on additional cooking system and lesser user training may also be considered for evaluation. Table 4.1d presents the definitions of identified behavioral criteria which need to be addressed to for quantifying the preference of cooking devices.

Table 4.1d Definitions of Behavioral Criteria

Criteria No	*Criteria*	*Definitions*
CR 19.	Aesthetics	Looks of the device as an indicator of users preferred choice
CR 20.	Motivation to buy	The level of inner urge to use the device, may be as a status symbol, gifted article etc.

Criteria No	Criteria	Definitions
CR 21.	Taste of food	Liking of food cooked by user
CR 22.	Cleanliness of utensils	Level of efforts required in cleaning the utensils as an indicator of convenience
CR 23.	Ease of operation	Convenience of handling the device as a indicator of its user friendliness
CR 24.	Type of dishes cooked	The level of meeting diverse cooking needs of a family
CR 25.	Need for additional cooking system	Indicator of self sufficiency of the device in meeting entire cooking needs

4.1.5. Commercial Criteria

The user can be motivated to purchase with a wide product range, good after sales service with better market/service network. Market research helps in modifying the products suitable to end user and need of user training is reduced at times. Sales promotion, buyer behavior, market segmentation and positioning of the product are considered as a part of market research. In literature, a few more issues like impact on related industries by certain fuel-device combinations have been given a thought which are not considered in the present study. Table 4.1e discusses the commercial aspects governing the choice of any cooking devices.

Table 4.1e Definitions of Commercial Criteria

Criteria No	Criteria	Definitions
CR 26.	Improvement in models	Product range available in the market
CR 27.	Spares and after sales service	Kind of after sales service available for the device, availability of spare parts
CR 28.	Distribution network	Availability of device in a retail outlet
CR 29.	Market research	Weather or not the needs of end users considered by the device manufacturers
CR 30.	Need for user training	The level of user friendliness of the device

In the exercise of quantifying the preference of cooking energy device, some of the above criteria are desired to be maximized, i.e. the maximum value of these criteria is desirable. Also, some of the above criteria are desired to be minimized, Table 4.2a gives the classification of criteria on maximization and minimization type at a glance. In the present study, available subsidy is considered as maximization criteria as desired by the users and discussed in the economic criteria.

Table 4.2a Maximization and Minimization Criteria

Maximization Criteria	*Minimization Criteria*
CR 3 Durability	CR 1 Fuel consumption
CR 4 Quality, reliability	CR 2 Cooking time
CR 5 Sophistication level	CR 6 Size/Weight
CR 7 Ruggedness	CR 9 Need for tracking
CR 8 Continuity of use	CR 11 Initial cost
CR 10 Nutrition value of food	CR 12 Fuel cost per month
CR 14 Available subsidy	CR 13 Maintenance cost per year
CR 18 Overall safety	CR 15 Rate of interest on loan
CR 19 Aesthetics	CR 16 Pollution hazards
CR 20 Motivation to buy	CR 17 Human drudgery
CR 24 Taste of food	CR 25 Need for additional cooking system
CR 22 Cleanliness of utensils	CR 30 Need for user training
CR 23 Ease of operation	
CR 24 Type of dishes cooked	
CR 26 Improvement in models	
CR 27 Spares and after sales service	
CR 28 Distribution network	
CR 29 Market research	

Table 4.2a indicates 18 maximization criteria and 12 minimization criteria. Higher quality and reliability of device may lead to higher durability and robustness, nutritional values and continuity of use will increase the use patterns and will reduce need of additional cooking systems. Most of the behavioral criteria are maximization type. The economic criteria are minimization type except a few. The social issues except safety are minimization type of criteria. The usefulness of cooking energy devices thus is a maximization problem in terms of operations research.

There are a large numbers of behavioral issues involved in the preference of cooking energy devices which are qualitative in nature. Table 4.2b gives a comparison of quantitative and qualitative criteria in the present planning problem.

Table 4.2b Quantitative and Qualitative Criteria

Quantitative Criteria	*Qualitative Criteria*
CR 1 Fuel consumption	CR 4 Quality /Reliability
CR 2 Cooking time	CR 5 Sophistication level
CR 3 Durability	CR 7 Ruggedness
CR 6 Size/Weight	CR 8 Continuity of use
CR 11 Initial cost	CR 10 Nutrition value of food
CR 12 Fuel cost per month	CR 9 Need for tracking
CR 13 Maintenance cost per year	CR 16 Pollution hazards
CR 14 Available subsidy	CR 17 Human drudgery
CR 15 Rate of interest on loan	CR 18 Overall safety
	CR 19 Aesthetics
	CR 20 Motivation to buy
	CR 21 Taste of food
	CR 22 Cleanliness of utensils
	CR 23 Ease of operation

Quantitative Criteria	*Qualitative Criteria*
	CR 24 Type of dishes cooked
	CR 25 Need for additional cooking system
	CR 26 Improvement in models
	CR 27 Spares and after sales service
	CR 28 Distribution network
	CR 29 Market research
	CR 30 Need for user training

Table 4.2b indicates that the cooking device preference is a basic socio-economic planning issue and thus involves many qualitative criteria. Twenty one criteria in the pool of 30 criteria are found to be qualitative in nature.

Table 4.2c presents the summary of significant criteria in multi criteria evaluation of a cooking device.

Table 4.2c Significant Criteria in Cooking Energy Decisions

Name of Criteria	*Desired Value*	*Significance*
Fuel Consumption*	Low	Reduced cost , Reduced fuel collection time
Maximum Temperature*	High	Reduced Cooking Time
Cooking Time*	Low	Higher efficiency, More convenience, Lower nutrient value
Durability/Ruggedness	High	Reduced costs, Higher reliability , Lower maintenance
Quality/Reliability	High	Increased suitability, Lower maintenance
Heat rate control, Storage	High	Added sophistication
Need of Tracking	Low	Only for solar cookers, Higher Efficiency, Reduced cooking time
Seasonal Independence	High	Reduced need of additional system, More continence
Initial, Fuel & Maintenance	Low	Easy commercialization,

Name of Criteria	*Desired Value*	*Significance*
Costs*		Increased Reliability, Convenience
Available subsidy *	High	Reduced quality, Easy commercialization
Availability of Finance *	High	Easy commercialization
Pollution Hazards, Safety	Low	Increased social utility
Human Drudgery	Low	Convenience, Increased productive time for earning for family, education etc
Aesthetics	High	Increased commercialization, Higher motivation
Improvement in models	High	Commercialization, Convenience, Higher motivation
After Sales Service	High	Increased reliability, Commercialization
Type of Dishes Cooked	High	Versatile cooking, Convenience, Higher motivation to use
Cleanliness of Utensils	High	Versatile cooking, Convenience, Higher motivation to use
Need of Additional Cooking System	Low	Convenience, Reduced Costs, Increased Reliability
User Training	Low	Convenience, Higher motivation to use

* Quantitative Criteria

4.2. Selection of Devices

Since cooking is carried out by using both renewable and non-renewable fuels a large variety of fuel-device combinations are available in India. Out of the all available devices nine prevailing devices representative of cooking energy utilization in India are selected for the present problem. These devices are numbered as A1 to A9. The devices identified are *chulha* (cook stove, (A1)), improved *chulha* (A2), Kerosene stove (A3), Biogas stove (A4), LPG stove (A5), Microwave oven (A6), Electric oven (hot plate (A7)), SBC (A8) and PSC (A9).

The cooking energy scenario discussing the dissemination of these devices has been presented in Chapter 2 (Cooking Energy Issues in India). Further, kerosene stove considered in the evaluation is kerosene pressure stove as an indicator of the category of stoves using kerosene. Though various versions of improved *chulhas* are available the device considered for evaluation is an indicator the category of stoves using fuel-wood more efficiently. Box solar cooker considered for evaluation is a device without electrical back up.

4.3. Details of Survey

The present evaluation consists of nine quantitative and twenty one qualitative criteria as discussed in the previous section. The data for quantitative criteria has been taken secondary source mainly through published literature. No experimentation is conducted for noting the data on quantitative criteria for various cooking energy devices. Since majority of the criteria are qualitative the evaluation on these criteria is planned to be identified through a survey. The overall objective of the survey is to know priorities in the preference selection of cooking energy devices. The sub-objectives of survey are as follows.

i. To know the importance of all the identified criteria for different decision making groups involved in the technology dissemination

ii. To compare the devices on identified criteria

iii. To identify the barriers for further dissemination of PSC

To facilitate the evaluation four expert groups are identified and more than 100 of experts are consulted to know their perceptions. The identified groups are policy makers/professionals, researchers, educators and actual users. Policy makers/professionals refer to the officers of MNES, SNAs and manufacturers. A group of researchers as facilitators for technology up-gradation is also identified to know their perceptions. Educators are consulted considering their role as awareness creators. Actual users of the identified devices in general and PSC in particular are consulted to know their perceptions.

Separate response sheets are designed for knowing the importance of all the identified criteria for different decision making groups involved in the technology dissemination and comparing the devices on identified criteria as given in Appendix II and III respectively. Since the aim is to know importance of criteria in assessing contemporary cooking devices on 30 criteria a response sheet based on tabular column is felt appropriate. Two tabular columns are designed, one to know the importance of criteria and the other to know the comparison of cooking devices. Both the response sheets are tested with trial runs involving the faculty members /research scholars at the Institute and actual users of SBC and PSC in and around the Institute. The main aim is to receive feedback regarding the appropriateness of the information sought in the prescribed format. The changes based on suggestions from the in-house respondents are incorporated in the final response sheets. The response sheets are having two sections and an explanatory note. First part of the sheet is intended to get information on the respondents like name, designation and address; the second is to record their judgments.

The survey was conducted during January-May 2002. The response sheets were mailed through post/e-mail to identified experts. Personal interviews and discussions were also conducted with a few of them. Actual users are consulted for knowing their perceptions on various qualitative criteria in the vicinity of Pilani (Rajasthan), Valsad (Gujarat), Pune (Maharashtra), Nasik (Maharashtra), Indore

(Madhya Pradesh), Mount Abu (Rajasthan), Coimbatore (Tamil Nadu) etc. The survey is based on convenient sampling technique. Appendix IV gives list of respondents/experts which are consulted for the data collection. The details of respondents are given in Table 4.3.

Table 4.3 Analysis of Responses

Group	*Requests sent*	*Responses received*	*Suitable responses*
Professionals	25	14 (56%)	12 (48%)
Researchers	25	13 (52%)	10 (40 %)
Educators	35	18 (51%)	15 (43%)
Actual Users	50	35 (70%)	29 (58%)
Total	**135**	**80 (60 %)**	**66 (49 %)**

The experts are asked to assign importance of the criterion on a 10 point qualitative linear scale as given in Table 4.4. The same scale is used for comparing the identified devices on qualitative criteria in the present problem. The values for quantitative criteria required for comparing the devices are noted from secondary source (published literature) as mentioned earlier.

Table 4.4 Scale used for Comparative Judgments

Legend	*Verbal Term*	*Numerical Value*	*Explanation*
VH	Very High	10	Highest level of judgment
H	High	08	Dominance of the judgment
M	Medium	06	Compromising level of judgment
L	Low	04	Lower level of judgment
VL	Very Low	02	Peripheral level of judgment
NA	Not Applicable	00	Not applicable to present problem

4.4. Computation of Weightages

Weighted average values have been computed for importance of criterion on 10 point scale. Custom built software interface is developed in Visual Basic environment to compute weightages. The weighted average values are calculated as below.

$$Weightage = \frac{\sum W_j N_j}{N} \quad (1)$$

Where W_j indicates the importance of j^{th} criteria (on assigned scale) by the numbers of respondents N_j for the criteria and N are the total numbers of respondents. Figure 4.2 shows the visual interface for data entry for the said program.

Figure 4.2 Interface for Data Entry for Computation of Weightages

The need of changing scale and continuous updating of responses received is also addressed in the program. The program uses Microsoft Access at the backhand for storage and computation of weightages. Figure 4.3 shows the interface for updating the computations of weightages. Graphical output facility is also felt necessary to get deeper understanding of weightage vectors as shown in Figure 4.4.

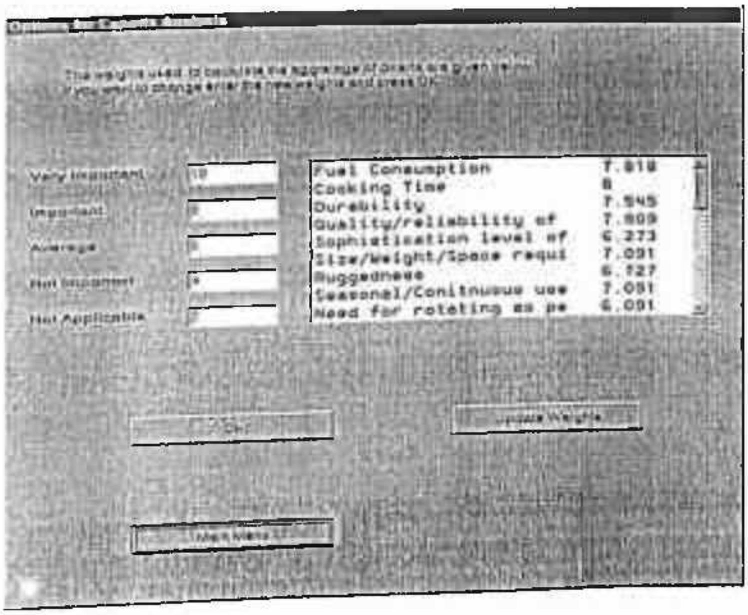


Figure 4.3 Interface Showing Computations of Weightages

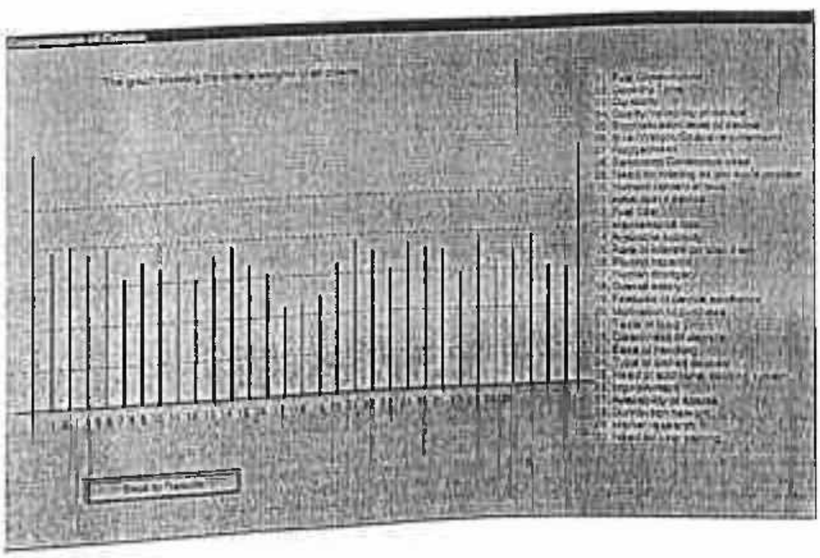


Figure 4.4 Graphical Outputs of Weight Vectors

The assigned weightages for various groups identified for the present problem are computed using the software. Table 4.5 shows the sub-criteria weightages calculated for different decision making groups.

Table 4.5 Computed Sub Criteria Weightages for Different Groups

Sub Criteria	*Policy Makers*	*Researchers*	*Educators*	*Users*	*Overall*
CR 1.	8.75	8.00	6.53	6.00	7.09
CR 2.	8.25	10.00	7.46	6.66	7.67
CR 3.	7.75	7.00	7.37	8.66	7.93
CR 4.	6.75	7.00	7.85	8.66	7.54
CR 5.	6.50	5.00	6.14	7.66	6.51
CR 6.	7.00	9.00	7.06	6.00	6.64
CR 7.	6.00	7.00	7.20	4.00	6.19
CR 8.	7.00	5.00	7.20	6.33	6.70
CR 9.	6.50	4.00	6.15	4.33	6.51
CR 10.	6.00	8.00	7.60	8.66	7.41
Average	**7.05**	**7.00**	**7.05**	**6.99**	**7.01**
CR 11.	7.50	7.00	7.46	7.33	7.41
CR 12.	7.40	7.00	5.85	3.66	5.86
CR 13.	6.25	6.00	5.60	3.33	5.48
CR 14.	4.57	5.00	4.42	7.33	5.03
CR 15.	4.50	7.00	4.25	5.33	4.60
Average	**6.04**	**6.40**	**5.51**	**5.39**	**5.67**
CR 16.	5.42	4.00	4.40	5.33	4.33
CR 17.	6.75	8.00	6.42	5.33	5.90
CR 18.	7.25	9.00	7.33	9.00	8.66
Average	**6.47**	**7.00**	**6.05**	**6.55**	**6.29**
CR 19.	7.25	7.00	7.33	7.00	6.96
CR 20.	6.66	5.00	6.42	6.00	6.27
CR 21.	6.75	8.00	8.00	8.00	7.61
CR 22.	6.75	9.00	7.33	7.66	7.35
CR 23.	8.50	8.00	7.20	8.00	7.74
CR 24.	5.25	6.00	6.71	6.66	6.64
CR 25.	6.25	6.00	6.13	6.00	6.12
Average	**6.77**	**7.00**	**7.07**	**7.04**	**6.95**
CR 26.	6.75	7.00	6.60	7.30	6.83
CR 27.	8.50	7.00	6.42	6.33	7.03
CR 28.	8.00	6.00	7.33	5.66	7.09
CR 29.	6.25	5.00	6.00	6.00	6.29
CR 30.	6.25	7.00	6.42	6.66	6.46
Average	**7.15**	**6.40**	**6.55**	**6.39**	**6.74**

Analysis of overall weightages shows that usefulness of the selected cooking energy devices are governed by technical (7.01) followed by behavioral (6.95), commercial (6.74) and social issues (6.29). It is also observed that economic criteria have been given less weightages (5.67) by the evaluators. Analysis of weightages reveal that overall safety (8.66), durability (7.93) and ease of operations (7.74) are given due importance by the respondents. The rate of interest on loan (4.60) has been allocated the least weightage. The respondents have neither given too high importance to any of the criterion nor have they out rightly considered any criterion trivial in the analysis. The total differential in the weightages accounts to be 3.33. Moreover, all the groups have highest weightage to technical and least weightage to social criteria. The sub criteria weightages are normalized for further computation for priorities. Table 4.6 shows the normalized sub criteria weightages.

Table 4.6 Normalized Sub Criteria Weightages for Different Groups

Sub Criteria	*Policy Makers*	*Researchers*	*Educators*	*Users*	*Overall*
CR 1.	0.0429	0.0394	0.0331	0.0308	0.0355
CR 2.	0.0408	0.0488	0.0377	0.0341	0.0384
CR 3.	0.0382	0.0343	0.0373	0.0444	0.0397
CR 4.	0.0320	0.0340	0.0395	0.0443	0.0376
CR 5.	0.0320	0.0245	0.0311	0.0393	0.0326
CR 6.	0.0345	0.0441	0.0358	0.0308	0.0332
CR 7.	0.0295	0.0343	0.0365	0.0205	0.0310
CR 8.	0.0345	0.0245	0.0365	0.0325	0.0335
CR 9.	0.0320	0.0196	0.0311	0.0222	0.0326
CR 10.	0.0295	0.0392	0.0385	0.0444	0.0371
CR 11.	0.0369	0.0343	0.0378	0.0376	0.0371
CR 12.	0.0364	0.0343	0.0296	0.0188	0.0293
CR 13.	0.0308	0.0294	0.0284	0.0171	0.0274
CR 14.	0.0225	0.0245	0.0224	0.0376	0.0252
CR 15.	0.0222	0.0343	0.0215	0.0274	0.0230
CR 16.	0.0267	0.0196	0.0223	0.0274	0.0217
CR 17.	0.0332	0.0392	0.0325	0.0274	0.0296
CR 18.	0.0357	0.0441	0.0371	0.0462	0.0433
CR 19.	0.0357	0.0343	0.0371	0.0359	0.0348

Sub Criteria	*Policy Makers*	*Researchers*	*Educators*	*Users*	*Overall*
CR 20.	0.0328	0.0245	0.0325	0.0308	0.0314
CR 21.	0.0332	0.0392	0.0405	0.0411	0.0381
CR 22.	0.0332	0.0441	0.0371	0.0393	0.0368
CR 23.	0.0419	0.0392	0.0365	0.0411	0.0387
CR 24.	0.0259	0.0294	0.0304	0.0342	0.0332
CR 25.	0.0308	0.0294	0.0311	0.0308	0.0306
CR 26.	0.0332	0.0343	0.0337	0.0376	0.0342
CR 27.	0.0419	0.0343	0.0325	0.0325	0.0352
CR 28.	0.0394	0.0294	0.0371	0.0290	0.0355
CR 29.	0.0308	0.0245	0.0304	0.0308	0.0315
CR 30.	0.0308	0.0343	0.0325	0.0342	0.0323

The aggregate normal weightages are calculated for main criteria. Table 4.7 shows the aggregate normal weightages calculated for main criteria which are computed for further analysis of the problem.

Table 4.7 Normalized Weightages for Main Criteria

Criteria	*Policy Makers*	*Researchers*	*Educators*	*Users*	*Overall*
Technical	0.346	0.342	0.357	0.343	0.352
Economic	0.149	0.157	0.140	0.138	0.141
Social	0.096	0.103	0.092	0.137	0.095
Behavioral	0.233	0.240	0.245	0.253	0.246
Commercial	0.176	0.157	0.166	0.164	0.167

Analysis of normalized main criteria weightages shows that usefulness of the selected cooking energy devices are governed by technical criteria (0.352). All the respondent groups have assigned highest weightage to these criteria. The second level of important criteria is evident as behavioral ones (0.246). All the respondent groups have weighed the criteria next to technical. The commercial criteria are found to be occupying the third level of importance (0.167) which is evident from the consistent responses. The economic issues are given fairly less importance (0.141) followed by the social issues (0.095). The importance of social issue clearly indicates the lower level awareness.

4.5. Evaluation by Outranking (PROMETHEE)

There are many methods such as PROMETHEE, ELECTRE etc. belonging to outranking category of multi criteria evaluations as discussed in the earlier chapter on literature survey. Preference Ranking Organization METHod for Enrichment Evaluation has been used to rank the devices in this section. This methodology is known as the one of the most efficient methodologies in the field of multi criteria evaluations. The PROMETHEE framework has been used for energy planning (Harlambopoulos and Polatidis 2003; Goumas *et al*, 1999; Georgopoulou *et al*, 2003) as discussed in the literature review. This technique has all the advantages of the outranking methods, combined with ease of use and decreased complexity. It performs a pair-wise comparison of devices with respect to a number of criteria. It allows the establishment of a pay-off matrix for evaluation of devices with respect to any criterion through objective assessment and considers the degree of cognition.

The analysis has been carried out on the basis of pay-off matrices constructed for all the decision making groups and an overall pay-off matrix. This algorithm attempts to find the relative strengths of one device over all the other devices. It computes MCPI which indicates aggregate strengths of the device over its weaknesses.

4.5.1. Formulation of Pay-off Matrices

For enabling the formulation of pay-off matrices, evaluation matrices are formulated for all the decision making groups on the basis of the judgments noted as discussed in the details of survey. This matrix is useful for comparing the performance of various devices on the selected criteria. Evaluation matrix is an array indicating the performance of a particular device against all the criteria on selected scale. The pay-off matrix indicates the trade off values of all the identified devices on the selected criteria in a tabular form. Table 4.8 a shows the overall payoff matrix, which is an arithmetic mean of all the individual matrices of all respondents. Tables 4.8b to 4.8e indicate the pay-off matrices and Table 4.8 f shows standard deviation for all the decision making groups.

Since biogas stove, SBC and PSC are dependent on renewable energy, fuel consumption and fuel costs are taken as zero. On the other hand, need for tracking is assigned zero value in all the pay-off matrices for all other devices except SBC and PSC, as energy input for cooking with these devices is independent of the Sun's position. Many of the identified devices are not given any subsidy as they require less capital investments. The criteria like fuel consumption, cooking time, size/weight/space needs, various costs involved, pollution hazards, human drudgery and need for additional cooking system are desired to be minimized and are indicated by negative sign in all the pay-off matrices. Thus the problem is converted into maximization problem. The pay-off values are indicating quantity of fuel consumption per family per day, cooking time in seconds, durability in years, various costs in Rupees. Size/weight/space need is indicating the overall bulk in kilograms whereas rate of interest on loan is indicated in percent.

Table 4.8a Overall Payoff Matrix

Devices *CR No*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	-2.000	-1.000	-0.500	0.000	-0.250	-2.000	-2.000	0.000	0.000
CR 2.	-60.000	-60.000	-30.000	-15.000	-15.000	-5.000	-30.000	-180.000	-20.000
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000
CR 4.	5.150	5.642	5.992	5.958	8.158	8.042	7.758	5.633	6.042
CR 5.	2.808	3.875	4.500	5.908	7.817	9.042	8.517	5.433	5.942
CR 6.	-2.000	-1.000	-2.000	-50.000	-10.000	-5.000	-3.000	-5.000	-15.000
CR 7.	7.542	7.333	7.308	6.617	7.325	6.617	5.958	5.708	5.467
CR 8.	-4.617	-4.717	-4.617	-4.850	-4.592	-5.058	-5.058	-6.625	-6.592
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-7.633	-9.075
CR 10.	4.650	4.817	4.917	5.667	6.050	6.292	6.167	8.492	8.367
CR 11.	-10.000	-50.000	-200.000	-5000.000	-4000.000	-8000.000	-5000.000	-2000.000	-7000.000
CR 12.	-20.000	-10.000	-100.000	0.000	-250.000	-200.000	-400.000	0.000	0.000
CR 13.	0.000	0.000	-50.000	-200.000	-50.000	-200.000	-200.000	-50.000	-20.000
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000
CR 15.	0.000	0.000	0.000	0.000	-13.000	-13.000	-13.000	-3.000	-3.000
CR 16.	-7.492	-6.167	-6.758	-4.675	-4.717	-3.475	-3.267	-1.850	-1.767
CR 17.	-7.350	-6.608	-5.683	-5.308	-3.592	-3.042	-2.958	-3.750	-3.742
CR 18.	5.175	5.708	4.542	5.967	5.350	5.917	5.475	8.383	8.125
CR 19.	3.292	3.983	6.175	5.400	7.025	8.600	8.167	6.508	6.075

Devices CR No	*A1*	*A2*	*A3*	*A4*
CR 20.	4.383	4.775	5.767	5.483
CR 21.	6.250	6.417	5.492	6.500
CR 22.	2.975	3.850	4.167	5.400
CR 23.	5.475	5.508	6.242	6.408
CR 24.	8.017	8.200	7.942	8.025
CR 25.	-3.683	-3.517	-3.767	-3.708
CR 26.	4.350	5.150	5.392	5.817
CR 27.	6.733	6.250	6.683	6.108
CR 28.	6.217	5.717	7.283	5.542
CR 29.	3.475	3.950	5.317	5.308
CR 30.	-2.550	-3.683	-3.283	-4.325

A5	A6	A7	A8	A9
7.325	6.625	5.750	5.050	5.050
7.142	6.975	6.975	8.067	8.067
7.258	8.858	8.633	8.117	7.992
7.883	7.883	7.317	6.333	5.775
8.783	7.083	7.050	5.167	5.742
-3.058	-4.133	-3.833	-5.983	-5.625
5.908	6.108	5.683	5.267	5.117
7.208	7.008	6.900	5.058	5.167
8.083	6.933	7.117	5.067	4.575
6.958	6.625	7.042	5.858	5.800
-3.258	-5.525	-5.883	-6.617	-7.458

Table 4.8b Payoff Matrix for Policy Makers

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	-2.000	-1.000	-0.500	0.000	-0.250	-2.000	-2.000	0.000	0.000
CR 2.	-60.000	-60.000	-30.000	-15.000	-15.000	-5.000	-30.000	-180.000	-20.000
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000
CR 4.	6.000	6.500	7.500	7.500	8.500	8.500	7.500	4.000	4.500
CR 5.	2.500	3.500	4.000	5.500	8.000	9.500	9.000	5.000	5.500
CR 6.	-2.000	-1.000	-2.000	-50.000	-10.000	-5.000	-3.000	-5.000	-15.000
CR 7.	7.500	7.000	6.500	6.000	8.500	8.000	7.500	5.500	5.000
CR 8.	-3.000	-3.000	-3.000	-4.000	-2.500	-3.500	-3.500	-8.500	-8.500
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-8.000	-8.500
CR 10.	5.000	5.000	5.000	5.000	6.000	5.500	5.000	9.500	9.000
CR 11.	-10.000	-50.000	-200.000	-5,000.000	-4,000.000	-8,000.000	-5,000.000	-2,000.000	-7,000.000
CR 12.	-20.000	-10.000	-100.000	0.000	-250.000	-200.000	-400.000	0.000	0.000
CR 13.	0.000	0.000	-50.000	-200.000	-50.000	-200.000	-200.000	-50.000	-20.000
CR 14.	0.000	50.000	0.000	2,000.000	0.000	0.000	0.000	500.000	2,000.000
CR 15.	0.000	0.000	0.000	0.000	-13.000	-13.000	-13.000	-3.000	-3.000
CR 16.	-8.500	-7.000	-6.500	-5.500	-5.000	-3.500	-3.000	-2.000	-2.000
CR 17.	-9.000	-7.500	-5.000	-4.500	-2.500	-2.500	-2.500	-5.000	-4.500

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 18.	5.500	6.500	5.500	5.000	7.000	7.000	4.500	8.000	7.500
CR 19.	2.500	3.000	9.500	5.000	6.500	10.000	9.000	5.500	4.500
CR 20.	2.000	2.500	6.000	5.000	9.500	7.500	4.000	3.000	3.000
CR 21.	8.000	8.000	5.500	6.000	6.500	5.500	5.500	9.000	9.000
CR 22.	2.500	3.000	5.000	5.000	8.500	9.500	9.000	8.000	7.500
CR 23.	4.500	4.500	6.500	6.500	9.000	10.000	9.000	4.000	3.500
CR 24.	8.000	8.000	8.500	9.500	10.000	7.000	7.000	4.000	5.500
CR 25.	-3.000	-3.000	-3.000	-2.500	-4.500	-5.000	-5.000	-6.000	-6.500
CR 26.	5.000	6.000	6.500	6.000	6.500	5.500	5.000	5.000	5.000
CR 27.	8.000	7.000	7.000	6.500	6.500	6.500	6.000	3.500	4.000
CR 28.	7.000	7.000	7.000	5.500	8.000	8.000	8.000	5.000	4.500
CR 29.	2.500	4.000	6.000	4.500	7.500	6.500	6.500	4.500	4.000
CR 30.	-2.000	-3.000	-3.000	-3.500	-2.500	-5.500	-6.000	-7.000	-8.500

Table 4.8c Payoff Matrix for Researchers

Devices *CR No*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	-2.000	-1.000	-0.500	0.000	-0.250	-2.000	-2.000	0.000	0.000
CR 2.	-60.000	-60.000	-30.000	-15.000	-15.000	-5.000	-30.000	-180.000	-20.000
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000
CR 4.	6.400	6.400	7.200	6.000	8.400	8.000	8.000	4.800	6.000
CR 5.	4.000	4.400	6.000	6.400	7.600	8.400	8.800	4.800	6.000
CR 6.	-2.000	-1.000	-2.000	-50.000	-10.000	-5.000	-3.000	-5.000	-15.000
CR 7.	6.000	6.000	7.200	6.000	7.200	6.400	6.400	5.200	5.600
CR 8.	-6.000	-6.000	-6.400	-4.800	-6.800	-6.800	-6.800	-5.200	-4.800
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-6.400	-9.200
CR 10.	5.200	5.200	5.200	6.400	5.600	5.200	5.200	7.600	8.000
CR 11.	-10.000	-50.000	-200.000	-5000.000	-4000.000	-8000.000	-5000.000	-2000.000	-7000.000
CR 12.	-20.000	-10.000	-100.000	0.000	-250.000	-200.000	-400.000	0.000	0.000
CR 13.	0.000	0.000	-50.000	-200.000	-50.000	-200.000	-200.000	-50.000	-20.000
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000
CR 15.	0.000	0.000	0.000	0.000	-13.000	-13.000	-13.000	-3.000	-3.000
CR 16.	-8.000	-6.000	-8.000	-4.400	-6.000	-4.800	-4.400	-2.800	-2.800
CR 17.	-7.600	-7.200	-6.400	-6.000	-5.600	-5.200	-5.200	-4.400	-4.800

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 18.	5.600	6.000	4.800	7.200	4.800	4.800	4.800	8.800	8.000
CR 19.	4.000	5.200	5.600	5.600	7.200	7.600	8.000	5.600	5.600
CR 20.	5.200	5.600	6.400	5.600	6.800	6.000	6.000	5.200	5.200
CR 21.	6.000	6.000	5.600	7.600	6.800	6.400	6.400	7.600	7.600
CR 22.	3.600	4.800	5.200	6.800	6.800	8.800	8.800	8.800	8.800
CR 23.	6.000	6.800	6.000	7.200	7.200	6.400	6.400	6.400	5.600
CR 24.	8.400	8.400	8.400	8.000	8.800	6.800	7.200	5.600	6.000
CR 25.	-4.000	-4.000	-4.400	-4.800	-3.600	-5.600	-5.200	-7.600	-7.200
CR 26.	4.800	4.800	4.400	4.800	4.000	4.400	4.400	6.800	6.800
CR 27.	6.800	6.800	7.600	6.400	8.000	7.200	8.000	6.000	5.600
CR 28.	5.200	4.400	7.600	5.600	8.800	7.200	8.000	4.000	3.600
CR 29.	4.400	4.400	5.600	6.000	6.000	6.000	6.000	5.200	4.800
CR 30.	-4.400	-6.400	-5.200	-6.400	-5.200	-6.800	-7.200	-7.600	-8.400

Table 4.8d Payoff Matrix for Educators

Devices *CR No*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	-2.000	-1.000	-0.500	0.000	-0.250	-2.000	-2.000	0.000	0.000
CR 2.	-60.000	-60.000	-30.000	-15.000	-15.000	-5.000	-30.000	-180.000	-20.000
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000
CR 4.	5.200	6.000	5.600	6.000	8.400	8.000	7.200	6.400	6.000
CR 5.	2.400	3.600	4.000	6.400	8.000	9.600	7.600	5.600	5.600
CR 6.	-2.000	-1.000	-2.000	-50.000	-10.000	-5.000	-3.000	-5.000	-15.000
CR 7.	8.000	8.000	7.200	6.800	7.600	6.400	5.600	6.800	5.600
CR 8.	-6.800	-7.200	-6.400	-5.600	-6.400	-5.600	-5.600	-6.800	-6.400
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-8.800	-9.600
CR 10.	4.400	4.400	4.800	5.600	5.600	6.800	6.800	9.200	8.800
CR 11.	-10.000	-50.000	-200.000	-5000.000	-4000.000	-8000.000	-5000.000	-2000.000	-7000.000
CR 12.	-20.000	-10.000	-100.000	0.000	-250.000	-200.000	-400.000	0.000	0.000
CR 13.	0.000	0.000	-50.000	-200.000	-50.000	-200.000	-200.000	-50.000	-20.000
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000
CR 15.	0.000	0.000	0.000	0.000	-13.000	-13.000	-13.000	-3.000	-3.000
CR 16.	-4.800	-4.000	-5.200	-2.800	-3.200	-1.600	-2.000	0.400	0.400
CR 17.	-4.800	-4.400	-4.000	-4.400	-1.600	-0.800	-0.800	-1.600	-2.000

Devices CR No	*A1*	*A2*	*A3*	*A4*
CR 18.	5.600	6.000	3.200	6.000
CR 19.	4.000	4.400	5.600	6.000
CR 20.	6.000	6.000	6.000	6.000
CR 21.	6.000	6.000	5.200	6.400
CR 22.	2.800	3.600	2.800	4.800
CR 23.	4.400	4.400	4.800	5.600
CR 24.	8.000	8.400	7.200	7.600
CR 25.	-2.400	-2.400	-2.000	-3.200
CR 26.	3.600	4.800	6.000	6.800
CR 27.	6.800	7.200	6.800	7.200
CR 28.	8.000	6.800	9.200	6.400
CR 29.	4.000	4.400	6.000	6.400
CR 30.	-0.800	-2.000	-1.600	-2.400

A5	*A6*	*A7*	*A8*	*A9*
3.600	5.200	5.600	8.400	8.000
8.400	8.800	8.000	7.600	7.200
6.000	6.000	6.000	6.000	6.000
7.600	8.000	8.000	8.000	8.000
6.400	8.800	8.400	8.000	8.000
8.000	8.800	7.200	7.600	6.000
8.000	7.200	6.000	4.400	4.800
-0.800	-3.600	-2.800	-6.000	-4.800
6.800	7.200	6.000	3.600	4.000
8.000	8.000	7.600	6.400	6.400
9.200	7.200	6.800	5.600	5.200
8.000	8.000	8.000	6.400	6.400
-2.000	-4.800	-4.000	-5.200	-5.600

Table 4.8e Payoff Matrix for Users

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	-2.000	-1.000	-0.500	0.000	-0.250	-2.000	-2.000	0.000	0.000
CR 2.	-60.000	-60.000	-30.000	-15.000	-15.000	-5.000	-30.000	-180.000	-20.000
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000
CR 4.	3.000	3.667	3.667	4.333	7.333	7.667	8.333	7.333	7.667
CR 5.	2.333	4.000	4.000	5.333	7.667	8.667	8.667	6.333	6.667
CR 6.	-2.000	-1.000	-2.000	-50.000	-10.000	-5.000	-3.000	-5.000	-15.000
CR 7.	8.667	8.333	8.333	7.667	6.000	5.667	4.333	5.333	5.667
CR 8.	-2.667	-2.667	-2.667	-5.000	-2.667	-4.333	-4.333	-6.000	-6.667
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-7.333	-9.000
CR 10.	4.000	4.667	4.667	5.667	7.000	7.667	7.667	7.667	7.667
CR 11.	-10.000	-50.000	-200.000	-5000.000	-4000.000	-8000.000	-5000.000	-2000.000	-7000.000
CR 12.	-20.000	-10.000	-100.000	0.000	-250.000	-200.000	-400.000	0.000	0.000
CR 13.	0.000	0.000	-50.000	-200.000	-50.000	-200.000	-200.000	-50.000	-20.000
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000
CR 15.	0.000	0.000	0.000	0.000	-13.000	-13.000	-13.000	-3.000	-3.000
CR 16.	-8.667	-7.667	-7.333	-6.000	-4.667	-4.000	-3.667	-3.000	-2.667
CR 17.	-8.000	-7.333	-7.333	-6.333	-4.667	-3.667	-3.333	-4.000	-3.667

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 18.	4.000	4.333	4.667	5.667	6.000	6.667	7.000	8.333	9.000
CR 19.	2.667	3.333	4.000	5.000	6.000	8.000	7.667	7.333	7.000
CR 20.	4.333	5.000	4.667	5.333	7.000	7.000	7.000	6.000	6.000
CR 21.	5.000	5.667	5.667	6.000	7.667	8.000	8.000	7.667	7.667
CR 22.	3.000	4.000	3.667	5.000	7.333	8.333	8.333	7.667	7.667
CR 23.	7.000	6.333	7.667	6.333	7.333	6.333	6.667	7.333	8.000
CR 24.	7.667	8.000	7.667	7.000	8.333	7.333	8.000	6.667	6.667
CR 25.	-5.333	-4.667	-5.667	-4.333	-3.333	-2.333	-2.333	-4.333	-4.000
CR 26.	4.000	5.000	4.667	5.667	6.333	7.333	7.333	5.667	4.667
CR 27.	5.333	4.000	5.333	4.333	6.333	6.333	6.000	4.333	4.667
CR 28.	4.667	4.667	5.333	4.667	6.333	5.333	5.667	5.667	5.000
CR 29.	3.000	3.000	3.667	4.333	6.333	6.000	7.667	7.333	8.000
CR 30.	-3.000	-3.333	-3.333	-5.000	-3.333	-5.000	-6.333	-6.667	-7.333

Table 4.8f Standard Deviation of Payoff Matrices for Decision Making Groups

Devices CR No	A1	A2	A3	A4	A5	A6	A7	A8	A9
CR 1.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 2.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 3.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 4.	1.518	1.334	1.760	1.294	0.552	0.344	0.506	1.510	1.294
CR 5.	0.797	0.411	1.000	0.572	0.213	0.598	0.626	0.690	0.529
CR 6.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 7.	1.133	1.054	0.759	0.795	1.037	0.985	1.334	0.738	0.313
CR 8.	2.089	2.233	2.064	0.661	2.326	1.447	1.447	1.410	1.516
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.018	0.457
CR 10.	0.551	0.354	0.233	0.573	0.661	1.150	1.284	0.999	0.636
CR 11.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 12.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 13.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 14.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 15.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 16.	1.817	1.599	1.207	1.417	1.159	1.360	1.020	1.182	1.102
CR 17.	1.799	1.477	1.476	1.001	1.857	1.859	1.829	1.491	1.256
CR 18.	0.785	0.946	0.966	0.921	1.473	1.080	1.118	0.328	0.629
CR 19.	0.821	1.007	2.341	0.490	1.040	1.058	0.577	1.113	1.269
CR 20.	1.729	1.571	0.757	0.423	1.513	0.750	1.258	1.418	1.418
CR 21.	1.258	1.067	0.206	0.757	0.581	1.239	1.239	0.646	0.646
CR 22.	0.465	0.755	1.137	0.938	0.912	0.481	0.320	0.482	0.578
CR 23.	1.253	1.237	1.188	0.657	0.823	1.819	1.170	1.638	1.845
CR 24.	0.300	0.231	0.618	1.066	0.875	0.233	0.823	1.209	0.789
CR 25.	1.283	1.012	1.604	1.049	1.586	1.464	1.477	1.334	1.480
CR 26.	0.661	0.574	1.018	0.828	1.287	1.412	1.283	1.337	1.197
CR 27.	1.091	1.509	0.962	1.236	0.917	0.760	1.052	1.371	1.052
CR 28.	1.552	1.373	1.598	0.709	1.269	1.131	1.120	0.772	0.714
CR 29.	0.877	0.661	1.116	1.045	0.946	0.946	0.946	1.258	1.774
CR 30.	1.526	1.898	1.482	1.746	1.406	0.900	1.354	1.020	1.347

An analysis of pay-off matrices reveal the strengths of PSC as fuel consumption, durability, nutrition value of food, fuel cost, available subsidy, pollution hazards, human drudgery, taste of food, cleanliness of utensils etc. The SBCs have also indicated similar strengths except cooking time. LPG stove has higher pay-off values on all the criterion except initial, fuel cost, rate of interest on loan, distribution network. Pay-off values for *chulha* and improved *chulha* indicate strengths in terms of continuity of use, ease of operation, type of dishes cooked, spares and after sales service. Kerosene stoves are indicated by moderate pay-off values for most of the criteria. Micro-wave and electric ovens are indicating strengths for many criteria except various costs and need for user training. The trends are discernible for all the respondent groups. Standard deviation shows the robustness of judgments by all the groups.

The detailed discussion on the results based on the above has been presented in next chapter (results and discussions).

4.5.2. Application of PROMETHEE

The PROMETHEE evaluation methods consist of four variations. The PROMETHEE II methodology has been used for ranking the devices. It provides a complete order for the evaluation that will help the decision makers realize the results easily.

Establishment of Preference Functions

Firstly, pair-wise comparisons of elements in a given payoff matrix is computed to know the preferences of devices for all the criteria as follows.

When two elements a and b are to be compared for any criterion j, they are expressed in terms of preference function $P_j(a, b)$ as follows.

$P_j(a, b) = 0$: an indifference between a and b *or* no preference of a over b

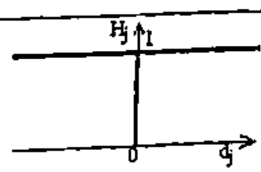
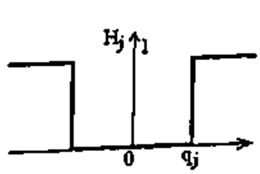
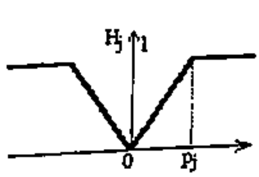
$P_j(a, b) \sim 0$: weak preference of a over b

$P_j(a, b) \sim 1$: strong preference of a over b

$P_j(a, b) = 1$: strict preference of a over b

The method uses preference function $P_j(a, b)$ which is a function of the difference d_j between two devices for any criterion j, i. e. $d_j = f(a, j) - f(b, j)$, where $f(a, j)$ and $f(b, j)$ are values of two devices a and b for criterion j. The indifference and preference thresholds q and p are also defined depending upon the type of criterion function. Two devices are indifferent for criterion j as long as d_j does not exceed the indifference threshold q. If d_j becomes greater than p, there is a strict preference.

Brans *et al.* (1984; 1986) have offered six generalized criteria functions for reference namely, usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and Gaussian criterion. The criterion functions are indicated in Figure 4.5

Types of Generalized Criteria		***Parameters***	***Description***
1. Usual Criterion		-	There is indifference only if there is no difference between the actions scores
2. Quasi Criterion		q	there is indifference as long as the scores difference is less than q
3. Criterion with Linear Preference		p	The preference varies linearly with the difference between the scores between 0 and p. If the difference is more than p, the action is strictly preferred

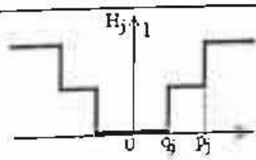
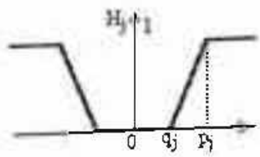
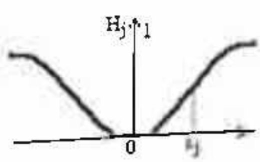
Types of Generalized Criteria		Parameters	Description
4. Level Criterion		q p	There is indifference as long as the score difference is less than q , low preference if the scores difference is between q and p , and strict preference if the scores difference is higher than p.
5. Criterion with Linear Preference and Indifference Area		q p	There is indifference as long as the score difference is less than q. The preference varies linearly with the difference between the scores between q and p, and becomes strict if the scores difference is higher than p.
6. Gaussian Criterion		σ	The preference increases with the difference between the scores as expressed in $H(d) = 1-\exp(-d^2/2\sigma^2)$

Figure 4.5 Different Types of Criterion Functions (Source: Brans *et al*, 1984; 1986)

To model decision maker's preference realistically, it is necessary to know if there is any indifference or there exists a strict preference between two devices for each criterion. Usual criterion function is chosen for the present problem in which even a small difference makes the device preferred over the other. The preference functions are computed for each criterion for all the devices. The details of usual function are defined below.

Logic $H_1(d) = 0$ if $d = 0$

$= 1$ if $d \neq 0$

Parameters Not defined

Description There is a indifference between a and b if and only if $f(a) = f(b)$. The decision maker has a strict preference for the device having the greatest worth

Computation of Multi Criteria Preference Index

The MCPI is computed for all the devices to know the devices which are superior as compared to the others. The procedure for computing MCPI is as follows.

Multi criteria preference index, $\pi(a,b)$ a weighted average of the preference functions $P_j(a, b)$ for all the criteria is defined as

$$\pi(a,b) = \frac{\sum_{j=1}^{J} w_j P_j(a,b)}{\sum_{j=1}^{J} w_j} \quad (2)$$

$$\phi^+(a) = \sum_A \pi(a,b) \quad (3)$$

$$\phi^-(a) = \sum_A \pi(b,a) \quad (4)$$

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (5)$$

Where w_j = Weight assigned to the criterion j;

$\phi^+(a)$ =Outranking index of a in the alternative set A;

$\phi^-(a)$ = Outranked index of a in the alternative set A;

$\phi(a)$ = Net ranking of a in the alternative set A. The value having maximum $\phi(a)$ is considered as the best.

Ranking of Devices

Following the above computations PROMETHEE II ranks the devices according to the relation given below...

a outranks b *iff* $\phi(a) > \phi(b)$, a is indifferent to b iff $\phi(a) = \phi(b)$ (6)

The $\phi^{+}(a)$ and $\phi^{-}(a)$ values are computed for all the devices following the above equations (3) and (4) respectively. The net $\phi(a)$ is computed using equation (5) and the devices are ranked from maximum to minimum net $\phi(a)$ value.

The detailed discussion on the results based on the above has been presented in section 5.1 (results and discussions).

4.5.3 Development of Software

The need is felt to develop a custom built computer code to compute the preference of PSC over all the identified devices. Pay-off values and weightages of the criterion are necessary inputs. The necessary inputs can be given through a text file or key board. The program code in FORTRAN computes indifference values, preference function for each criterion in terms of the usual functions, MCPI, $\phi^{+}(a)$, $\phi^{-}(a)$, net $\phi(a)$ and the rank for all the devices. The output can be stored in a text file. Figure 4.6 shows the flow chart for the program (Raju, 1995).

4.5.4 Sensitivity Analyses

An attempt has been made to check aspects which impede the dissemination of PSC not rising to first position among the available devices. Extensive sensitivity analyses are carried out for changes in performance of identified devices on various criteria. The sensitivity runs are also taken to check the influence of weightages over the ranking pattern. More than fifty permutations and combinations of changes in weightages and performance of devices are attempted. The details of which are given in section 5.5 (sensitivity analyses studies).

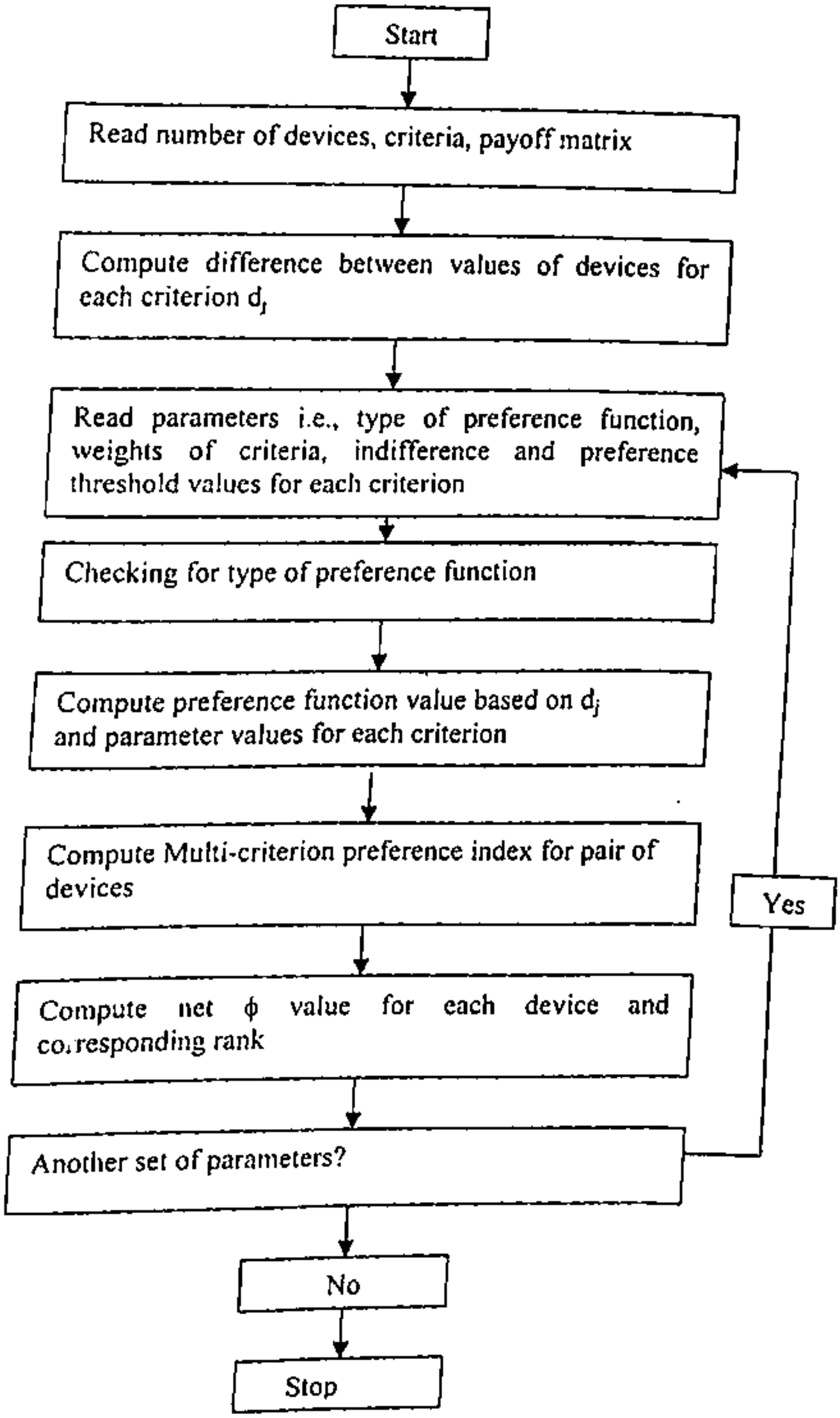


Figure 4.6 Flow Chart for PROMETHEE

4.6. Evaluation by Priority (AHP)

Priority based evaluations using AHP have been very widely used in energy planning. Use of AHP for selecting energy alternatives in cooking and lighting (Ramanathan and Ganesh, 1994), old vehicle elimination (Tzeng and Tsaur, 1990), electric utility planning (Akash *et al*, 1999) and several other applications have been reported in the literature. Pertinent literature also indicates that AHP is flexible decision making tool for solving complex multi-criteria problems in diverse areas, because it enables decomposition of given problem (unstructured situation) into its component parts (criteria, sub-criteria and devices), arrange its parts in a structured order (hierarchy) and assures that both qualitative and quantitative aspects of a problem are properly incorporated in evaluation process using a predefined scale. It further synthesizes the judgments into overall priorities of the devices (Wedley, 1990).

4.6.1. Evolution of Hierarchical Structure

The present problem is decomposed into a hierarchical structure as shown in Figure 4.7. The figure consists of three level of hierarchy with usefulness at top level (objective), main criteria such as technical, economic, social, behavioral and commercial at the second level. The third level of hierarchy consists of sub criteria which are indicated in the criteria block for convenience of drawing the structure. The devices are indicated at the end of structure as per fundamentals of AHP methodology. Elements at each hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level.

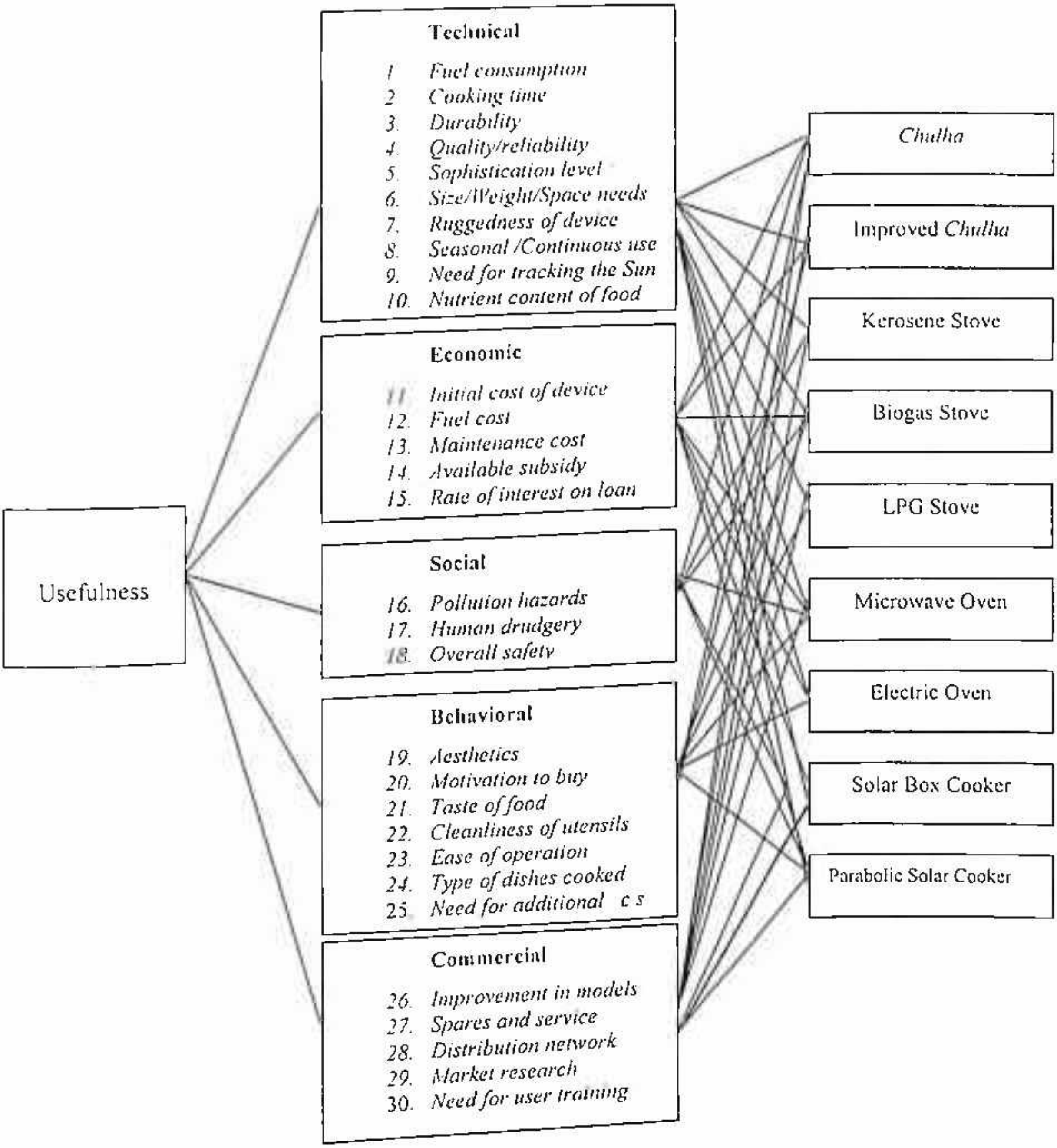


Figure 4.7 Hierarchy for Evaluation of Devices

4.6.2. Application of AHP

For choosing between the devices a decision maker must weigh and prioritize different criterions. That means he has not only to assign preferences for each device, but also weightages to criterions identified for assessment.

Pair-Wise Comparisons

Following an initial step of developing hierarchy as discussed in the previous section, the pair-wise comparisons of main criteria and sub-criteria are carried out, using qualitative scale. Once the qualitative judgments are made, they are translated into numbers by means of the fundamental scale. Saaty (1982) has suggested a scale of 1-9 as indicated in Table 4.9. The present problem uses intermediate values.

Table 4.9 Scale of Preference between Two Elements

Preferences	*Definition*
1	Equally preferred
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	Intermediates values
Reciprocals	Used to reflect dominance of second device as compared with the first

The degree of importance of the criteria (criterion weightages) is computed by direct method as discussed in section 4.4 (computation of weightages). The preference of devices at a particular level over those in the succeeding level is measured by procedure of pair-wise comparisons between the assigned values. This procedure is repeated for elements at each level in upward direction. This procedure is repeated for all the respondent groups.

Computation of Eigenvectors

After performing step-by-step procedure and creating comparison matrices at different hierarchical levels, aggregate Eigenvectors are computed until the composite final vectors of weight coefficients for the devices are computed.

To elicit pair wise comparisons performed at given level, a matrix A, is created in turn by putting the result of pair wise comparison of element i with element j into the position a_{ji}

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & a_{2n} \\ a_{n1} & a_{n2} & \cdot & a_{nn} \end{bmatrix} \qquad (7)$$

Reciprocal value of the comparison is placed in a position a_{ji}. The result of pair wise comparisons is weight coefficient for each element at given level, with respect to the element of a higher level. The entries of final weight coefficients vector reflect the relative importance (value) of each device with respect to the usefulness stated at the top of hierarchy. Pair-wise comparison for Technical (Tech), Economic (Eco), Social (Soc), Behavioral (Beha) and Commercial (Comm) criteria from survey data for overall responses is carried out as below.

$A =$ (8)

	Tech	*Eco*	*Soc*	*Beha*	*Comm*
Tech	1	0.400	0.269	0.699	0.475
Eco	2.500	1	0.673	1.740	1.180
Soc	3.710	1.480	1	2.580	1.760
Beha	1.430	0.574	0.387	1	0.678
Comm	2.100	0.847	0.568	1.470	1

(λ_{max} = 5, N'=5, CI=0, RI= 1.12, CR=0)

Corresponding set of criteria weights is Technical - 0.352, Economic- 0.141, Social - 0.095, Behavioral- 0.246 and Commercial - 0.167. The sum of all weights is unity. The values of consistency index and consistency ratio are zero as the present method uses direct judgments from the respondents.

Pair-wise comparison of devices is carried out for main criteria indicated below.

	Ch	ImC	Ke	Bio	LPG	MiW	ElO	SBC	PSC
Ch	1	0.889	0.891	0.851	0.702	0.726	0.726	0.926	0.914
ImC	1.124	1	1.002	0.956	0.790	0.816	0.816	1.041	1.027
Ke	1.122	0.998	1	0.955	0.788	0.815	0.815	1.040	1.026
Bio	1.174	1.045	1.047	1	0.825	0.853	0.853	1.089	1.074
LPG	1.422	1.265	1.268	1.211	1	1.034	1.034	1.318	1.300
MiW	1.375	1.224	1.226	1.171	0.967	1	1.001	1.275	1.257
ElO	1.375	1.224	1.226	1.171	0.967	1.001	1	1.275	1.257
SBC	1.079	0.959	0.961	0.918	0.758	0.784	0.784	1	0.986
PSC	1.094	0.973	0.974	0.931	0.768	0.795	0.795	1.014	1

.forTechnical (9)

((λ_{max} = 9, N'=9, CI=0, RI= 1.45, CR=0)

Following these, 5 matrices of 9 x 9 are formulated. Corresponding set of weight of devices for all decision making groups with respect to Technical Criteria are; *Chulha(A1)* - 0.0929 , Improved *Chulha* (A2) -0.1044, Kerosene Stove *(A3)*- 0.1042, Biogas Stove*(A4)* - 0.1091, LPG Stove *(A5)* - 0.1321, Microwave Oven *(A6)*- 0.1278, Electric Oven *(A7)* - 0.1278, SBC *(A8)*- 0.1002, and PSC *(A9)* - 0.1016. Pair-wise comparison of devices is carried out for all sub criteria as above. Following these 30 matrices of 9 x 9 are formulated to evolve sub-criteria weights factors for all the devices. Comparison of devices with respect to main criteria is calculated to evolve priorities of devices with respect to main criteria for all the groups. A sample calculation for overall matrix indicated below is carried out and tested for inconsistency (λ_{max} = 9, N'=9, CI=0, RI= 1.45, CR=0).

	Tech	Eco	Soc	Beha	Comm
Ch	0.0929	0.0118	0.0738	0.1026	0.1158
ImC	0.1044	0.1265	0.0900	0.1062	0.1060
Ke	0.1042	0.1126	0.0794	0.1028	0.1235
Bio	0.1091	0.1118	0.1058	0.1097	0.1235
LPG	0.1321	0.0963	0.1106	0.1123	0.1215
MiW	0.1278	0.0796	0.1244	0.1156	0.1145
ElO	0.1278	0.0881	0.1279	0.1272	0.1147
SBC	0.1002	0.1344	0.1464	0.1123	0.1042
PSC	0.1016	0.1321	0.1417	0.1114	0.0992

(10)

Choosing the Best Device

After obtaining weight vector, it is then multiplied with the weight coefficient of element at higher level (that is used as criterion for pair wise comparisons). Procedure is repeated upward for each level, until the top of the hierarchy is reached. Overall weight coefficient, with respect to goal, for each decision device is then obtained. The device with the highest weight coefficient value should be taken as the best device. The final composite priorities of devices are calculated by linear combination of products of criteria weights and corresponding columns of above matrix.

Test of Consistency

Small changes in pair-wise comparison matrix imply small changes in maximum Eigenvector value (λ_{max}) of the matrix. It is also necessary to test the consistency because of the varied importance of each hierarchy. Consistency ratios are computed for the judgments of evaluation as well as on entire hierarchical structure. The consistency ratio of less than 0.1 is acceptable. Consistency ratio is the ratio of Consistency Index (CI) and Average Random Index (RI) where RI is CI for randomly generated pair-wise comparison matrix. For a matrix of size N', Consistency Index is calculated as C.I. = $(\lambda_{max} - N')/(N' - 1)$. When the consistency has been calculated, the result is compared to those of the same index of a randomly generated reciprocal matrix from scale 1 to 9 with reciprocals forced. This index is called the Random Index (RI) which is shown in Table 4.10

Table 4.10 Relation between Size of Matrix and Average Random Index

Size of Matrix	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Average RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The detailed discussion on the results based on the above has been presented in section 5.2 of the next chapter (results and discussions).

4.6.3. Development of Software

The need is felt to develop a custom built computer code to compute the preference of PSC over all the identified devices by using the priority structure. The module developed consists text boxes for taking standard inputs, buttons to activate a process, input boxes to take the matrix input and user choices, message boxes to alert the user by displaying appropriate information, flex grid to display the pair wise comparison matrix and gives graphical output. The software can handle a maximum of 30 elements at each level. The software takes elements in upper triangular matrix, fixes diagonal elements as unity and computes the lower triangular matrix by reciprocals as discussed earlier.

After giving input it prompts for any change in the above matrix before calculating Eigen values. Then difference between two successive Eigen values are shown on confirming becomes the Eigen vector for that matrix. The maximum value of the Eigenvectors is the best device. It also has the sensitivity analyses option from which one can change any of the pair wise comparison matrix and the check how it affects the decision making. This is very useful because often data in multi-criteria decision making problems is uncertain and changeable. The module is developed in Visual basic 6.0. Figure 4.8 shows the flow chart of the program.

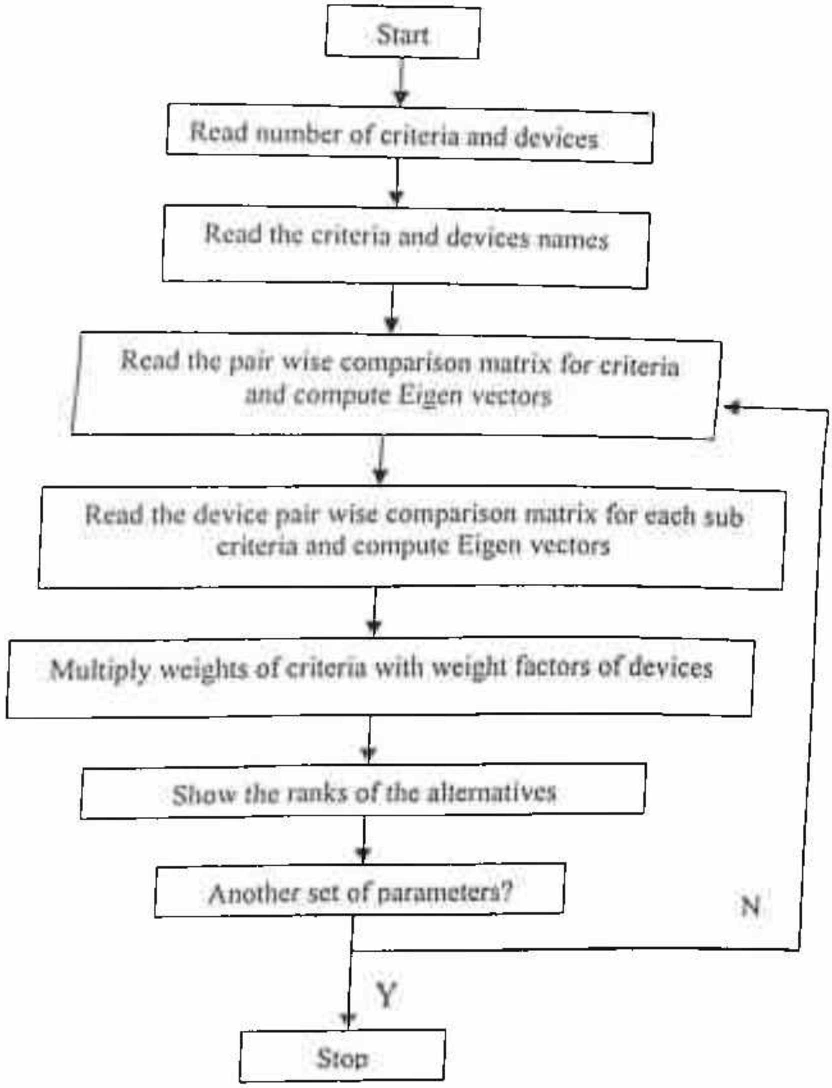


Figure 4.8 Flow Chart for AHP

To make the module interactive and user friendly interactive screens are developed. Few of the graphical user interfaces are shown in Figures 4.9, 4.0, 4.11 where the welcome screen, interim computations and final graphical output facility respectively are indicated.

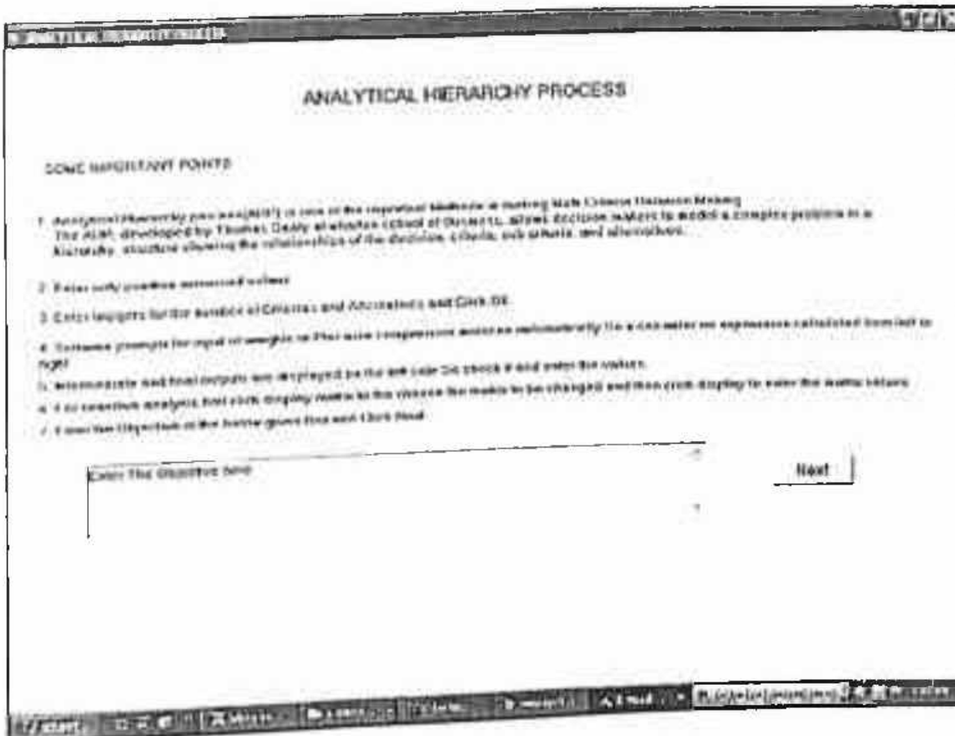


Figure 4.9 Start Window with Instructions and Objective

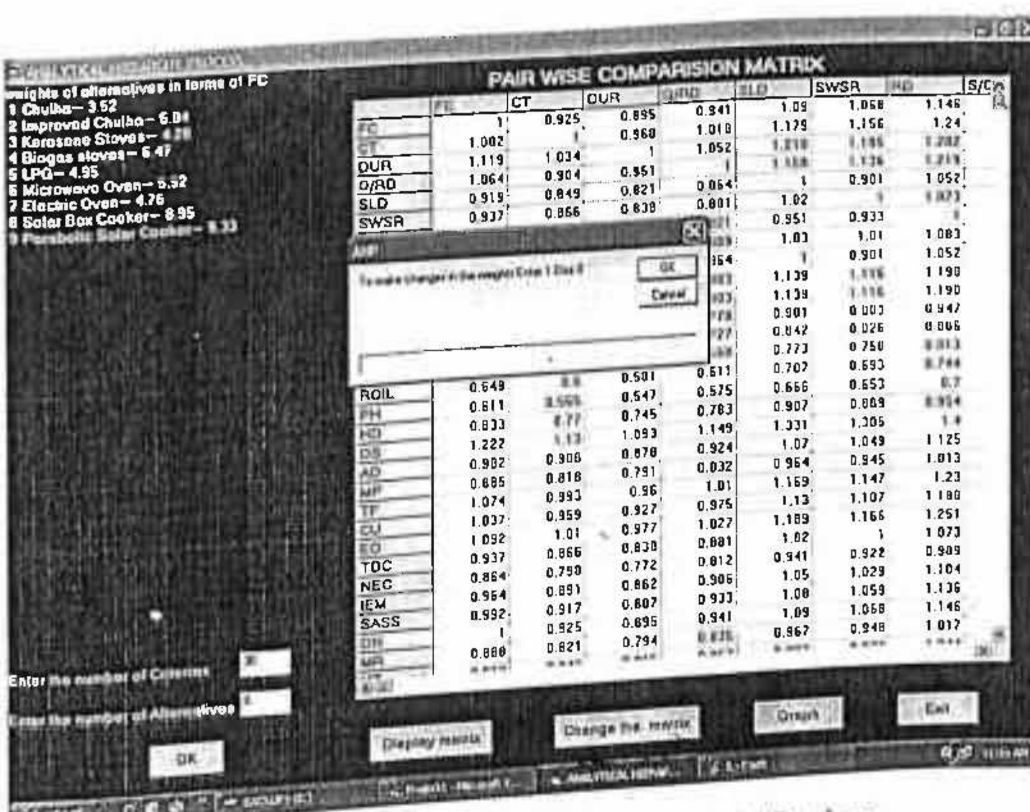


Figure 4.10 Interface for Weight Inputs of Devices

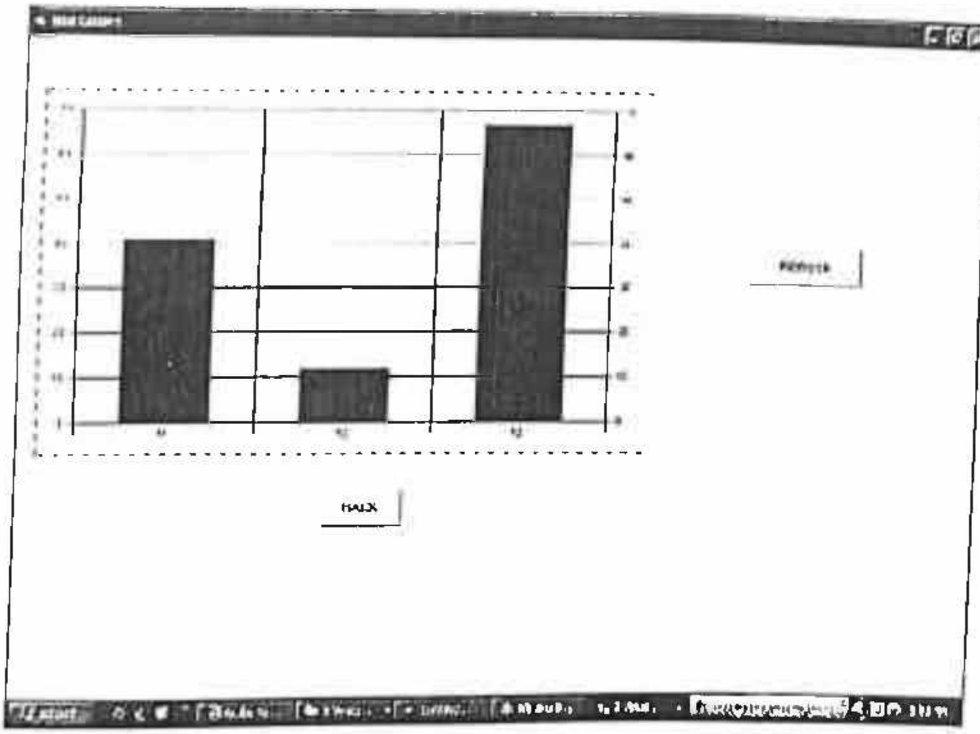


Figure 4.11 Bar Graph Window Showing Output

4.6.4. Sensitivity Analyses

Sensitivity analyses are performed for all the decision making groups to assess the effect of parameters on the ranking pattern. The ranking of PSCs is studied for all the decision making groups. Five most sensitive cooking energy devices amongst the pool of devices are considered for ranking. The sensitivity runs are also taken to check the influence of weightages over the ranking pattern. More than fifty permutations and combinations of changes in weightages and performance of devices are attempted. The details of which are given in section 5.5 (sensitivity analyses studies).

4.7. Multi Attribute Utility Assessment

Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine tangible and intangible criteria for ranking of devices. Multi Attribute Utility Theory is developed to help decision makers to assign utility values to devices in terms of single attribute utility functions and combining individual evaluations to obtain overall utility values. Additive utility assessment model is employed in the present problem for assessing relative utility of PSC. The advantage of the additive form is its simplicity (Butler *et al*, 2001).

However, it is observed that MAUT is not very extensively used in energy planning. This may be due to requirements of interactive decision environment required for formulating utility functions and complexity of computing scaling constants using the algorithm. Selecting portfolios for solar energy projects (Golabi *et al*, 1981), energy policy making (Jones *et al*, 1990), environmental impact assessment (McDaniels, 1996), electric power system expansion planning (Voropai and Ivanova , 2002) and strategic decision making for hydro projects (Mladineo *et al*, 1987) are the applications identified in the literature.

4.7.1. Formulation of Evaluation Matrix

The evaluation matrix is formulated as discussed in evaluation by outranking. The experts are asked to assign their judgments on a 10 point linear scale for qualitative criteria. Ranking of criteria in order of importance to identify the scaling constants for criteria and sub-criteria level is carried out. Table 4.11a indicates the aggregate evaluation matrix for the present problem. Tables 4.11b to 4.11e indicate the evaluation matrices for different groups. The Judgments for qualitative criteria are aggregate opinion of all the respondents computed by arithmetic means of all responses whereas quantitative criteria are from the literature. Table 4.11f shows standard deviation for all the decision making groups.

Table 4.11a Overall Evaluation Matrix for Utility Assessment

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
CR 1.	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000	0.0355
CR 2.	60.000	60.000	30.000	15.000	15.000	5.000	30.000	180.000	20.000	0.0384
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000	0.0397
CR 4.	5.150	5.642	5.992	5.958	8.158	8.042	7.758	5.633	6.042	0.0376
CR 5.	2.808	3.875	4.500	5.908	7.817	9.042	8.517	5.433	5.942	0.0326
CR 6.	2.000	1.000	2.000	50.000	10.000	5.000	3.000	5.000	15.000	0.0332
CR 7.	7.542	7.333	7.308	6.617	7.325	6.617	5.958	5.708	5.467	0.0310
CR 8.	7.383	7.283	7.383	7.150	7.408	6.942	6.942	5.375	5.408	0.0335
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.367	2.925	0.0326
CR 10.	4.650	4.817	4.917	5.667	6.050	6.292	6.167	8.492	8.367	0.0371
CR 11.	10.000	50.000	200.000	5000.000	4000.000	8000.000	5000.000	2000.000	7000.000	0.0371
CR 12.	20.000	10.000	100.000	0.000	250.000	200.000	400.000	0.000	0.000	0.0293
CR 13.	0.000	0.000	50.000	200.000	50.000	200.000	200.000	50.000	20.000	0.0274
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000	0.0252
CR 15.	0.000	0.000	0.000	0.000	13.000	13.000	13.000	3.000	3.000	0.0230
CR 16.	3.908	5.233	4.642	6.725	6.683	7.925	8.133	9.550	9.633	0.0217
CR 17.	4.050	4.792	5.717	6.092	7.808	8.358	8.442	7.650	7.658	0.0296
CR 18.	5.175	5.708	4.542	5.967	5.350	5.917	5.475	8.383	8.125	0.0433
CR 19.	3.292	3.983	6.175	5.400	7.025	8.600	8.167	6.508	6.075	0.0348

Devices CR No	*A1*	*A2*	*A3*	*A4*
CR 20.	4.383	4.775	5.767	5.483
CR 21.	6.250	6.417	5.492	6.500
CR 22.	2.975	3.850	4.167	5.400
CR 23.	5.475	5.508	6.242	6.408
CR 24.	8.017	8.200	7.942	8.025
CR 25.	7.717	7.883	7.633	7.692
CR 26.	4.350	5.150	5.392	5.817
CR 27.	6.733	6.250	6.683	6.108
CR 28.	6.217	5.717	7.283	5.542
CR 29.	3.475	3.950	5.317	5.308
CR 30.	8.850	7.717	8.117	7.075

A5	A6	A7	A8	A9	Scaling Constant
7.325	6.625	5.750	5.050	5.050	0.0314
7.142	6.975	6.975	8.067	8.067	0.0381
7.258	8.858	8.633	8.117	7.992	0.0368
7.883	7.883	7.317	6.333	5.775	0.0387
8.783	7.083	7.050	5.167	5.742	0.0332
8.342	7.267	7.567	5.417	5.775	0.0306
5.908	6.108	5.683	5.267	5.117	0.0342
7.208	7.008	6.900	5.058	5.167	0.0352
8.083	6.933	7.117	5.067	4.575	0.0355
6.958	6.625	7.042	5.858	5.800	0.0315
8.142	6.075	5.517	4.783	3.942	0.0323

Table 4.11b Evaluation Matrix for Policy Makers

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
CR 1.	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000	0.0429
CR 2.	60.000	60.000	30.000	15.000	15.000	5.000	30.000	180.000	20.000	0.0408
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000	0.0382
CR 4.	6.000	6.500	7.500	7.500	8.500	8.500	7.500	4.000	4.500	0.0320
CR 5.	2.500	3.500	4.000	5.500	8.000	9.500	9.000	5.000	5.500	0.0320
CR 6.	2.000	1.000	2.000	50.000	10.000	5.000	3.000	5.000	15.000	0.0345
CR 7.	7.500	7.000	6.500	6.000	8.500	8.000	7.500	5.500	5.000	0.0295
CR 8.	9.000	9.000	9.000	8.000	9.500	8.500	8.500	3.500	3.500	0.0345
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.000	3.500	0.0320
CR 10.	5.000	5.000	5.000	5.000	6.000	5.500	5.000	9.500	9.000	0.0295
CR 11.	10.000	50.000	200.000	5,000.000	4,000.000	8,000.000	5,000.000	2,000.000	7,000.000	0.0369
CR 12.	20.000	10.000	100.000	0.000	250.000	200.000	400.000	0.000	0.000	0.0364
CR 13.	0.000	0.000	50.000	200.000	50.000	200.000	200.000	50.000	20.000	0.0308
CR 14.	0.000	50.000	0.000	2,000.000	0.000	0.000	0.000	500.000	2,000.000	0.0225
CR 15.	0.000	0.000	0.000	0.000	13.000	13.000	13.000	3.000	3.000	0.0222
CR 16.	3.500	5.000	5.500	6.500	7.000	8.500	9.000	10.000	10.000	0.0267
CR 17.	3.000	4.500	7.000	7.500	9.500	9.500	9.500	7.000	7.500	0.0332
CR 18.	5.500	6.500	5.500	5.000	7.000	7.000	4.500	8.000	7.500	0.0357
CR 19.	2.500	3.000	9.500	5.000	6.500	10.000	9.000	5.500	4.500	0.0357

Devices *CR No*	*A1*	*A2*	*A3*	*A4*
CR 20.	2.000	2.500	6.000	5.000
CR 21.	8.000	8.000	5.500	6.000
CR 22.	2.500	3.000	5.000	5.000
CR 23.	4.500	4.500	6.500	6.500
CR 24.	8.000	8.000	8.500	9.500
CR 25.	9.000	9.000	9.000	9.500
CR 26.	5.000	6.000	6.500	6.000
CR 27.	8.000	7.000	7.000	6.500
CR 28.	7.000	7.000	7.000	5.500
CR 29.	2.500	4.000	6.000	4.500
CR 30.	10.000	9.000	9.000	8.500

A5	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
9.500	7.500	4.000	3.000	3.000	0.0328
6.500	5.500	5.500	9.000	9.000	0.0332
8.500	9.500	9.000	8.000	7.500	0.0332
9.000	10.000	9.000	4.000	3.500	0.0419
10.000	7.000	7.000	4.000	5.500	0.0259
7.500	7.000	7.000	6.000	5.500	0.0308
6.500	5.500	5.000	5.000	5.000	0.0332
6.500	6.500	6.000	3.500	4.000	0.0419
8.000	8.000	8.000	5.000	4.500	0.0394
7.500	6.500	6.500	4.500	4.000	0.0308
9.500	6.500	6.000	5.000	3.500	0.0308

Table 4.11c Evaluation Matrix for Researchers

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
CR 1.	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000	0.0394
CR 2.	60.000	60.000	30.000	15.000	15.000	5.000	30.000	180.000	20.000	0.0488
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000	0.0343
CR 4.	6.400	6.400	7.200	6.000	8.400	8.000	8.000	4.800	6.000	0.0340
CR 5.	4.000	4.400	6.000	6.400	7.600	8.400	8.800	4.800	6.000	0.0245
CR 6.	2.000	1.000	2.000	50.000	10.000	5.000	3.000	5.000	15.000	0.0441
CR 7.	6.000	6.000	7.200	6.000	7.200	6.400	6.400	5.200	5.600	0.0343
CR 8.	6.000	6.000	5.600	7.200	5.200	5.200	5.200	6.800	7.200	0.0245
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.600	2.800	0.0196
CR 10.	5.200	5.200	5.200	6.400	5.600	5.200	5.200	7.600	8.000	0.0392
CR 11.	10.000	50.000	200.000	5000.000	4000.000	8000.000	5000.000	2000.000	7000.000	0.0343
CR 12.	20.000	10.000	100.000	0.000	250.000	200.000	400.000	0.000	0.000	0.0343
CR 13.	0.000	0.000	50.000	200.000	50.000	200.000	200.000	50.000	20.000	0.0294
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000	0.0245
CR 15.	0.000	0.000	0.000	0.000	13.000	13.000	13.000	3.000	3.000	0.0343
CR 16.	4.000	6.000	4.000	7.600	6.000	7.200	7.600	9.200	9.200	0.0196
CR 17.	4.400	4.800	5.600	6.000	6.400	6.800	6.800	7.600	7.200	0.0392
CR 18.	5.600	6.000	4.800	7.200	4.800	4.800	4.800	8.800	8.000	0.0441
CR 19.	4.000	5.200	5.600	5.600	7.200	7.600	8.000	5.600	5.600	0.0343

Devices *CR No*	*A1*	*A2*	*A3*	*A4*
CR 20.	5.200	5.600	6.400	5.600
CR 21.	6.000	6.000	5.600	7.600
CR 22.	3.600	4.800	5.200	6.800
CR 23.	6.000	6.800	6.000	7.200
CR 24.	8.400	8.400	8.400	8.000
CR 25.	8.000	8.000	7.600	7.200
CR 26.	4.800	4.800	4.400	4.800
CR 27.	6.800	6.800	7.600	6.400
CR 28.	5.200	4.400	7.600	5.600
CR 29.	4.400	4.400	5.600	6.000
CR 30.	7.600	5.600	6.800	5.600

A5	A6	A7	A8	A9	Scaling Constant
6.800	6.000	6.000	5.200	5.200	0.0245
6.800	6.400	6.400	7.600	7.600	0.0392
6.800	8.800	8.800	8.800	8.800	0.0441
7.200	6.400	6.400	6.400	5.600	0.0392
8.800	6.800	7.200	5.600	6.000	0.0294
8.400	6.400	6.800	4.400	4.800	0.0294
4.000	4.400	4.400	6.800	6.800	0.0343
8.000	7.200	8.000	6.000	5.600	0.0343
8.800	7.200	8.000	4.000	3.600	0.0294
6.000	6.000	6.000	5.200	4.800	0.0245
6.800	5.200	4.800	4.400	3.600	0.0343

Table 4.11d Evaluation Matrix for Educators

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
CR 1.	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000	0.0331
CR 2.	60.000	60.000	30.000	15.000	15.000	5.000	30.000	180.000	20.000	0.0377
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000	0.0373
CR 4.	5.200	6.000	5.600	6.000	8.400	8.000	7.200	6.400	6.000	0.0395
CR 5.	2.400	3.600	4.000	6.400	8.000	9.600	7.600	5.600	5.600	0.0311
CR 6.	2.000	1.000	2.000	50.000	10.000	5.000	3.000	5.000	15.000	0.0358
CR 7.	8.000	8.000	7.200	6.800	7.600	6.400	5.600	6.800	5.600	0.0365
CR 8.	5.200	4.800	5.600	6.400	5.600	6.400	6.400	5.200	5.600	0.0365
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.200	2.400	0.0311
CR 10.	4.400	4.400	4.800	5.600	5.600	6.800	6.800	9.200	8.800	0.0385
CR 11.	10.000	50.000	200.000	5000.000	4000.000	8000.000	5000.000	2000.000	7000.000	0.0378
CR 12.	20.000	10.000	100.000	0.000	250.000	200.000	400.000	0.000	0.000	0.0296
CR 13.	0.000	0.000	50.000	200.000	50.000	200.000	200.000	50.000	20.000	0.0284
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000	0.0224
CR 15.	0.000	0.000	0.000	0.000	13.000	13.000	13.000	3.000	3.000	0.0215
CR 16.	4.800	5.600	4.400	6.800	6.400	8.000	7.600	10.000	10.000	0.0223
CR 17.	4.800	5.200	5.600	5.200	8.000	8.800	8.800	8.000	7.600	0.0325
CR 18.	5.600	6.000	3.200	6.000	3.600	5.200	5.600	8.400	8.000	0.0371
CR 19.	4.000	4.400	5.600	6.000	8.400	8.800	8.000	7.600	7.200	0.0371

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*
CR 20.	6.000	6.000	6.000	6.000	6.000
CR 21.	6.000	6.000	5.200	6.400	7.600
CR 22.	2.800	3.600	2.800	4.800	6.400
CR 23.	4.400	4.400	4.800	5.600	8.000
CR 24.	8.000	8.400	7.200	7.600	8.000
CR 25.	7.200	7.200	7.600	6.400	8.800
CR 26.	3.600	4.800	6.000	6.800	6.800
CR 27.	6.800	7.200	6.800	7.200	8.000
CR 28.	8.000	6.800	9.200	6.400	9.200
CR 29.	4.000	4.400	6.000	6.400	8.000
CR 30.	8.800	7.600	8.000	7.200	7.600

A6	*A7*	*A8*	*A9*	*Scaling Constant*
6.000	6.000	6.000	6.000	0.0325
8.000	8.000	8.000	8.000	0.0405
8.800	8.400	8.000	8.000	0.0371
8.800	7.200	7.600	6.000	0.0365
7.200	6.000	4.400	4.800	0.0304
6.000	6.800	3.600	4.800	0.0311
7.200	6.000	3.600	4.000	0.0337
8.000	7.600	6.400	6.400	0.0325
7.200	6.800	5.600	5.200	0.0371
8.000	8.000	6.400	6.400	0.0304
5.600	5.600	4.400	4.000	0.0325

Table 4.11e Evaluation Matrix for Users

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*Scaling Constant*
CR 1.	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000	0.0308
CR 2.	60.000	60.000	30.000	15.000	15.000	5.000	30.000	180.000	20.000	0.0341
CR 3.	1.000	4.000	15.000	5.000	20.000	5.000	5.000	10.000	20.000	0.0444
CR 4.	3.000	3.667	3.667	4.333	7.333	7.667	8.333	7.333	7.667	0.0443
CR 5.	2.333	4.000	4.000	5.333	7.667	8.667	8.667	6.333	6.667	0.0393
CR 6.	2.000	1.000	2.000	50.000	10.000	5.000	3.000	5.000	15.000	0.0308
CR 7.	8.667	8.333	8.333	7.667	6.000	5.667	4.333	5.333	5.667	0.0205
CR 8.	9.333	9.333	9.333	7.000	9.333	7.667	7.667	6.000	5.333	0.0325
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.667	3.000	0.0222
CR 10.	4.000	4.667	4.667	5.667	7.000	7.667	7.667	7.667	7.667	0.0444
CR 11.	10.000	50.000	200.000	5000.000	4000.000	8000.000	5000.000	2000.000	7000.000	0.0376
CR 12.	20.000	10.000	100.000	0.000	250.000	200.000	400.000	0.000	0.000	0.0188
CR 13.	0.000	0.000	50.000	200.000	50.000	200.000	200.000	50.000	20.000	0.0171
CR 14.	0.000	50.000	0.000	2000.000	0.000	0.000	0.000	500.000	2000.000	0.0376
CR 15.	0.000	0.000	0.000	0.000	13.000	13.000	13.000	3.000	3.000	0.0274
CR 16.	3.333	4.333	4.667	6.000	7.333	8.000	8.333	9.000	9.333	0.0274
CR 17.	4.000	4.667	4.667	5.667	7.333	8.333	8.667	8.000	8.333	0.0274
CR 18.	4.000	4.333	4.667	5.667	6.000	6.667	7.000	8.333	9.000	0.0462
CR 19.	2.667	3.333	4.000	5.000	6.000	8.000	7.667	7.333	7.000	0.0359

Table 4.11f Standard Deviation of Evaluation Matrices for Decision Making Groups

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 2.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 3.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 4.	1.518	1.334	1.760	1.294	0.552	0.344	0.506	1.510	1.294
CR 5.	0.797	0.411	1.000	0.572	0.213	0.598	0.626	0.690	0.529
CR 6.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 7.	1.133	1.054	0.759	0.795	1.037	0.985	1.334	0.738	0.313
CR 8.	2.089	2.233	2.064	0.661	2.326	1.447	1.447	1.410	1.516
CR 9.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.018	0.457
CR 10.	0.551	0.354	0.233	0.573	0.661	1.150	1.284	0.999	0.636
CR 11.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 12.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 13.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 14.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR 15.	0.000	0.000	0.000	0.000	0.000	0.538	0.673	0.526	0.427
CR 16.	0.658	0.727	0.634	0.670	0.597	1.144	1.154	0.473	0.481
CR 17.	0.772	0.299	0.962	0.995	1.305	1.080	1.118	0.328	0.629
CR 18.	0.785	0.946	0.966	0.921	1.473	1.058	0.577	1.113	1.269
CR 19.	0.821	1.007	2.341	0.490	1.040	0.854	1.258	1.418	1.418
CR 20.	1.729	1.571	0.757	0.423	1.234	1.239	1.239	0.646	0.646
CR 21.	1.258	1.067	0.206	0.757	0.581	0.481	0.320	0.482	0.578
CR 22.	0.465	0.755	1.137	0.938	0.912	1.819	1.170	1.638	1.845
CR 23.	1.253	1.237	1.188	0.657	0.823	0.233	0.823	1.209	0.789
CR 24.	0.300	0.231	0.618	1.066	0.875	1.652	1.403	1.802	1.520
CR 25.	1.016	0.823	1.089	1.314	0.585	1.412	1.283	1.337	1.197
CR 26.	0.661	0.574	1.018	0.828	1.287	0.760	1.052	1.371	1.052
CR 27.	1.091	1.509	0.962	1.236	0.917	1.131	1.120	0.772	0.714
CR 28.	1.552	1.373	1.598	0.709	1.269	0.946	0.946	1.258	1.774
CR 29.	0.877	0.661	1.116	1.045	0.946	0.822	0.509	0.463	0.529
CR 30.	0.985	1.532	0.971	1.187	1.185				

The analysis is carried out on the basis of overall evaluation matrix. The evaluation matrix is formulated the procedure as discussed in section 4.5.1. Standard deviation shows the robustness of judgments by all the groups.

4.7.2. Application of MAUT

Multi-attribute Utility Theory takes into consideration the decision maker's preferences in the form of utility function which is defined over a set of attributes. The utility value can be determined in the following three steps.

i. Determination of single attribute utility functions. The values of utilities vary between zero and one and reflect the level of importance in the achievement of that attribute.

ii. Verification of preferential and utility independence conditions.

iii. Derivations of the multi attribute utility function.

A utility function is a device which quantifies the preferences of a decision-maker by assigning a numerical index to varying levels of satisfaction of a criterion. For a single criterion *(X)*, the utility of satisfaction of a consequence x' is denoted by $u(x')$. Utility functions are constructed such that $u\,(x')$ is less preferred to $u\,(x'')$, i.e. $u\,(x') < u\,(x'')$, if and only if x' is less preferred to x'', i.e. $x' < x''$. In other words, a utility function is a transformation of some level of performance, x', measured in its natural units into an equivalent level of decision-maker satisfaction, as shown in Figure 4.12.

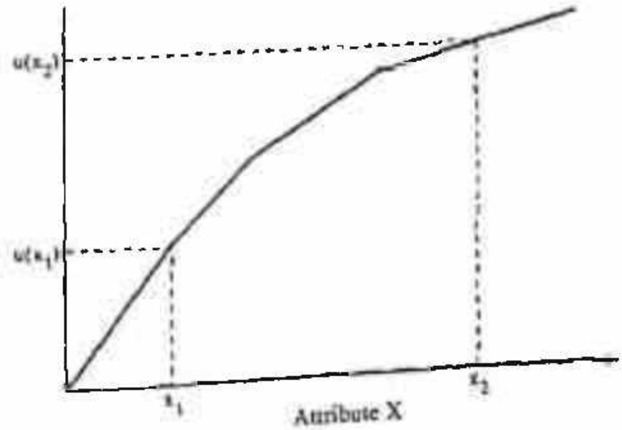


Figure 4.12 Increasing Utility Functions

Theoretically, decision makers comprise three types: risk averse, risk neutral, and risk prone, as shown in Figures 4.13 a, b & c respectively, the decision-maker's risk attitude being reflected in the shape of the utility curve which combines the decision-maker's preference attributes, i.e. increasing or decreasing utility with increasing x^*.

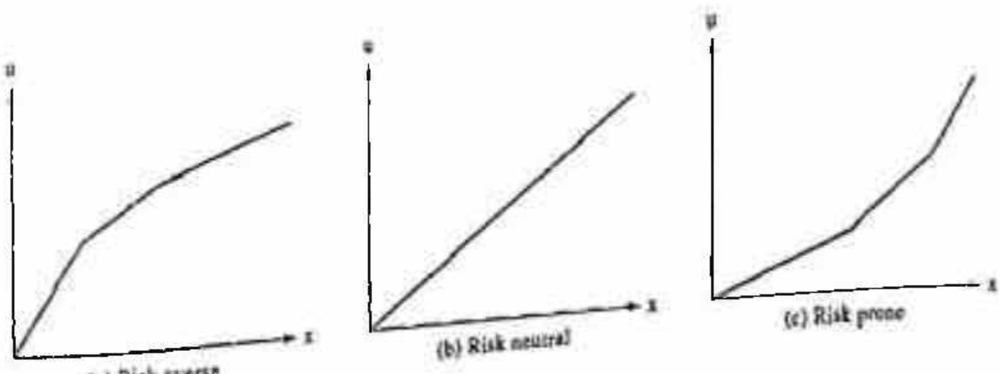


Figure 4.13 Types of Decision Makers

All decisions involve choosing one, from several, devices. Each device is assessed for desirability on a number of scored criteria. Utility function connects the criteria scores with desirability. The utility functions are of two important forms. The first form assumes that decision maker's overall utility function is additively separable and the other assumes that it is multiplicatively separable with respect to the single attribute utility functions. The most common formulation of a multi-criteria utility function is the additive model.

$$U_i = k_j \cdot u_{ij}, \text{ for all } i. \tag{11}$$

Where

U_i is the overall utility value of device i

u_{ij} is the utility value of the j^{th} criterion for the i^{th} device

u_{ij} equals $u(X_i)$, for $1 \geq i \geq n$ and $i \geq j \geq m$

X_i equals (x_{ij}) for $1 \geq i \geq n$ and $1 \geq j \geq m$

n is total number of criteria, m is total number of devices

k_j is the scaling constant of j^{th} criterion

Identification of Best and Worst Outcomes

The first step involves identification of the best and worst outcomes (criteria scores) of each of the criteria. The present problem is decomposed into a hierarchy with utility (objective) at the top of the hierarchy, five major criterions and thirty sub-criterions at levels and sub-levels of the hierarchy. Qualitative comparisons are used for weighting of non-quantifiable elements. The values of 2, 4, 6, 8 and 10 are allotted to indicate values of performance for very low, low, moderate, high and very high respectively. The best utility is allotted value of unity and the worst as zero. Some of the criteria (for example different costs) are negatively oriented in terms of desirability and are appropriately allocated the relative utility value.

Assignment of Intermediate Utilities

To assign intermediate values utility functions are assumed to be linear. The intermediate utility values are thus obtained by normalizing the evaluation matrix as follows. The decision makers are assumed to be risk neutral as suitable to the present planning problem (Keeney and Raffia, 1993).

$$u(j) = \frac{A_j - A_{min}}{A_{max} - A_{min}} \quad \textit{for maximization criteria} \qquad (12)$$

$$u(j) = \frac{A_{max} - A_j}{A_{max} - A_{min}} \quad \textit{for minimization criteria} \qquad (13)$$

Tables 4.12a to 4.12e shows the normalized evaluation matrix based on the above computations.

Computation of Final Utilities

Following the above normalization of evaluation matrix is computed. The final utilities are computed by multiplying the normalized utility values (on the scale of zero to one) by respective scaling constants and finally adding the utilities of devices as follows.

$$Utility = \sum_{1}^{30} k_i u_{ij} \qquad (14)$$

The results of evaluation are presented in section 5.3 (multi attribute utility assessment)

4.7.3 Sensitivity Analyses

Sensitivity analyses are carried out to formulate strategies for increasing the utility of PSC. The ranking of PSCs is studied for all the decision making groups. The sensitivity runs are also taken to check the influence of weightages over the ranking pattern. Different permutations and combinations of changes in weightages and performance of devices are attempted. The details of which are given in section 5.5 (sensitivity analyses studies).

This chapter presents the results of multi criteria evaluation studies on identified cooking energy devices with special reference to PSC. Three evaluation methodologies namely PROMETHEE (outranking), AHP (priority) and MAUT (utility) have been applied to the present problem of assessing the overall usefulness of cooking energy devices in multi criteria contexts.

The Spearman correlation coefficient test is employed to get the degree of correlation among the ranks obtained by different multi criteria evaluation methods.

Sensitivity analyses are performed to know the effect of parameter changes on the ranking of PSC with a view to suggest alternative strategies for its better dissemination in Indian populaces.

5.1. Evaluation by Outranking (PROMETHEE)

Following the formulations of pay off matrices, MCPI is computed for all the decision making groups following step by step approach of PROMETHEE as discussed in section 4.5. Difference between devices for criteria was calculated for all the 30 criteria yielding a matrix of 9 x 9. A sample matrix for fuel consumption (CR 1) based on overall pay-off matrix and indicating the difference between criteria is as shown in Table 5.1. Preference function for criteria was also computed for 30 criteria considering the usual criterion function. A sample matrix for fuel consumption (CR 1) based on overall pay-off matrix and indicating the assignment of preference function is as shown in Table 5.2.

Table 5.1 Difference between Devices for Fuel Consumption (CR 1)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
A1	0.000	-1.000	-1.500	-2.000	-1.175	0.000	0.000	-2.000	-2.000
A2	1.000	0.000	-0.500	-1.000	-0.750	1.000	1.000	-1.000	-1.000
A3	1.500	0.500	0.000	-0.500	-0.250	1.5000	1.5000	-0.500	-0.500
A4	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000
A5	1.750	0.750	0.250	-0.250	0.000	1.750	1.750	-0.250	-0.250
A6	0.000	-1.000	-1.500	-2.000	-1.750	0.000	0.000	-2.000	-2.000
A7	0.000	-1.000	-1.500	-2.000	-1.750	0.000	0.000	-2.000	-2.000
A8	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000
A9	2.000	1.000	0.500	0.000	0.250	2.000	2.000	0.000	0.000

Table 5.2 Preference Functions for Fuel Consumption (CR 1) for the Devices

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
A1	0.000	1.000	1.000	1.000	1.000	0.000	0.000	1.000	1.000
A2	0.000	0.000	1.000	1.000	1.000	0.000	0.000	1.000	1.000
A3	0.000	0.000	0.000	1.000	1.000	0.000	0.000	1.000	1.000
A4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A5	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	1.000
A6	0.000	1.000	1.000	1.000	0.000	0.000	0.000	1.000	1.000
A7	0.000	1.000	1.000	1.000	1.000	0.000	0.000	1.000	1.000
A8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Multi Criteria Preference Index and ranking pattern for the devices is shown in Table 5.3a to 5.3e. The diagonal elements in the matrix are zero as alternatives are compared with same. ϕ^{+} Values are obtained by adding all rows as explained by Equation 3. $\phi-$ Values have been obtained by adding columns as explained by Equation 4. Net ϕ values have been obtained as explained by Equation 5

Table 5.3a Overall MCPI and Ranking Pattern

	MCPI Values									ϕ^{+}	ϕ^{-}	ϕ	Rank
	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*				
A1	0.000	0.205	0.338	0.296	0.213	0.311	0.311	0.423	0.385	2.4804	4.9509	*-2.4705*	*9*
A2	0.674	0.000	0. 350	0.329	0.250	0.371	0.415	0.461	0.419	3.268	4.4013	*-1.1329*	*8*
A3	0.515	0.594	0.000	0.440	0.123	0.421	0.453	0.539	0.496	3.5811	3.8937	*-0.3126*	*5*
A4	0.649	0.615	0.504	0.000	0.178	0.323	0.390	0.525	0.467	3.6504	3.6897	*-0.0393*	*4*
A5	0.729	0.718	0.792	0.751	0.000	0.510	0.619	0.612	0.643	5.3738	2.1124	*3.2613*	*1*
A6	0.596	0.596	0.521	0.546	0.371	0.000	0.526	0.609	0.643	4.4083	2.8699	*1.5384*	*2*
A7	0.596	0.553	0.451	0.474	0.300	0.219	0.000	0.643	0.641	3.8772	3.4284	*0.4888*	*3*
A8	0.458	0.539	0.434	0.410	0.360	0.357	0.357	0.000	0.577	3.4933	4.1965	*-0.7032*	*7*
A9	0.615	0.581	0.500	0.443	0.317	0.357	0.359	0.385	0.000	3.5616	4.1515	*-0.5899*	*6*

Table 5.3b MCPI and Ranking Pattern for Policy Makers

	MCPI Values									ϕ^{+}	ϕ^{-}	ϕ	*Rank*
	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*				
A1	0.000	0.204	0.239	0.311	0.297	0.357	0.357	0.411	0.430	2.6382	4.3041	*-1.6659*	*9*
A2	0.402	0.000	0.194	0.218	0.256	0.423	0.423	0.475	0.433	2.8231	4.2903	*-1.4672*	*8*
A3	0.555	0.615	0.000	0.484	0.238	0.439	0.543	0.614	0.534	4.0224	2.8978	*1.1246*	*3*
A4	0.605	0.636	0.324	0.000	0.155	0.315	0.429	0.526	0.505	3.4946	3.3809	*0.1137*	*4*
A5	0.648	0.712	0.644	0.731	0.000	0.459	0.647	0.649	0.682	5.1727	1.9885	*3.1842*	*1*
A6	0.545	0.545	0.474	0.543	0.281	0.000	0.486	0.581	0.614	4.0692	2.8313	*1.2379*	*2*
A7	0.486	0.516	0.266	0.371	0.162	0.098	0.000	.0522	0.578	3.0283	3.6582	*-0.6299*	*5*
A8	0.525	0.525	0.322	0.324	0.320	0.355	0.384	0.000	0.342	3.1374	4.2225	*-1.0851*	*7*
A9	0.536	0.536	0.435	0.360	0.280	0.386	0.389	0.384	0.000	3.3062	4.1185	*-0.8123*	*6*

Table 5.3c MCPI and Ranking Pattern for Researchers

	MCPI Values												
	A1	***A2***	***A3***	***A4***	***A5***	***A6***	***A7***	***A8***	***A9***	ϕ^+	ϕ^-	ϕ	*Rank*
A1	0.000	0.098	0.304	0.270	0.314	0.373	0.373	0.436	0.451	2.617	4.176	***-1.558***	*9*
A2	0.446	0.000	0.397	0.235	0.304	0.475	0.475	0.500	0.475	3.308	3.735	***-0.426***	*7*
A3	0.446	0.480	0.000	0.392	0.206	0.490	0.426	0.515	0.471	3.426	3.490	***-0.063***	*4*
A4	0.608	0.583	0.520	0.000	0.333	0.500	0.495	0.490	0.490	4.019	2.872	***1.147***	*2*
A5	0.642	0.657	0.608	0.490	0.000	0.505	0.554	0.475	0.525	4.455	2.656	***1.799***	*1*
A6	0.505	0.466	0.348	0.392	0.324	0.000	0.118	0.402	0.466	3.019	3.558	***-0.539***	*8*
A7	0.505	0.466	0.363	0.343	0.240	0.279	0.000	0.446	0.451	3.093	3.357	***-0.264***	*6*
A8	0.539	0.500	0.422	0.363	0.495	0.471	0.471	0.000	0.441	3.704	3.637	***0.063***	*3*
A9	0.485	0.485	0.529	0.387	0.441	0.466	0.466	0.373	0.000	3.612	3.769	***-0.156***	*5*

Table 5.3d Overall MCPI and Ranking Pattern for Educators

	MCPI Values									ϕ^+	ϕ^-	ϕ	*Rank*
	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*				
A1	0.000	0.143	0.298	0.272	0.258	0.360	0.233	0.427	0.657	2.437	4.436	*-1.998*	*9*
A2	0.524	0.000	0.464	0.272	0.282	0.378	0.378	0.460	0.390	3.149	3.875	*-0.726*	*7*
A3	0.490	0.451	0.000	0.275	0.124	0.327	0.361	0.473	0.330	2.830	4.226	*-1.396*	*8*
A4	0.643	0.502	0.640	0.000	0.202	0.314	0.317	0.412	0.431	3.460	3.286	*0.174*	*4*
A5	0.622	0.622	0.668	0.626	0.000	0.346	0.58	0.585	0.585	4.657	2.293	*2.364*	*1*
A6	0.521	0.558	0.554	0.520	0.484	0.000	0.443	0.581	0.588	4.249	2.581	*1.668*	*2*
A7	0.521	0.521	0.483	0.480	0.279	0.174	0.000	0.580	0.552	3.590	3.091	*0.498*	*3*
A8	0.503	0.540	0.499	0.459	0.354	0.343	0.380	0.000	0.398	3.476	3.842	*-0.366*	*6*
A9	0.611	0.538	0.602	0.382	0.309	0.339	0.307	0.325	0.000	3.411	3.630	*-0.218*	*5*

Table 5.3e MCPI and Ranking Pattern for Users

	MCPI Values									ϕ^+	ϕ^-	ϕ	Rank
	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*				
A1	0.000	0.166	0.125	0.280	0.186	0.294	0.260	0.323	0.320	1.954	5.283	*-3.329*	*9*
A2	0.641	0.000	0.314	0.207	0.190	0.321	0.287	0.291	0.325	2.257	4.603	*-2.027*	*8*
A3	0.658	0.386	0.000	0.354	0.210	0.369	0.335	0.391	0.362	3.0670	3.9587	*-0.8918*	*6*
A4	0.641	0.673	0.566	0.000	0.190	0.173	0.231	0.243	0.342	3.0579	4.0310	*-0.9731*	*7*
A5	0.721	0.721	0.680	0.754	0.000	0.352	0.479	0.422	0.477	4.6066	2.5130	*2.0936*	*1*
A6	0.615	0.615	0.511	0.610	0.497	0.000	0.248	0.537	0.535	4.1688	2.5030	*1.6658*	*3*
A7	0.650	0.656	0.571	0.648	0.403	0.277	0.000	0.533	0.566	4.3041	2.6225	*1.6816*	*2*
A8	0.677	0.709	0.591	0.607	0.434	0.388	0.393	0.000	0.321	4.1216	3.1827	*0.9389*	*4*
A9	0.680	0.675	0.600	0.571	0.402	0.328	0.390	0.443	0.000	4.0894	3.2474	*0.8419*	*5*

The highest net ϕ value is considered to be the best, whereas low ϕ is the least preferred. In the present study LPG Stove having a maximum net ϕ value of is found to be the most preferred device and *chulha* having a minimum net ϕ value of is found to be the least preferred device. The most preferred device was found to be LPG as per all the respondent groups, the net ϕ being 3.261 as allotted by the overall evaluation and 3.184, 1.979, 2.364, 2.093 as per the policy makers, researchers, educators and users respectively. The positive net ϕ values are indicating that the said device has more strengths as compared to the weaknesses on all the criteria applied. The least preferred device was found to be *chulha* as per all the respondent groups, the net ϕ being -2.470 as allotted by the overall evaluation and -1.665,-1.558 -1.998, -3.329 as per the policy makers, researchers, educators and users respectively. The negative net ϕ values are indicating that the said device has more weaknesses as compared to the strengths on all the criteria applied. The ranking pattern for other identified devices does not resemble such clear judgments. Table 5.4 presents the summary of results for PSC.

Table 5.4 Summary of Outranking Evaluation for PSC

Sr No	*Group*	ϕ^+	ϕ^-	ϕ	*Rank*
1	Overall	3.5616	4.1515	-0.5899	6
2	Policy Makers	3.3062	4.1185	-0.8123	6
3	Researchers	3.6120	3.7690	-0.1560	5
4	Educators	3.4110	3.6300	-0.2180	5
5	Users	4.0894	3.2474	0.8419	5

From the Table 5.4 it is clear that PSC is occupies fifth to sixth rank in the cooking energy ladder identified for the present problem. Most of the respondent groups have indicated that weaknesses are predominant over the strengths However; the user group has recorded a different judgment. Since the net ϕ value is indicative of relative strengths over the weaknesses in that particular group, its magnitude has little significance. The competing devices in the evaluation are LPG, microwave and electric oven, biogas stove and kerosene stove in a few cases. Figure 5.1 shows the summary of rankings.

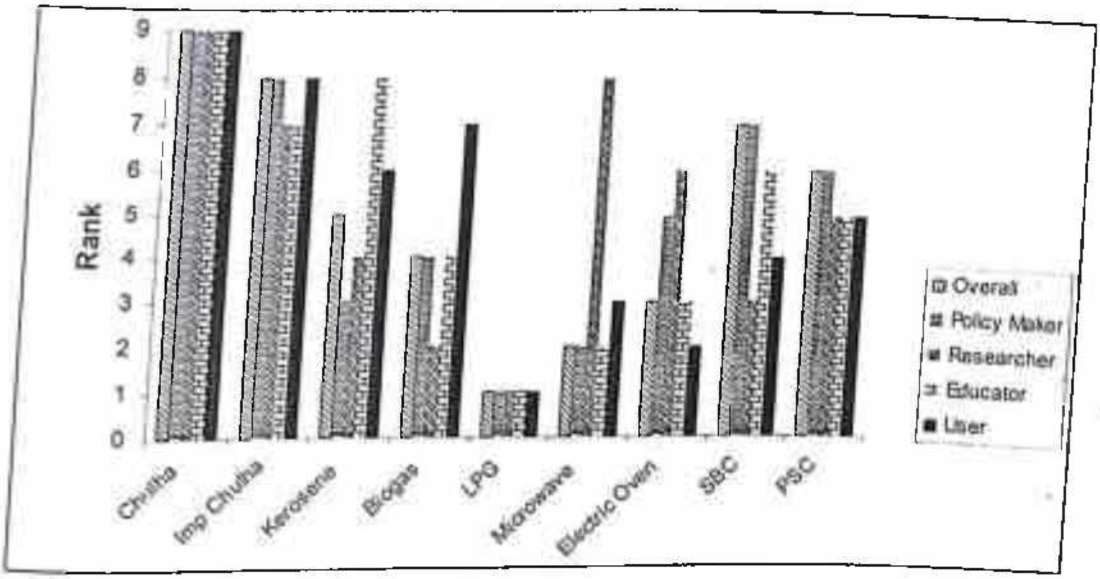


Figure 5.1 Summary of Rankings by Outranking Evaluation

Figure 5.1 indicates confirms the consumer affluence of cooking energy technologies as discussed in introduction to the thesis. However, the ranking PSC is found to be competitive to SBC. The sensitivity analyses to devise alternative strategies for improvement in the rank of PSC are discussed towards the end of this chapter.

5.2. Evaluation by Priority (AHP)

Following the computation of weightages for criteria as discussed in section 4.4 of the methodology and the formulation of hierarchical structure, pair wise comparisons are performed for all the 30 criteria involved in the problem. Since the methodology followed uses direct weighing of criteria the check for inconsistency is not required as such. However, the consistency ratios for all the 9 x 9 matrices are computed using MATLAB and is found equal to zero ((λ_{max} = 9, N'=9, CI=0, RI= 1.45, CR=0).

The sample calculations for local priorities of durability (CR 3) are shown in Table 5.5. Following this methodology the local priorities for all the devices are computed for all the decision making groups.

Table 5.5 Pair-wise Comparison Matrix for Durability (CR3)

	A1	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	***Priorities***
A1	1	0.25	0.067	0.2	0.05	0.2	0.2	0.1	0.05	***0.0118***
A2	4	1	0.267	0.8	0.2	0.8	0.8	0.4	0.2	***0.0471***
A3	15	3.75	1	3	0.75	3	3	1.5	0.75	***0.1765***
A4	5	1.25	0.333	1	0.25	1	1	0.5	0.25	***0.0588***
A5	20	5	1.333	4	1	4	4	2	1	***0.2353***
A6	5	1.25	0.333	1	0.25	1	1	0.5	0.25	***0.0588***
A7	5	1.25	0.333	1	0.25	1	1	0.5	0.25	***0.0588***
A8	10	2.5	0.667	2	0.5	2	2	1	0.5	***0.1176***
A9	20	5	1.333	4	1	4	4	2	1	***0.2353***

The summations of products of these local priorities and weightages yield global priorities for the devices. The global priorities are shown in Table 5.6.

Table 5.6 Global Priorities for the Devices

Devices	*Overall*	*Policy Makers*	*Researchers*	*Educators*	*Users*
A1	0.0882	0.0859	0.0868	0.0830	0.0748
A2	0.0894	0.0912	0.0895	0.0901	0.0850
A3	0.0906	0.0970	0.0907	0.0872	0.0828
A4	0.1213	0.1205	0.1286	0.1231	0.1185
A5	0.1341	0.1435	0.1325	0.1392	0.1376
A6	0.1277	0.1362	0.1236	0.1324	0.1292
A7	0.1303	0.1269	0.1228	0.1241	0.1283
A8	0.1078	0.0987	0.1135	0.1098	0.1162
A9	0.1108	0.1002	0.1120	0.1111	0.1278

The device with maximum global priority is preferred by the decision group. An analysis of the global priorities indicates that LPG has been given highest global priority by all the decision making groups and *chulha* has been given the least priority by the respondent groups. This is perfectly matching with the rankings computed by outranking method as discussed in previous chapter. Table 5.7 presents the summary of results for PSC.

Table 5.7 Summary of Priorities for PSC

Sr No	*Group*	*Priority*	*Rank*
1	Overall	0.1108	5
2	Policy Makers	0.1002	5
3	Researchers	0.1120	6
4	Educators	0.1111	5
5	Users	0.1277	4

The magnitude of global priority values are indicative of relative strengths over the weaknesses in that particular group and have a little significance in comparison with the magnitudes obtained by other evaluation techniques.

From the Table 5.7 it is clear that PSC is occupies fourth to sixth rank in the cooking energy ladder identified for the present problem. The competing devices in the evaluation are LPG, microwave and electric oven, biogas stove and kerosene stove in a few cases. Figure 5.2 shows the summary of rankings by priority.

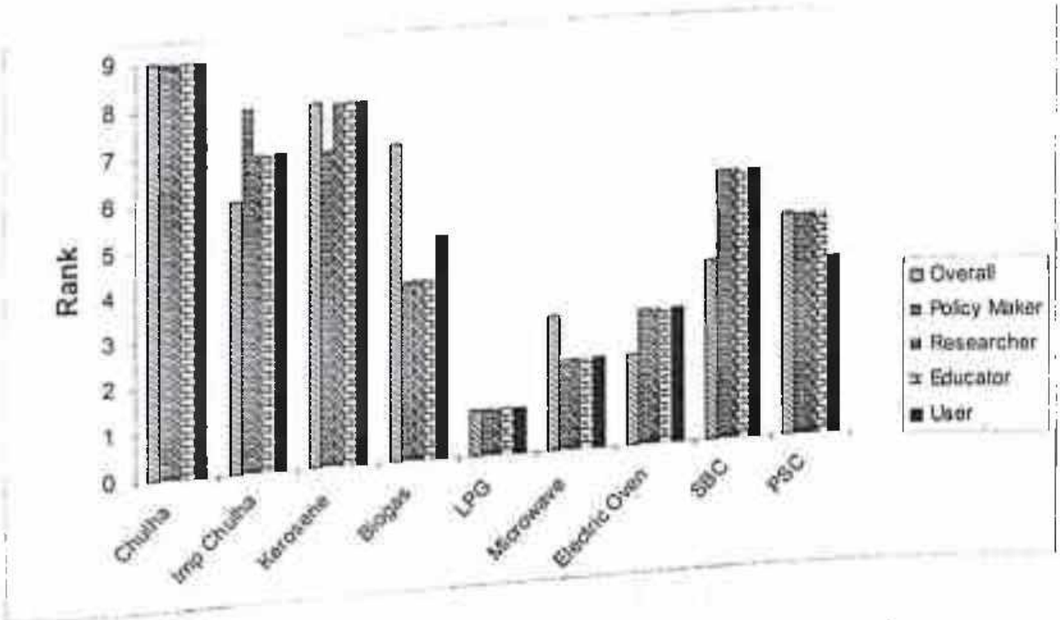


Figure 5.2 Summary of Rankings by Priority Evaluation

Figure 5.2 confirms the consumer affluence of cooking energy technologies as discussed in introduction to the thesis. However, the ranking PSC is found to be competitive to SBC. The sensitivity analyses to devise alternative strategies for improvement in the rank of PSC are discussed towards the end of this chapter.

5.3. Multi Attribute Utility Assessment

Following the formulations of evaluation matrices, the utility of identified devices is computed for all the decision making groups applying the step by step approach of MAUT as discussed in section 4.6 of the previous chapter. The evaluation matrices are normalized by assigning maximum utility for a device is assigned as one and the minimum as zero. The intermediate utilities of other devices under the sub-criteria are determined by the pair of lotteries with probability as 0.5 and linear utility functions as discussed in section 4.7.2 of the methodology. The linear utility functions are employed since the device selection is a risk neutral problem involving not much investment. The normalized evaluation matrices for all the decision making groups are presented in Table 5.8.

The product of sub criteria weightages and the normalized utilities yield the local utilities for the devices. The summation of utilities of a device on all the sub criteria gives the final utility of the identified device. Tables 5.9a to 5.9 e present the final utility values for the identified devices on all the sub criteria. The last rows in the tabulations indicate overall utilities and the rank obtained by the device.

Table 5.8 Normalized Overall Evaluation Matrix

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	0.000	0.500	0.750	1.000	0.875	0.000	0.000	1.000	1.000
CR 2.	0.686	0.686	0.857	0.943	0.943	1.000	0.857	0.000	0.914
CR 3.	0.000	0.158	0.737	0.211	1.000	0.211	0.211	0.474	1.000
CR 4.	0.000	0.163	0.280	0.269	1.000	0.961	0.867	0.161	0.296
CR 5.	0.000	0.171	0.271	0.497	0.803	1.000	0.916	0.421	0.503
CR 6.	0.980	1.000	0.980	0.000	0.816	0.918	0.959	0.918	0.714
CR 7.	1.000	0.900	0.888	0.554	0.896	0.554	0.237	0.116	0.000
CR 8.	0.988	0.939	0.988	0.873	1.000	0.770	0.770	0.000	0.016
CR 9.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	0.330
CR 10.	0.000	0.043	0.069	0.265	0.364	0.427	0.395	1.000	0.967
CR 11.	1.000	0.995	0.976	0.375	0.501	0.000	0.375	0.751	0.125
CR 12.	0.950	0.975	0.750	1.000	0.375	0.500	0.000	1.000	1.000
CR 13.	1.000	1.000	0.750	0.000	0.750	0.000	0.000	0.750	0.900
CR 14.	0.000	0.025	0.000	1.000	0.000	0.000	0.000	0.250	1.000
CR 15.	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.769	0.769
CR 16.	1.000	0.769	0.872	0.508	0.515	0.298	0.262	0.015	0.000
CR 17.	1.000	0.831	0.620	0.535	0.144	0.019	0.000	0.180	0.178
CR 18.	0.165	0.304	0.000	0.371	0.210	0.358	0.243	1.000	0.933
CR 19.	0.000	0.130	0.543	0.397	0.703	1.000	0.918	0.606	0.524
CR 20.	0.000	0.114	0.402	0.320	1.000	0.797	0.397	0.194	0.194
CR 21.	0.294	0.359	0.000	0.392	0.641	0.576	0.576	1.000	1.000
CR 22.	0.000	0.149	0.203	0.412	0.728	1.000	0.962	0.874	0.853
CR 23.	0.000	0.014	0.318	0.388	1.000	1.000	0.765	0.356	0.125
CR 24.	0.788	0.839	0.767	0.790	1.000	0.530	0.521	0.000	0.159
CR 25.	0.214	0.157	0.242	0.222	0.000	0.368	0.265	1.000	0.877
CR 26.	0.000	0.455	0.592	0.834	0.886	1.000	0.758	0.521	0.436
CR 27.	0.779	0.554	0.756	0.488	1.000	0.907	0.857	0.000	0.050
CR 28.	0.468	0.325	0.772	0.276	1.000	0.672	0.724	0.140	0.000
CR 29.	0.000	0.133	0.516	0.514	0.977	0.883	1.000	0.668	0.652
CR 30.	1.000	0.769	0.851	0.638	0.856	0.435	0.321	0.171	0.000

Table 5.9a Overall Utility Matrix

Devices / CR No	A1	A2	A3	A4	A5	A6	A7	A8	A9
CR 1.	0.0000	0.0178	0.0266	0.0355	0.0311	0.0000	0.0000	0.0355	0.0355
CR 2.	0.0263	0.0263	0.0329	0.0362	0.0362	0.0384	0.0329	0.0000	0.0351
CR 3.	0.0000	0.0063	0.0293	0.0084	0.0397	0.0084	0.0084	0.0188	0.0397
CR 4.	0.0000	0.0061	0.0105	0.0101	0.0376	0.0361	0.0326	0.0060	0.0111
CR 5.	0.0000	0.0056	0.0088	0.0162	0.0262	0.0326	0.0299	0.0137	0.0164
CR 6.	0.0325	0.0332	0.0325	0.0000	0.0271	0.0305	0.0318	0.0305	0.0237
CR 7.	0.0310	0.0279	0.0275	0.0172	0.0278	0.0172	0.0073	0.0036	0.0000
CR 8.	0.0331	0.0314	0.0331	0.0292	0.0335	0.0258	0.0258	0.0000	0.0005
CR 9.	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0000	0.0108
CR 10.	0.0000	0.0016	0.0026	0.0098	0.0135	0.0159	0.0146	0.0371	0.0359
CR 11.	0.0371	0.0369	0.0362	0.0139	0.0186	0.0000	0.0139	0.0279	0.0046
CR 12.	0.0278	0.0286	0.0220	0.0293	0.0110	0.0147	0.0000	0.0293	0.0293
CR 13.	0.0274	0.0274	0.0206	0.0000	0.0206	0.0000	0.0000	0.0206	0.0247
CR 14.	0.0000	0.0006	0.0000	0.0252	0.0000	0.0000	0.0000	0.0063	0.0252
CR 15.	0.0230	0.0230	0.0230	0.0230	0.0000	0.0000	0.0000	0.0177	0.0177
CR 16.	0.0217	0.0167	0.0189	0.0110	0.0112	0.0065	0.0057	0.0003	0.0000
CR 17.	0.0296	0.0246	0.0184	0.0158	0.0043	0.0006	0.0000	0.0053	0.0053
CR 18.	0.0071	0.0131	0.0000	0.0161	0.0091	0.0155	0.0105	0.0433	0.0404
CR 19.	0.0000	0.0045	0.0189	0.0138	0.0245	0.0348	0.0320	0.0211	0.0182
CR 20.	0.0000	0.0036	0.0126	0.0100	0.0314	0.0250	0.0125	0.0061	0.0061
CR 21.	0.0112	0.0137	0.0000	0.0149	0.0244	0.0219	0.0219	0.0381	0.0381
CR 22.	0.0000	0.0055	0.0075	0.0152	0.0268	0.0368	0.0354	0.0322	0.0314
CR 23.	0.0000	0.0005	0.0123	0.0150	0.0387	0.0387	0.0296	0.0138	0.0048
CR 24.	0.0262	0.0278	0.0255	0.0262	0.0332	0.0176	0.0173	0.0000	0.0053
CR 25.	0.0065	0.0048	0.0074	0.0068	0.0000	0.0112	0.0081	0.0306	0.0269
CR 26.	0.0000	0.0156	0.0203	0.0285	0.0303	0.0342	0.0259	0.0178	0.0149
CR 27.	0.0274	0.0195	0.0266	0.0172	0.0352	0.0319	0.0302	0.0000	0.0018
CR 28.	0.0166	0.0116	0.0274	0.0098	0.0355	0.0239	0.0257	0.0050	0.0000
CR 29.	0.0000	0.0042	0.0163	0.0162	0.0308	0.0278	0.0315	0.0210	0.0205
CR 30.	0.0323	0.0248	0.0275	0.0206	0.0276	0.0140	0.0104	0.0055	0.0000
Total	*0.4495*	*0.4958*	*0.5776*	*0.5238*	*0.7183*	*0.5925*	*0.5265*	*0.4871*	*0.5239*
Rank	*9*	*7*	*3*	*6*	*1*	*2*	*4*	*8*	*5*

Table 5.9b Utility Matrix for Policy Makers

Devices CR No	A1	A2	A3	A4	A5	A6	A7	A8	A9
CR 1.	0.0000	0.0215	0.0322	0.0429	0.0375	0.0000	0.0000	0.0429	0.0429
CR 2.	0.0280	0.0280	0.0350	0.0385	0.0385	0.0408	0.0350	0.0000	0.0373
CR 3.	0.0000	0.0060	0.0281	0.0080	0.0382	0.0080	0.0080	0.0181	0.0382
CR 4.	0.0142	0.0178	0.0249	0.0249	0.0320	0.0320	0.0249	0.0000	0.0036
CR 5.	0.0000	0.0046	0.0069	0.0137	0.0251	0.0320	0.0297	0.0114	0.0137
CR 6.	0.0338	0.0345	0.0338	0.0000	0.0282	0.0317	0.0331	0.0317	0.0246
CR 7.	0.0211	0.0169	0.0126	0.0084	0.0295	0.0253	0.0211	0.0042	0.0000
CR 8.	0.0316	0.0316	0.0316	0.0259	0.0345	0.0288	0.0288	0.0000	0.0000
CR 9.	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0000	0.0040
CR 10.	0.0000	0.0000	0.0000	0.0000	0.0066	0.0033	0.0000	0.0295	0.0262
CR 11.	0.0369	0.0367	0.0360	0.0139	0.0185	0.0000	0.0139	0.0277	0.0046
CR 12.	0.0346	0.0355	0.0273	0.0364	0.0137	0.0182	0.0000	0.0364	0.0364
CR 13.	0.0308	0.0308	0.0231	0.0000	0.0231	0.0000	0.0000	0.0231	0.0277
CR 14.	0.0000	0.0006	0.0000	0.0225	0.0000	0.0000	0.0000	0.0056	0.0225
CR 15.	0.0222	0.0222	0.0222	0.0222	0.0000	0.0000	0.0000	0.0171	0.0171
CR 16.	0.0267	0.0205	0.0185	0.0144	0.0123	0.0062	0.0041	0.0000	0.0000
CR 17.	0.0332	0.0255	0.0128	0.0102	0.0000	0.0000	0.0000	0.0128	0.0102
CR 18.	0.0102	0.0204	0.0102	0.0051	0.0255	0.0255	0.0000	0.0357	0.0306
CR 19.	0.0000	0.0024	0.0333	0.0119	0.0190	0.0357	0.0309	0.0143	0.0095
CR 20.	0.0000	0.0022	0.0175	0.0131	0.0328	0.0241	0.0087	0.0044	0.0044
CR 21.	0.0237	0.0237	0.0000	0.0047	0.0095	0.0000	0.0000	0.0332	0.0332
CR 22.	0.0000	0.0024	0.0119	0.0119	0.0285	0.0332	0.0308	0.0261	0.0237
CR 23.	0.0064	0.0064	0.0193	0.0193	0.0355	0.0419	0.0355	0.0032	0.0000
CR 24.	0.0173	0.0173	0.0194	0.0237	0.0259	0.0130	0.0130	0.0000	0.0065
CR 25.	0.0270	0.0270	0.0270	0.0308	0.0154	0.0116	0.0116	0.0039	0.0000
CR 26.	0.0000	0.0221	0.0332	0.0221	0.0332	0.0111	0.0000	0.0000	0.0000
CR 27.	0.0419	0.0326	0.0326	0.0279	0.0279	0.0279	0.0233	0.0000	0.0047
CR 28.	0.0281	0.0281	0.0281	0.0113	0.0394	0.0394	0.0394	0.0056	0.0000
CR 29.	0.0000	0.0092	0.0216	0.0123	0.0308	0.0246	0.0246	0.0123	0.0092
CR 30.	0.0308	0.0261	0.0261	0.0237	0.0284	0.0142	0.0118	0.0071	0.0000
Total	*0.5305*	*0.5845*	*0.6571*	*0.5318*	*0.7214*	*0.5603*	*0.4601*	*0.4063*	*0.4308*
Rank	*6*	*3*	*2*	*5*	*1*	*4*	*7*	*9*	*8*

Table 5.9c Utility Matrix for Researchers

Devices *CR No*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	0.0000	0.0197	0.0296	0.0394	0.0345	0.0000	0.0000	0.0394	0.0394
CR 2.	0.0335	0.0335	0.0418	0.0460	0.0460	0.0488	0.0418	0.0000	0.0446
CR 3.	0.0000	0.0054	0.0253	0.0072	0.0343	0.0072	0.0072	0.0162	0.0343
CR 4.	0.0151	0.0151	0.0227	0.0113	0.0340	0.0302	0.0302	0.0000	0.0113
CR 5.	0.0000	0.0020	0.0102	0.0123	0.0184	0.0225	0.0245	0.0041	0.0102
CR 6.	0.0432	0.0441	0.0432	0.0000	0.0360	0.0405	0.0423	0.0405	0.0315
CR 7.	0.0137	0.0137	0.0343	0.0137	0.0343	0.0206	0.0206	0.0000	0.0069
CR 8.	0.0098	0.0098	0.0049	0.0245	0.0000	0.0000	0.0000	0.0196	0.0245
CR 9.	0.0196	0.0196	0.0196	0.0196	0.0196	0.0196	0.0196	0.0000	0.0098
CR 10.	0.0000	0.0000	0.0000	0.0168	0.0056	0.0000	0.0000	0.0336	0.0392
CR 11.	0.0343	0.0341	0.0335	0.0129	0.0172	0.0000	0.0129	0.0258	0.0043
CR 12.	0.0326	0.0334	0.0257	0.0343	0.0129	0.0172	0.0000	0.0343	0.0343
CR 13.	0.0294	0.0294	0.0221	0.0000	0.0221	0.0000	0.0000	0.0221	0.0265
CR 14.	0.0000	0.0006	0.0000	0.0245	0.0000	0.0000	0.0000	0.0061	0.0245
CR 15.	0.0343	0.0343	0.0343	0.0343	0.0000	0.0000	0.0000	0.0264	0.0264
CR 16.	0.0196	0.0121	0.0196	0.0060	0.0121	0.0075	0.0060	0.0000	0.0000
CR 17.	0.0392	0.0343	0.0245	0.0196	0.0147	0.0098	0.0098	0.0000	0.0049
CR 18.	0.0088	0.0132	0.0000	0.0265	0.0000	0.0000	0.0000	0.0441	0.0353
CR 19.	0.0000	0.0103	0.0137	0.0137	0.0274	0.0309	0.0343	0.0137	0.0137
CR 20.	0.0000	0.0061	0.0184	0.0061	0.0245	0.0123	0.0123	0.0000	0.0000
CR 21.	0.0078	0.0078	0.0000	0.0392	0.0235	0.0157	0.0157	0.0392	0.0392
CR 22.	0.0000	0.0102	0.0136	0.0271	0.0271	0.0441	0.0441	0.0441	0.0441
CR 23.	0.0098	0.0294	0.0098	0.0392	0.0392	0.0196	0.0196	0.0196	0.0000
CR 24.	0.0257	0.0257	0.0257	0.0221	0.0294	0.0110	0.0147	0.0000	0.0037
CR 25.	0.0265	0.0265	0.0235	0.0206	0.0294	0.0147	0.0176	0.0000	0.0029
CR 26.	0.0098	0.0098	0.0049	0.0098	0.0000	0.0049	0.0049	0.0343	0.0343
CR 27.	0.0172	0.0172	0.0286	0.0114	0.0343	0.0229	0.0343	0.0057	0.0000
CR 28.	0.0090	0.0045	0.0226	0.0113	0.0294	0.0204	0.0249	0.0023	0.0000
CR 29.	0.0000	0.0000	0.0184	0.0245	0.0245	0.0245	0.0245	0.0123	0.0061
CR 30.	0.0343	0.0172	0.0274	0.0172	0.0274	0.0137	0.0103	0.0069	0.0000
Total	*0.4732*	*0.5191*	*0.5978*	*0.5911*	*0.6577*	*0.4584*	*0.4721*	*0.4902*	*0.5519*
Rank	*7*	*5*	*2*	*3*	*1*	*9*	*8*	*6*	*4*

Table 5.9d Utility Matrix for Educators

Devices / *CR No*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	0.0000	0.0166	0.0248	0.0331	0.0290	0.0000	0.0000	0.0331	0.0331
CR 2.	0.0259	0.0259	0.0323	0.0355	0.0355	0.0377	0.0323	0.0000	0.0345
CR 3.	0.0000	0.0059	0.0275	0.0079	0.0373	0.0079	0.0079	0.0177	0.0373
CR 4.	0.0000	0.0099	0.0049	0.0099	0.0395	0.0346	0.0247	0.0148	0.0099
CR 5.	0.0000	0.0052	0.0069	0.0173	0.0242	0.0311	0.0225	0.0138	0.0138
CR 6.	0.0351	0.0358	0.0351	0.0000	0.0292	0.0329	0.0343	0.0329	0.0256
CR 7.	0.0365	0.0365	0.0243	0.0183	0.0304	0.0122	0.0000	0.0183	0.0000
CR 8.	0.0091	0.0000	0.0183	0.0365	0.0183	0.0365	0.0365	0.0091	0.0183
CR 9.	0.0311	0.0311	0.0311	0.0311	0.0311	0.0311	0.0311	0.0000	0.0078
CR 10.	0.0000	0.0000	0.0032	0.0096	0.0096	0.0193	0.0193	0.0385	0.0353
CR 11.	0.0378	0.0376	0.0369	0.0142	0.0189	0.0000	0.0142	0.0284	0.0047
CR 12.	0.0281	0.0289	0.0222	0.0296	0.0111	0.0148	0.0000	0.0296	0.0296
CR 13.	0.0284	0.0284	0.0213	0.0000	0.0213	0.0000	0.0000	0.0213	0.0256
CR 14.	0.0000	0.0006	0.0000	0.0224	0.0000	0.0000	0.0000	0.0056	0.0224
CR 15.	0.0215	0.0215	0.0215	0.0215	0.0000	0.0000	0.0000	0.0165	0.0165
CR 16.	0.0207	0.0175	0.0223	0.0127	0.0143	0.0080	0.0096	0.0000	0.0000
CR 17.	0.0325	0.0293	0.0260	0.0293	0.0065	0.0000	0.0000	0.0065	0.0098
CR 18.	0.0171	0.0200	0.0000	0.0200	0.0029	0.0143	0.0171	0.0371	0.0342
CR 19.	0.0000	0.0031	0.0124	0.0155	0.0340	0.0371	0.0309	0.0278	0.0247
CR 20.	0.0000	0.0000	0.0000	0.0000	0.0325	0.0325	0.0000	0.0000	0.0000
CR 21.	0.0116	0.0116	0.0000	0.0174	0.0347	0.0405	0.0405	0.0405	0.0405
CR 22.	0.0000	0.0049	0.0000	0.0124	0.0223	0.0371	0.0346	0.0322	0.0322
CR 23.	0.0000	0.0000	0.0033	0.0100	0.0299	0.0365	0.0232	0.0265	0.0133
CR 24.	0.0274	0.0304	0.0213	0.0243	0.0274	0.0213	0.0122	0.0000	0.0030
CR 25.	0.0215	0.0215	0.0239	0.0167	0.0311	0.0144	0.0191	0.0000	0.0072
CR 26.	0.0000	0.0112	0.0225	0.0300	0.0300	0.0337	0.0225	0.0000	0.0037
CR 27.	0.0081	0.0163	0.0081	0.0163	0.0325	0.0325	0.0244	0.0000	0.0000
CR 28.	0.0260	0.0148	0.0371	0.0111	0.0371	0.0186	0.0148	0.0037	0.0000
CR 29.	0.0000	0.0030	0.0152	0.0182	0.0304	0.0304	0.0304	0.0182	0.0182
CR 30.	0.0325	0.0244	0.0271	0.0217	0.0244	0.0108	0.0108	0.0027	0.0000
Total	*0.4509*	*0.4917*	*0.5295*	*0.5422*	*0.7253*	*0.6255*	*0.5129*	*0.4749*	*0.5011*
Rank	*9*	*7*	*4*	*3*	*1*	*2*	*5*	*8*	*6*

Table 5.9e Utility Matrix for Users

Devices CR No	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
CR 1.	0.0000	0.0154	0.0231	0.0308	0.0270	0.0000	0.0000	0.0308	0.0308
CR 2.	0.0234	0.0234	0.0292	0.0322	0.0322	0.0341	0.0292	0.0000	0.0312
CR 3.	0.0000	0.0070	0.0327	0.0093	0.0444	0.0093	0.0093	0.0210	0.0444
CR 4.	0.0000	0.0055	0.0055	0.0111	0.0360	0.0388	0.0443	0.0360	0.0388
CR 5.	0.0000	0.0103	0.0103	0.0186	0.0331	0.0393	0.0393	0.0248	0.0269
CR 6.	0.0302	0.0308	0.0302	0.0000	0.0251	0.0283	0.0295	0.0283	0.0220
CR 7.	0.0205	0.0189	0.0189	0.0158	0.0079	0.0063	0.0000	0.0047	0.0063
CR 8.	0.0325	0.0325	0.0325	0.0135	0.0325	0.0190	0.0190	0.0054	0.0000
CR 9.	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0000	0.0079
CR 10.	0.0000	0.0081	0.0081	0.0202	0.0363	0.0444	0.0444	0.0444	0.0444
CR 11.	0.0376	0.0374	0.0367	0.0141	0.0188	0.0000	0.0141	0.0282	0.0047
CR 12.	0.0179	0.0183	0.0141	0.0188	0.0071	0.0094	0.0000	0.0188	0.0188
CR 13.	0.0171	0.0171	0.0128	0.0000	0.0128	0.0000	0.0000	0.0128	0.0154
CR 14.	0.0000	0.0009	0.0000	0.0376	0.0000	0.0000	0.0000	0.0094	0.0376
CR 15.	0.0274	0.0274	0.0274	0.0274	0.0000	0.0000	0.0000	0.0211	0.0211
CR 16.	0.0274	0.0228	0.0213	0.0152	0.0091	0.0061	0.0046	0.0015	0.0000
CR 17.	0.0274	0.0235	0.0235	0.0176	0.0078	0.0020	0.0000	0.0039	0.0020
CR 18.	0.0000	0.0031	0.0062	0.0154	0.0185	0.0246	0.0277	0.0400	0.0462
CR 19.	0.0000	0.0045	0.0090	0.0157	0.0224	0.0359	0.0337	0.0314	0.0292
CR 20.	0.0000	0.0077	0.0039	0.0116	0.0308	0.0308	0.0308	0.0193	0.0193
CR 21.	0.0000	0.0091	0.0091	0.0137	0.0365	0.0411	0.0411	0.0365	0.0365
CR 22.	0.0000	0.0074	0.0049	0.0147	0.0319	0.0393	0.0393	0.0344	0.0344
CR 23.	0.0164	0.0000	0.0329	0.0000	0.0247	0.0000	0.0082	0.0247	0.0411
CR 24.	0.0205	0.0274	0.0205	0.0068	0.0342	0.0137	0.0274	0.0000	0.0000
CR 25.	0.0031	0.0092	0.0000	0.0123	0.0216	0.0308	0.0308	0.0123	0.0154
CR 26.	0.0000	0.0113	0.0075	0.0188	0.0263	0.0376	0.0376	0.0188	0.0075
CR 27.	0.0186	0.0000	0.0186	0.0046	0.0325	0.0325	0.0279	0.0046	0.0093
CR 28.	0.0000	0.0000	0.0116	0.0000	0.0290	0.0116	0.0174	0.0174	0.0058
CR 29.	0.0000	0.0000	0.0041	0.0082	0.0205	0.0185	0.0287	0.0267	0.0308
CR 30.	0.0342	0.0316	0.0316	0.0184	0.0316	0.0184	0.0079	0.0053	0.0000
Total	***0.3763***	***0.4329***	***0.5084***	***0.4448***	***0.7128***	***0.5939***	***0.6144***	***0.5627***	***0.6276***
Rank	***9***	***8***	***6***	***7***	***1***	***4***	***3***	***5***	***2***

The utility values obtained for the entire decision making groups are summarized in Table 5.10. The device with maximum utility is preferred by the decision group.

Table 5.10 Global Utilities for the Devices

Devices	*Overall*	*Policy Makers*	*Researchers*	*Educators*	*Users*
A1	0.4495	0.5305	0.4732	0.4509	0.3763
A2	0.4958	0.5845	0.5191	0.4917	0.4329
A3	0.5776	0.6571	0.5978	0.5295	0.5084
A4	0.5238	0.5318	0.5911	0.5422	0.4448
A5	0.7183	0.7214	0.6577	0.7253	0.7128
A6	0.5925	0.5603	0.4584	0.6255	0.5939
A7	0.5265	0.4601	0.4721	0.5129	0.6144
A8	0.4871	0.4063	0.4902	0.4749	0.5627
A9	0.5239	0.4308	0.5519	0.5011	0.6276

An analysis of the global priorities indicates that LPG has been given highest utility by all the decision making groups. There are no consensuses on the lowest utility values amongst the groups. Table 5.11 presents the summary of results for PSC.

Table 5.11 Summary of Utilities for PSC

Sr No	*Group*	*Utility*	*Rank*
1	Overall	0.5239	5
2	Policy Makers	0.4308	8
3	Researchers	0.5519	4
4	Educators	0.5011	6
5	Users	0.6276	2

The magnitudes of utility values are indicative of relative strengths over the weaknesses in that particular group and have a little significance in comparison with the magnitudes obtained by other evaluation techniques.

From the Table 5.11 it is appears that PSC is occupies fourth to sixth rank in the cooking energy ladder identified for the present problem. The utilities and ranks assigned by users and policy makers however do not confirm the above results. The competing devices in the evaluation are LPG, microwave and electric oven, biogas stove and kerosene stove in a few cases. Figure 5.3 shows the summary of rankings by utility.

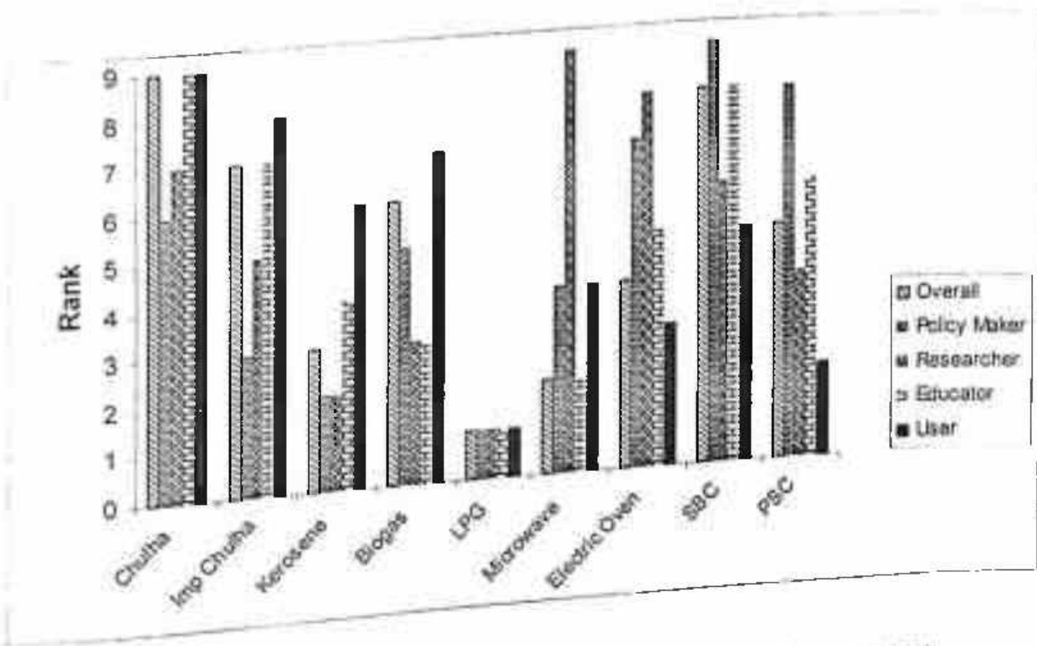


Figure 5.3 Summary of Rankings by Utility Assessment

The final rankings given by all the respondent groups using all the evaluation techniques are shown in Table 5.12.

The above discussion reveals that PSC occupies fifth to sixth position in the cooking energy ladder. The most preferred device being LPG and least preferred being *chulha*.

Table 5.12 Final Ranks obtained by Different Multi Criteria Evaluations

Device	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*
				Overall					
Outranking	9	8	5	4	1	2	3	7	6
Priority	9	6	8	7	1	3	2	4	5
Utility	9	7	3	6	1	2	4	8	5
				Policy Makers					
Outranking	9	8	3	4	1	2	5	7	6
Priority	9	8	7	4	1	2	3	6	5
Utility	6	3	2	5	1	4	7	9	8
				Researchers					
Outranking	9	7	4	2	1	8	6	3	5
Priority	9	7	8	4	1	2	3	6	5
Utility	7	5	2	3	1	9	8	6	4
				Educators					
Outranking	9	7	8	4	1	2	3	6	5
Priority	9	7	8	4	1	2	3	6	5
Utility	9	7	4	3	1	2	5	8	6
				Users					
Outranking	9	8	6	7	1	3	2	4	5
Priority	9	7	8	5	1	2	3	6	4
Utility	9	8	6	7	1	4	3	5	2

5.4. Spearman Ranking Correlation Coefficient

Spearman Ranking Correlation Coefficient *(R)* is useful to determine the measure of association between the ranks obtained by different multi criteria evaluation methods for a particular alternative/device (Raju and Pillai, 1999). If U_A and V_A are the ranks obtained by two different multi criteria evaluations for the same alternative *A*, then Spearman rank correlation coefficient is defined as follows.

$$R = 1 - \frac{6\sum_{A=1}^{A} D_A^2}{A(A^2 - 1)} \tag{15}$$

Where

$D_A = (U_A - V_A)$, A is number of alternatives.

$R = 1$ represents perfect association between the ranks,

$R = 0$ represents no association between the ranks

$R = -1$ represents perfect disagreement between the ranks

The value of R is computed to assess the degree of correlation as per the above equation. Since three methods are employed in the present problem they are correlated with other two methods resulting in six combinations. Since the relation of any two $A1$ and $A2$ is the same as that of $A2$ to $A1$ only three combinations need to be employed for each group. Table 5.13 shows the R values between groups of multi criteria evaluation methods.

Table 5.13 Spearman Rank Correlation Coefficient for Different Evaluations

Methods	***R Value***				
	Overall	***Policy Makers***	***Researchers***	***Educators***	***Users***
Outranking -Priority	0.9012	0.8189	0.3903	1.000	0.8683
Priority -Utility	0.6049	0.1193	0.0123	0.7680	0.8518
Outranking -Utility	0.9042	0.5720	0.7695	0.7680	0.9012

The analyses of R indicate that there is a good correlation between the ranks obtained by different evaluations. The correlation is not significant in two cases as shown in the Table 5.13 viz. priority-utility for researchers and priority utility for policy makers. Moreover, the range of coefficients is from 0.0123 to 1.000

5.5. Sensitivity Analyses Studies

A number of parameters are found important in assessing the usefulness of PSC in India. The parameters are classified as criteria weightages and the performance of PSC on these identified criteria. Both the issues are important since they can alter the final ranking obtained by PSC in the cooking energy ladder.

An analysis of overall weightages shows that usefulness of the selected cooking energy devices are governed by technical, followed by behavioral, commercial and social issues. It is also observed that economic criteria have been given less weightages by the evaluators. Analysis of sub-criteria weightages reveal that overall safety, durability and ease of operations are given due importance by the respondents. The rate of interest on loan has been allocated the least weightage.

An analysis of evaluations reveal the strengths of PSC as fuel consumption, durability, nutrition value of food, fuel cost, available subsidy, pollution hazards, human drudgery, taste of food, cleanliness of utensils etc. The major weaknesses being need of tracking, initial cost, sophistication level, cooking time, aesthetics, need of additional cooking system, spares, distribution network, market research and need of user training.

On the basis the above discussion, significant criteria identified for these are reduction in size/weight and space requirements, improvements in quality and reliability, reduction in initial cost, increase in available subsidy, better aesthetics, motivating potential buyers, improving ease of operation, convenience, type of dishes cooked improvements in models, spares and after sales service, distribution network, and market research. Alternative strategies are attempted with different combinations of the above identified criteria. More than 50 sensitivity analyses runs are taken for rank reversal under each of the evaluation methodologies. The rankings for a few alternative strategies are as shown in Table 5.14.

Table 5.14 Rankings of PSC for Alternative Dissemination Strategies

Sr. No	*Alternative Strategy*	*Criteria*	*Outranking*	*Priority*	*Utility*
1.	Improving quality and reliability	4	6	5	4
2.	Reducing the bulk weight, size etc	6	5	5	4
3.	Improving sophistication level	5	6	5	4
4.	Improving aesthetics	19	5	5	4
5.	Motivating potential buyers	20	5	5	4
6.	Maximizing ease of operation	23	5	5	4
7.	Cooking demos	24	5	5	4
8.	Improvement in existing models	26	5	5	4
9.	Reducing cost to Rs.2000	11	6	5	4
10	Increasing subsidy to 3000	14	6	6	4
11	Improving after sales service	27	3	5	4
12	Improvements in distribution network	28	4	5	4
13	Extensive market research	29	6	5	4
14	Improving on all technical criteria	1-10	3	5	2
15	Improving on all economic criteria	11-15	4	5	4
16	Improving on all behavioral criteria	19-25	3	4	2
17	Improving on all commercial criteria	26-30	3	3	1
18	Addressing techno economic issues	1-15	2	5	1
19	Addressing technical & behavioral issues	1-10 19-25	1	4	1
20	Addressing technical & commercial issues	1-10 26-30	1	2	1
21	Addressing economic & behavioral issues	11-25	3	4	1
22	Addressing economic & commercial issues	11-15 26-30	2	4	1
23	Addressing behavioral & commercial issues	19-30	1	2	1

The competing alternative in most of the sensitivity runs is microwave oven, electric oven and kerosene stove. Parabolic Solar Cooker has occupied fourth to sixth rank when individual improvements are attempted in most of the sensitivity runs. Simultaneously addressing a category of criteria is found to be a good alternative strategy. However economic improvements have a little impact on the ranking of PSC and resulting in fourth to fifth rank. The same was observed with social criteria. Individual issues are found not altering the ranking pattern and simultaneous addressing the behavioral issues has shown rank for PSC.

The equal weightage scenarios are also attempted for the present problem and PSC is occupying sixth rank in outranking evaluation by PROMETHEE, fifth rank in priority evaluation by AHP and fourth rank in utility assessment by MAUT.

The next chapter presents policy issues in commercialization of PSC keeping in view the results obtained by the evaluation studies and sensitivity analyses.

The significant criteria in deciding the preferences for cooking energy devices in general and PSC in particular have been discussed in methodology. The results of three evaluation studies namely outranking (PROMETHEE), Priority (AHP) and Utility (MAUT) and their sensitivity analyses presented in the results and discussion lead to identification of the significant criteria/groups of criteria to be addressed in further commercialization of PSC. This chapter presents the pros and cons of the suggested improvements for further dissemination of PSC in India. These are followed by discussion on policy framework for further commercialization.

6.1. Identified Improvements for PSC

The improvements suggested by sensitivity analyses studies which can improve the rank of PSC in cooking energy ladder in at least two evaluation methods employed are further considered in this section. The measures which have shown the rank reversal /change are listed below.

1. Reducing the bulk weight, size etc
2. Improving aesthetics
3. Motivating potential buyers
4. Arranging cooking demos
5. Improvement in existing models
6. Improving after sales service
7. Improvements in distribution network
8. Improvements in all technical criteria
9. Improving on all economic criteria
10. Improving on all behavioral criteria
11. Improving on all commercial criteria

12. Addressing techno economic issues
13. Addressing technical & behavioral issues
14. Addressing technical & commercial issues
15. Addressing economic & behavioral issues
16. Addressing economic & commercial issues
17. Addressing behavioral & commercial issues

The identified improvements for PSC indicate the following observations.

1. Only one technical improvement is found to make a little change in the rank of PSC
2. No economic issue considered in isolation is found to alter the rank. All economic issues considered together do not make any change in overall rank of PSC
3. No social issue is found to alter the rank
4. There are three behavioral issues which are significant in improving the rank
5. There are three commercial issues which are significant in improving the rank.
6. The behavioral and commercial groups are found significant in improving the rank of PSC if considered in isolation or with some other group of improvements as listed above.

Even though there are large numbers of technical criteria identified for evaluation in the present thesis and the weightage assigned to technical criteria is also the highest, there are constraints for improving on the technical issues. This is evident from the responses received from the respondent groups that they are well conversant with the developing nature of PSC technology and its limitations. Parabolic Solar

Cookers are appropriate technology devices. The reduction in size/weight and overall bulk of the device is found to be useful in altering the rank. The overall bulk of the cooker is high which is a major impediment confirmed by the evaluations. There is no provision for heat rate control and storage, making it sunshine and season dependant. The solar cookers disseminated often fail to offer the reliability user expects from resource-technology combination for cooking. Many a times the quality of solar cooker supplied is found to be poor. Spares parts do not meet the quality standards. These requirements are confirmed by the study. However, these have not shown any significant change in the ranking. The criteria like nutrient value of cooked food are also insignificant which may be due to lower educational levels.

The weightages assigned to economic criteria by the respondents is less. Moreover, the improvements in economic issues could not alter the rank of PSC which confirms that the problem of dissemination is not economic in nature.

The weightages assigned to social criteria are the lowest amongst the identified criteria. Users' do not realize its value in pollution prevention, drudgery reduction etc. These criteria could not alter the rank of the device.

Cooking with solar cookers is incompatible with traditional ways of cooking. Use of two cooking systems, one for frying and another for boiling adds to inconvenience. For most Indians, cooking and eating are private affairs. There is a reluctance to stand in the hot Sun to cook food in open. It is not possible to cook on a short notice. The solar cookers in general and PSC in particular are not used because they fail to fulfill vital needs or demand dramatic changes in cooking practices. The behavioral issues have been assigned higher weightage by the respondents and are found significant in altering the rank of PSC.

Lack of sales, service and support network, improvements in models and market research are found to be a barrier in user acceptance. The commercial issues have been assigned due weightage by the respondents and are found significant in altering the rank of PSC.

6.2. Systems Approach

The cooking energy substitution with PSC has to be addressed in a multi criteria context while planning and policy making.

The objective of the PSC programme may not be only to conserve fuel-wood or fossil fuel resources. The objectives of the programme needs to be modified as to ensure adequacy of energy supply at domestic and community levels in environmentally and socially acceptable manner. Parabolic Solar Cookers have the potential to be the vehicles to the overall goal amongst several technologies available. The assessment of comprehensive usefulness from time to time with more realistic information, higher sample size and close cooperation with the agencies involved in developmental efforts will ensure this. The approach to be adopted has to be holistic to know the problems, understand the interrelationships amongst different criteria (technical-economic-social-behavioral-commercial) and aimed at providing sustainable energy substitution solutions.

The problems identified are for PSC technology are requirement of low cost materials, reduction in weight, product development, production facilities including good quality control, financing, and a good market and service network. The need to overcome consumer inertia in terms of several behavioral issues is also confirmed by the research work. However once the above issues are addressed, behavioral inertia may be overcome to a significant extent.

The present stalemate may be due to limited investments in research and development, no follow up on improving products and programmes, lack of understanding field problems and missing links with the prospective users. In India large quantities of solar cookers are manufactured by companies subsidized by the government. A majority of the half-million solar cookers sold are in cities, almost none in rural areas where women suffer most from indoor air pollution from cooking. The programmes are social welfare initiatives failing to give product and services. The parallel programmes of commercialization and welfare have lead to ambiguity. In the pursuit of targets the main substance of motivation, quality control, maintenance, repair capacity building, institution strengthening and mobilization of communities have been lost. Once the above complex interrelationships are known, only an interdisciplinary and participatory approach can provide the sustainable solutions.

The principles to be adopted for the development and dissemination of PSC technology in India are discussed below.

(1) Integration into Socio-cultural Settings: Sound understanding of socio-cultural settings of the society is necessary. The type of food to be cooked, cooking habits, and financial conditions of the target population needs to be understood. The weightages assigned to behavioral issues and their sensitivity analyses have confirmed the importance of behavioral issues.

(2) Needs Orientation: The technology needs to be developed and disseminated as per the needs of consumers involving extensive market research which is identified in the commercial criteria. There are several indicators of needs like durability, fuel consumption, different costs, aesthetics, convenience, pollution hazards etc addressed in the present problem. Pure technology oriented things have failed in the past.

(3) Participatory Approach: This approach will ensure the due considerations of different actors involved in decision making process. This may be time consuming, but will help in breaking the inertia of consumers as well as agencies involved in dissemination process. This has been addressed by the multi criteria approaches in energy planning and the present work partially addresses this issue.

(4) Social and Environmental Sustainability as a Goal: Long term sustainability in terms of knowledge and experience building will help in disseminating similar technologies. Awareness creation, capacity building may be ensured. The weightages of social criteria in the present problem are indicators of lack of social consciousness.

(5) Assess to Technical Requirements and Support: The solar cooking technology is an appropriate technology and can be developed/modified by people as suitable to their needs. The technical support for such developments may be provided by the state. This will be help in making the designs robust and appropriate to the end users.

(6) Regular Monitoring and Intensive Follow Up: The users are given assurance on the part of the state that they wish to support the dissemination. The evaluations of the programme have to be done on regular basis. This may be in the form of availability of finance, lower rate of interests etc.

6.3. Barriers Identified through the Study

Total usefulness is primary consideration which shall be addressed by policy makers, product developers and marketers. This is a crucial for the dissemination of any renewable energy gadget in general and PSC in particular. There may be other indicators which can decide the status of technology in a country. They can be called to be derivatives of the primary consideration with respect to the dissemination aspect. It is not necessarily that masses are requiring a high technology option at lower cost. The following are major secondary considerations.

Technical Soundness

The technology of solar cookers is useful for Indian subcontinent due to ample solar radiation throughout the year. However, longer cooking times associated with SBC makes the technology unpopular and PSC have to overcome this major issue to build up the confidence in technology. The overall bulk of the devices, non availability of space and no facilities for storage and heat rate control make it unpopular for city dwellers. The cooker looks to be a prototype than a regular gadget. However, recent attempts by certain manufacturers have succeeded to give it a cozy look. The durability is high enough if supported by quality and reliability of spare parts. Low reflectivity glass in India compels the manufacturers to import the glass adding to the cost of the cooker. Acrylic film as a substitute to glass reflector also needs import. The nutrient value of food may not be appealing due to lower educational levels. A programme for solar thermal devices on the lines of photovoltaic global approval programme (PV-GAP) may be useful (Sastry, 2000).

Economic Viability

The initial cost of SBC varies between Rs. 1200-2000 depending upon the make and model. The PSCs cost Rs 7000 maximum. Even though there are no recurring fuel costs, higher initial cost is a major barrier in the economics. The concept of life cycle costing is still new to the users. The manufacturers are supported on 50 % cost sharing basis. Interest free loans to bulk users through IREDA and to individuals through couple of banks are introduced. Soft loans to financial intermediaries, non-profit organizations for on lending to individuals and for hire purchases are also highlights of the present policies of dissemination. The finance may be made available at low cost locally through banks, cooperative societies etc.

Social Acceptance

Solar cookers have excellent advantage over the other alternatives in terms of pollution hazards. The green source of energy has thus reduces human drudgery to a considerable extent in terms of fuel-wood collection, clean kitchens etc. The technology use lower concentration of energy and is safe as compared to other competing options. The awareness level on environment issues acts as a barrier in dissemination. This awareness levels can be boosted by campaigning for green energy issues through popular media. The awareness programmes prevailing today are through print media predominantly which are less effective. Television as media may be helpful in outreaching to large masses.

Behavioral Compatibility

Behavioral compatibility appears to be a major barrier in dissemination. The solar cookers can supplement to existing fuels and is not a stand alone solution for cooking. There is a quest for high technology options like microwaves in kitchens with sophisticated heat rate control etc. Also LPG is being marketed as a fuel for modern kitchens by the oil companies. The renewable nature of solar energy may not appeal due to the product features available. Trade fairs, demonstrations may be useful in building the confidence amongst the users on cleanliness of environment, utensils, taste of food as advantages of the technology. The reduction in overall bulk of cookers with improvement in aesthetics will also be improving the behavioral compatibility.

Commercial Utility

Solar cookers have to compete with existing alternatives in terms of product features with continuous market research and needs identification. The aesthetics and product range are necessary for the commercial utility of the technology. Support network in terms of spares, service and after sales service are essential. The sales and distribution network has to be expanded after accessing the market segmentation of the technology. The promoting agencies have to decide the target populations as rural and semi urban and then urban. User friendly features will be helpful in rapid dissemination of solar cookers.

6.4. Suggested Dissemination Framework

The framework of technology push framework needs to be converted into a demand pull kind of framework. The implementation approach needs to be tailored to take into consideration the local needs. The following suggestions may be helpful in better dissemination.

1. The role of NGOs as facilitators for PSC providing the necessary technical and logistic support may be attempted. This will help in developing the confidence into the technology. The users would adopt the role of hands-on planners and the actual implementers.
2. Multiple delivery mechanisms as indicated by the commercial criteria importance in the study will improve the commercialization barriers. The good after sales service is a must. The existing market channels of

consumer durables may be used with attractive commissions and tax benefits to PSC marketers/dealers.

3. Subsidies shall be eradicated since they fail to deliver the quality of products and hence reduce confidence in technology. The importance of economic criteria and sensitivity analyses studies have revealed the importance of quality and impact of subsidy.

4. The awareness creation and capacity building will ensure that the users' participation in implementation of the programme would increase. The role of NGOs and government will be facilitators of the technology and providing technical support.

5. The role of woman as an energy manager of the house, her level of participation in procuring the device, using and building confidence in technology will be helpful. Higher educational levels will ensure her role.

6. The industry support (e.g. wind industry in India) in making the technology a success is a must.

The next chapter presents summary and conclusions of the present research work and the further scope of work

India lives in villages and uses non-commercial fuels to meet their energy needs which are 36 % of the total energy needs. Though the solar cookers are being promoted in India since 1983-84, it has met with a limited success. The present research has attempted to know under which circumstances the dissemination of PSC can be expected better. The thesis is also an attempt to know whether the problem of dissemination is purely technology driven, related to purchasing power/economics, behavioral in nature, or the masses would prefer PSC in better marketing conditions etc. The level of importance given to a non-polluting and renewable energy device however seems to be lower and thus warrants a comprehensive evaluation.

The present research has evaluated PSC, a recent innovation in solar cooking technology on techno-economic, social, behavioral and commercial criteria in the present Indian context in comparison with other contemporary cooking energy devices for understanding the interventions necessary for its further commercialization.

The broad objectives of the work started with deeply assessing the cooking energy situation in India to understand the need of disseminating renewable energy devices. Nine prevailing cooking energy devices viz. *chulha*, improved *chulha*, kerosene stove, Biogas stoves, LPG stove, Electric oven, Microwave oven, SBC and PSC have been studied for their perceived advantages and limitations in view of the prevailing socio-economic scenario in India.

Extensive literature survey has been carried out to know the multi criteria evaluation framework for renewable energy planning and dissemination. Various evaluation techniques have been studied with their applications to a large variety of problems in energy planning. The thesis is an attempt to amalgamate the multi criteria evaluation techniques and dissemination of PSC in India. To these effect large varieties of evaluations of solar cookers were studied for identification of the criteria.

The study has identified various criteria governing the usefulness of various cooking energy devices with special reference to PSC. Finally, an entire range of 30 criteria has been found suitable for the evaluations under five aspects viz. technical, economic, social, behavioral and commercial. The problem of preference selection of cooking energy devices has thus been addressed in a multi criteria context. The evaluation has been carried out using 21 qualitative and 9 quantitative criteria. The relative strengths, weaknesses and constraints of prevailing cooking devices have been assessed based on these criteria.

The comprehensive ranking of devices as an indicator of its usefulness on the identified criteria has been modeled using three evaluation techniques viz. Outranking using PROMETHEE framework, Priority using AHP framework and Utility using Additive MAUT framework. This has lead to comparison of PSC with prevailing domestic cooking energy devices in India. The study has used the inputs from four decision making groups involved in PSC dissemination. The identified groups are policy makers, researchers, educators and actual users of PSC. Rank correlation coefficients have been also computed to know the robustness of ranks given by different evaluation techniques.

Sensitivity analyses have been carried out exclusively for PSC to know relative ranking with identified interventions. More than 50 sensitivity runs were taken for each evaluation technique. Based on these evaluations and sensitivity analyses, modalities of suggested interventions have been discussed in broad framework of prevailing renewable energy policies in India. The suggestions for better dissemination have been discussed. The conclusions of the evaluation derived from respective analyses are discussed below.

7.1. Conclusions

7.1.1 General Conclusions

1. The prevailing cooking energy situation in Indian households reveals the technology affluence of masses starting from free fuel-wood and agricultural waste to sophisticated fuels like LPG and electricity.
2. Multi criteria evaluations techniques are increasingly used in renewable energy planning due to increasing role of decision making groups in energy planning. The approach was found applicable to evaluation of PSC in India.
3. There are varieties of criteria important in preference selection of cooking energy devices in general and PSC in particular. The problem of usefulness is multi criteria in nature.
4. The problem of dissemination of PSC is maximization in nature as evident from 18 criteria which needs maximization as against 12 criteria of minimization nature.
5. There are a large numbers of subjective criteria in preference selection of PSC as evident from 21 qualitative criteria and 9 quantitative criteria amongst the identified ones for the present problem.

6. The decision making groups in PSC dissemination are policy makers (including manufacturers), researchers as technology up graders, educators as awareness creators and actual users.

7.1.2 Assigned Weightages

7. It is observed that the usefulness of PSC is governed by technical importance (7.01), followed by behavioral (6.95) and commercial (6.74). The importance to social criteria is lower (6.29) and economic criteria is the lowest (5.67) based on the overall weightage structure assigned by different decision making groups on 10 point scale.

8. Analysis of weightages reveal that overall safety (8.66), durability (7.93) and ease of operations (7.74) are given due importance by the respondents. The rate of interest on loan (4.60) has been allocated the least weightage. The respondents have neither given too high importance to any of the criterion nor have they out rightly considered any criterion trivial in the analysis. The total differential in the weightages accounts to be 3.33.

7.1.3 Multi Criteria Evaluation Studies

9. The strengths of PSC are zero fuel consumption, compatible cooking time, higher durability, higher nutrition value of food, zero fuel cost, lower maintenance costs, available subsidy, lower rate of interests, lower pollution hazards, lower human drudgery, better taste of food, higher cleanliness of utensils etc. The SBCs have also indicated similar strengths except cooking time.

10. The weaknesses of PSC are lower quality and reliability, lower sophistication in the device, higher weight, robustness, higher need of tracking, seasonal dependence, higher initial costs, several behavioral and commercial issues.

11. The standard deviation computed for the pay-off and evaluation matrices have indicated robustness of the judgments made by the members of various decision making groups.

12. Direct assignment of weightages by the respondents instead of following Saaty's scale was found suitable. Moreover, the numbers of permutations and combinations for 30 criteria for assignment weightages would have been a cumbersome exercise. The Consistency Ratio in most of the cases was zero indicating perfect consistency in priority evaluations.

13. Evaluation by outranking using PROMETHEE has ranked PSC on sixth position amongst the nine devices studied.

14. Evaluation by priority using AHP has ranked PSC on fifth position amongst the nine devices available

15. Evaluation by utility using additive MAUT has ranked PSC on fifth position amongst the nine devices available.

16. Spearman rank correlation coefficient has shown good correlation (0.6 to 1) between the ranks obtained by various techniques/groups.

17. Policy makers have given a 'defensive' ranking in all the evaluation techniques. The users have been proactive as compared to the educators and researcher in assigning the preferences which are evident from the final ranking patterns.

18. Liquefied Petroleum Gas was found to occupy the highest rank in all the evaluation techniques by all the decision making groups.

19. *Chulha* was found to occupy the lowest rank in all the evaluation techniques by all the decision making groups except once.

20. Usual (true) type criterion function is found suitable to the present planning problem in PROMETHEE evaluation.

21. The PROMETHEE evaluation has assigned negative net value ϕ to PSC in most of computations which indicates that the device has many weaknesses over the strengths. The value of net ϕ was found positive for LPG in all the computations.

22. The modified MAUT approach using hierarchical framework was found suitable to the present problem. This may be due to the risk neutral nature of the problem. Linear utility functions with probability of 0.5 have facilitated the evaluation without many alterations in the final rank obtained.

23. The priorities given to PSC are in the range of 0.1002-0.1278 as against highest priority value of 0.1376 for LPG.

24. The utility assigned to PSC is in the range of 0.4308-0.6276 on the scale of unity

7.1.4 Sensitivity Analyses

25. The competitive energy devices in most of the sensitivity runs were microwave ovens, electric ovens, kerosene stove.

26. Parabolic Solar Cookers have shown sensitivity to commercial and behavioral issues.

27. The ranking of PSC could not be altered with any changes in economic criteria considered in isolation or together.

28. A few technical interventions are capable of altering the rank of PSC. All technical parameters together could also not alter the rank of PSC significantly.

29. The social issue could not alter the rank of PSC. However the priorities are found sensitive to changes in weightages.

30. Assignment of equal weightages to all the sub-criteria could also not alter the ranking of PSC.

7.1.5 Policy Issues

31. The commercialization of renewable energy devices in general and PSC in particular warrants a systems approach.

32. The technical developments in product are must which have to be supported by commercial efforts such as better delivery network and good after sales service.

33. To make better dissemination of PSC behavioral issues needs to be tacked tactfully which will ensure building confidence in the technology. This may be achieved by arranging cooking demos etc.

34. Increased utilization is likely to bring down the costs of units. However, the availability of finance may be made better through local banks and cooperative societies.

35. Awareness creation will help in overcoming understanding apathy to social issues addressed in the problem.

7.2. Specific Contributions

1. The thesis is a maiden attempt to use multi criteria evaluations for cooking energy devices selection and commercialization in India.
2. Better insight into commercialization of renewable energy devices with special reference to PSC has been attempted. Quantification of several qualitative and quantitative issues involved in the problem.
3. A large numbers of criteria and prevailing devices have been used for comprehensive evaluation studies.
4. Direct ratings of weightages through responses colleted from various decision making groups involved in dissemination promoting a group decision making has been attempted.
5. The relative importances of criteria are generated by geometric mean approach of AHP.
6. The results have been validated using different evaluation techniques and Spearman ranking checks for robustness of the ranks is also computed.

7.3. Future Scope of Work

1. Extremely large sample size may be useful in devising better insight at the planning level.
2. Fuzzy evaluation techniques may be applied to tackle uncertainties in the data.
3. Development of decision support systems using latest computational aids useful for all renewable energy gadgets may be attempted.

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Appendix I: Techno-Economic Evaluation of PSC at BITS

Name of the Project: Performance Evaluation of Parabolic Solar Cookers

Principle Investigator: Prof. M. Ramachandran

Funding Agency: Ministry of Non-conventional Energy Sources, New Delhi.

The techno-economic analyses of PSC were carried out at BITS, Pilani under the above at Centre for Renewable Energy and Environment Development (CREED). Two models of PSC viz. the domestic model (SK-14) and community model (Scheffler) were evaluated.

The studies carried out were assessment of cooking performance for various items under different conditions, thermal efficiency evaluation, and stagnation temperature determination. The assessments were carried out for student mess and guest house. The models of cookers were installed, the cooks were trained to handle minor problems, and vessels were prepared for the testing by blackening at the bottom. Certain modifications like fabrication of counter weight for flap, caster wheels for cookers were also carried out. The salient features of tests were as follows…

1. Satisfactory cooking was carried out as per requirements with both the models
2. Different items were cooked including rice, cereals, rajma, urd, poories.
3. Cooking was possible only on the days when average solar radiation was more than 500 W/m^2 for approx 5 hours.
4. Cooking two meals are possible if average solar radiation was more than 700 W/m^2 for approx at lest 3 hours.

5. Pressure cookers can help in efficient cooking with PSCs

6. Savings of the order of 285 kg of LPG (Rs. 3000) was possible during the test period with Scheffler PSC. For 70 students, 1875 kg of LPG can be saved in a year which amounts to Rs.17000.

7. Average efficiency of Scheffler reflector was 25 % with stagnation temperature of 650 C (on day of solar radiation of 960 W/m^2).

8. Average efficiency of domestic model was 60 % with stagnation temperature of 300 C (on day of solar radiation of 900 W/m^2).

9. Savings of the order of 275 kg of LPG (Rs. 3000) can be achieved with domestic model of PSC if use for 10 people for 250 days.

10. The rice ~~was~~ grains were found broken during cooking and was not suitable to be served.

The above project was the basis for investigating the comprehensive evaluation of domestic model of PSC in the present Indian context in comparison with other contemporary cooking devices in a multi criteria context.

Appendix II: Proforma for Assessment of Preferences for Criteria/Sub-Criteria

Part (A) : Covering Letter

Dated: 12/2/2002

To,

Sub: Utility Assessment of Solar Cookers

Dear Sir/Madam,

It gives me immense pleasure to interact with you on the problem of assessment of overall utility of Parabolic Solar Cooker (PSC) in the Indian context. As we are aware this technology has been introduced in the country few years back and technical assessment has been carried out. To achieve successful commercialization there is a need to assess the utility of this device as of today and suggest suitable strategies for corrective action.

I am proposing to use *Multi Criteria Decision Making (MCDM) techniques* for the Comprehensive Utility Assessment of Solar Cookers as a part of my Ph. D thesis, under the supervisor of Prof. (Dr.) M. Ramachandran. There are number of criteria for deciding the utility of parabolic solar cookers vis-à-vis other devices for supplying cooking energy. (LPG, Kerosene, *Chulhas* etc)

Your judicious response will assure substantial judgment in this exercise and help to carry out the same successfully. I will be happy to acknowledge the same.

Please make it convenient to spare your valuable time to fill in and return the attached proforma. The collected information will be utilized for research purpose only.

I welcome your positive suggestions.

Thanking you.

Yours truly,

Sanjay D. Pohekar

Appendix II: Proforma for Assessment of Preferences for Criteria/Sub-Criteria (Contd...)

Part (B): Proforma

1. Name of the Respondent: ---

2. Designation: ---

3.Address:---

(Note: For evaluating solar cooker with respect to contemporary cooking energy devices/systems following criteria are being considered. Please indicate the priorities you would like to assign to the criteria mentioned below. Please mark a tick (√) against each of the rows as per your judgment. (Legend: VH: Very High, H: High, M: Medium, L: Low, VL: Very Low)

Criteria No	**Criteria**	**Importance Level as per your Judgment**				
		VH	H	M	L	VL
CR 1.	Fuel consumption					
CR 2.	Cooking time					
CR 3.	Durability					
CR 4.	Quality/reliability of device					
CR 5.	Sophistication level of device: (i.e. Storage of heat, heat rate control facilities etc)					
CR 6.	Size/Weight/Space requirements					
CR 7.	Ruggedness of device					
CR 8.	Seasonal /Continuous use					
CR 9.	Need for tracking					
CR 10.	Nutrient content of food					
CR 11.	Initial cost of device					
CR 12.	Fuel cost					
CR 13.	Maintenance cost					

Criteria No	Criteria	Importance Level as per your Judgment				
		VH	H	M	L	VL
CR 14.	Available subsidy					
CR 15.	Rate of interest on loan if any					
CR 16.	Pollution hazards					
CR 17.	Human drudgery					
CR 18.	Overall safety					
CR 19.	Features of device, aesthetics					
CR 20.	Motivation for purchase of device					
CR 21.	Taste of food					
CR 22.	Cleanliness of utensils					
CR 23.	Ease of operation/handling					
CR 24.	Type of dishes cooked					
CR 25.	Need of additional cooking system					
CR 26.	Improvement in existing models					
CR 27.	Availability of spares and after sales service					
CR 28.	Distribution network					
CR 29.	Market research					
CR 30.	Need for user training					

Thanks!

Signature of the Respondent

Appendix III: Proforma for Comparison of Devices

1. Name of the Respondent: --

2. Designation: --

3.Address:--

(Note: For comparing PSC with respect to contemporary domestic cooking energy devices/systems the following sub-criteria are considered. Please record your judgment in the table below as per Legend: VH: Very High, H: High, M Medium, L: Low, VL: Very Low)

Device → / Sub-Criteria ↓	1 *Chulha*	2 Improved *Chulha*	3 Kerosene Stoves	4 Biogas Chulha	5 LPG Stoves	6 Micro Wave Oven	7 Electric Oven	8 Solar Box Cooker	9 Parabolic Solar Cooker
Fuel consumption									
Cooking time									
Durability									
Quality, reliability of device									
Sophistication level of device									
Size/Weight/Space requirements									
Ruggedness of device									
Seasonal dependence									
Need for tracking	Not Applicable								
Nutrient content of food									
Initial Cost of device									
Fuel cost per month									
Maintenance cost per annum									
Available subsidy									
Rate of interest on loan if any									
Pollution Hazards									

Device → / Sub-Criteria ↓	1 *Chulha*	2 Improved *Chulha*	3 Kerosene Stoves	4 Biogas Chulha	5 LPG Stoves	6 Micro Wave Oven	7 Electric Oven	8 Solar Box Cooker	9 Parabolic Solar Cooker
Human Drudgery									
Overall safety									
Features of device, aesthetics									
Motivation for purchase of device									
Taste of Food									
Cleanliness of Utensils									
Ease of operation/handling									
Type of dishes cooked									
Need for additional cooking system									
Improvement in existing models									
Availability of spares and after sales service									
Distribution Network									
Market Research									
Need for user training									

Thanks!

Signature of the Respondent

Appendix IV: List of Respondents/Experts Consulted

(A) Professionals

1. Directors of MNES, New Delhi
2. Principal Scientific Officers of MNES at Hyderabad, New Delhi, Pune
3. Additional Chief Executive, Rajasthan Renewable Energy Corporation Ltd, Jaipur
4. Chairman, Institution of Engineers, Pune
5. Senior Technical Executive, Gujarat Energy Development Agency, Vadodara
6. Scientist C, Andhra Pradesh Energy Development Agency Ltd, Hyderabad
7. Managing Director, Gadhia Solar Energy Systems, Valsad
8. Managing Directors of Parabolic Solar Cooker Manufacturing Companies at Pune

(B) Researchers

9. Director, Appropriate Rural Technology Institute, Pune
10. Scientific Officers, Appropriate Rural Technology Institute, Pune
11. Researchers, Energy Studies Dept , Tezpur University, Tezpur
12. Researchers, School of Energy Studies and Center for Energy Studies, DAVV, Indore
13. Head, School of Energy Studies, North Maharashtra University , Jalgaon (MS)
14. Research Associates at The Energy and Resources Institute, New Delhi
15. Research Associates, Indian Institute of Technology, New Delhi
16. Assistant Professor, Indian Institute of Technology, Mumbai

17. Associate Professor and Head Energy Systems Engineering, Indian Institute of Technology, Mumbai

18. Head, Centre of Energy Studies, Kumaraguru College of Technology, Coimbatore

19. Coordinators, Centre of Renewable Energy and Environment Development, BITS, Pilani

20. Head, Indira Gandhi Institute of Development and Research , Mumbai

(C) Educators

21. Head, Mechanical Engineering Department , K K Wagh College of Engineering , Nasik (MS)

22. Principal, College of Engineering, Aurangabad

23. Faculty at Mechanical Engineering Department, Anna University, Chennai

24. Faulty at Birla Vishwakarma Mahvidyalaya, Vallabh Vidyanagar

25. Dean College of Engineering and Technology, Udaipur

(D) Users

26. Actual Users at Pune (5 Nos)

27. Actual Users at Valsad (3 Nos)

28. Actual Users at Pilani (5 Nos)

29. Actual Users at Mount Abu (3 Nos)

30. Actual Users at Nasik (5 Nos)

31. Actual Users at Coimbatore (1 Nos)

32. Actual Users at Indore (4 Nos)

33. Miscellaneous (3 Nos)

List of Publications/Presentations

I: International /National Journals

1. Pohekar SD, Ramachandran M. Multi-criteria evaluation of cooking energy alternatives for promoting parabolic solar cooker in India. Renewable Energy. 2004; 29(9): 1449-1460.
2. Pohekar SD, Ramachandran M. Application of multicriteria decision making to sustainable energy planning- a review. Renewable and Sustainable Energy Reviews. 2004; 8(4): 365-381.
3. Pohekar SD, Ramachandran M. Hierarchical approach to evaluation and promotion of parabolic solar cookers in India. Energy Education Science and Technology.2005; 14 (2):81-91. (Forthcoming)
4. Pohekar SD, Kumar D, Ramachandran M. Dissemination of cooking energy alternatives in India - a review. Renewable and Sustainable Energy Reviews. 2004 (Accepted -In Press).
5. Pohekar SD, Ramachandran M. Assessment of solar cooking technology and its dissemination in India. Energy and Fuel Users Journal.2004 (Accepted -In Press).
6. Pohekar SD, Ramachandran M. Usefulness of parabolic solar cookers as a sustainable energy options for India. All India special Issue on Renewable Energy. Institution of Engineers India.2004 (Accepted -In Press).
7. Pohekar SD, Ramachandran M. Multi-criteria evaluation of cooking devices with special reference to utility of parabolic solar cooker (PSC) in India. Energy. (Accepted for II review).
8. Pohekar SD, Ramachandran M. Multi-criteria decision making framework for dissemination of parabolic solar cookers in India, Journal of Solar Energy Society of India (Communicated).
9. Pohekar SD, Ramachandran M. Utility assessment of parabolic solar cooker as a domestic cooking device in India. Renewable Energy. (Communicated).

II: International/National Conferences

1. Pohekar SD, Ramachandran M, Deshmukh MK. Assessment of Solar Cooking Technologies. *In* the Proceedings of International Conference Strategic Technology Management for Sustainable Growth and Development at National Institute of Industrial Engineering. Mumbai. 2001.
2. Pohekar SD, Ramachandran M, Deshmukh MK. Multi-Criteria Decision Making for Utility Assessment of Parabolic Solar Cooker. *In* the Proceedings of National Conference on Advances in Cotemporary Physics and Energy at Indian Institute of Technology. New Delhi. 2002.
3. Pohekar SD, Ramachandran M. Development and Dissemination of Parabolic Solar Cookers: Study of Factors Governing the Overall Utility. *In* the Proceedings of International Conference on Renewable Energy Development and Commercialization in India at MHKWC. Malsisar. 2002
4. Pohekar SD, Ramachandran M, Deshmukh MK. Parabolic Solar Cookers as a Vital Breakthrough in Solar Cooking Technology. *In* the Proceedings of National Seminar on Renewable Energy Sources and other Technologies for Rural Development at SSGMCE. Shegaon. 2002.
5. Pohekar SD, Ramachandran M. Ranking Cooking Energy Alternatives by Multi-criteria Analysis. *In* the Proceedings of National Renewable Energy Convention and International Conference New Millennium-Alternative Energy Solutions for Sustainable Development at PSG College of Technology. Coimbatore. 2003.
6. Pohekar SD, Kurhekar S, Ramachandran M. A Comparative Analysis of Cooking Energy Options and their Dissemination in India, *In* the Proceedings of International Conference on Energy Environment Technologies for Sustainable Development. Malviya National Institute of Technology.Jaipur.2003

Brief Biography of the Candidate

Sanjay D. Pohekar did his B E Mechanical Engineering from Government College of Engineering, Amravati of Amravati University (Maharashtra) in 1990. He did his Master of Technology in Energy Management from School of Energy and Environment Studies, Devi Ahilya Vishwa Vidyalaya, Indore in 1994 and Post Graduate Diploma in Human Resource Management from Indira Gandhi National Open University, New Delhi in 1999. He took up the research in Renewable Energy Planning and Dissemination from 1999 at Birla Institute of Technology and Science, Pilani (Rajasthan). His areas of research are parabolic solar cooking, multi-criteria decision making, and renewable energy education.

Being an educator, he has undertaken teaching of Mechanical Engineering in Amravati University, University of Poona and BITS, Pilani since 1994. He has also taught various courses for distance learning programmes of BITS, Pilani in the area of Mechanical Engineering and Energy Management. He is also organized and conducted training MNES/SNA officers for short term training programmes at BITS, Pilani. He has also published papers in various international journals of repute and presented papers in various national/international conferences.

Brief Biography of the Supervisor

Prof. M Ramachandran did his B.E. (Mechanical Engineering) from Bangalore University and Ph. D. (Energy Studies) from Indian Institute of Science, Bangalore. He served in the field of renewable energy in various capacities for the past two decades. He has behind him 38 years of distinguished professional, administrative and academic career. He set up the Centre for Renewable Energy and Environment Development (CREED) at BITS, Pilani for implementing sponsored projects in Renewable Energy and also developed courses in Renewable Energy, Energy Efficiency and Technology Management and supervised several student projects in these areas. He has published extensively on renewable energy planning, demand side management. He is actively engaged in energy education, resource development and training activities in the field of renewable energy. His areas of research are integrated renewable energy systems, energy planning and policy, energy technology and demand side management

Presently, he is the Director of the BITS, Pilani-Dubai Centre at Dubai, UAE.