# ASSESSMENT OF BARRIERS TO THE DISSEMINATION OF DECENTRALIZED RENEWABLE ENERGY SYSTEMS IN UTTARAKHAND


**BY**

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**DEPARTMENT OF POWER AND INFRASTRUCTURE**

**SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF**

## DOCTOR OF PHILOSOPHY

**TO**

**UNIVERSITY OF PETROLEUM AND ENERGY STUDIES**
**DEHRADUN**
**AUGUST, 2015**

**Under the Guidance of**


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# ACKNOWLEDGEMENTS

It gives me great pleasure to express my deep sense of gratitude to my supervisors Dr. T. C. Kandpal, Dr. Parag Diwan and Dr. Hiranmoy Roy for their invaluable guidance and support during the course of the research work. I wish to express special gratitude to Dr. T. C. Kandpal for his precious time, thoughtful insights, meticulous and critical assessment during the doctoral research process. I am also grateful to Dr. Parag Diwan for his constant support and guidance during the endeavor.

I would also like to thank my seniors and colleagues namely Dr. Anirban Sengupta, Dr. Anil Kumar, Dr. Anshuman Gupta, Ravindra Yatagiri, Dr. Tarun Dhingra, Dr. Joji Rao, Atri Nautiyal, and Dr. Vipul Sharma for their constant motivation and support during the course of the study. I am also indebted to Abhishek Pandey, Chandan Sharma, Ashish Sharma, Ishan Pathak, Yashashwi Gyanpuri, Bidyut Bikash Das, Rohit Pratap Singh, Vipul Kumar, Dr. Swapnil Dubey and Dr. Chandrasekhar Rajoria for their valuable guidance and support during data collection.

I wish to express my gratitude to my parents Shri. M. A. Ansari and Smt. Shamshad Bano for their blessings and motivation. I am also thankful to Dr. Intekhab Alam and Nasreen Bano for their generous hospitality during my frequent study related visits to IIT Delhi. My special thanks to my wife Ms. Rajwant Kaur and daughter Sara Aslam for their constant support and care during the entire course of the research work.

## DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Mohammed Yaqoot



ii

## THESIS COMPLETION CERTIFICATE

This is to certify that the thesis entitled "**Assessment of Barriers to the Dissemination of Decentralized Renewable Energy Systems in Uttarakhand**" submitted by Mohammed Yaqoot to University of Petroleum and Energy Studies for the award of the degree of Doctor of Philosophy is a bona fide record of the research work carried out by him under our supervision and guidance. The content of the thesis, in full or parts have not been submitted to any other Institute or University for the award of any other degree or diploma.

11.08.15

Dr. Parag Diwan | Dr. T.C. Kandpal | Dr. Hiranmoy Roy

# EXECUTIVE SUMMARY

This study is an attempt to assess the potential of utilization of decentralized renewable energy systems (DRESs) in the state of Uttarakhand in India. Demographic, socio-economic, resource availability and climatic characteristics of Uttarakhand has been considered to identify and evaluate the suitability of application of DRESs in the state.

As solar and biomass based DRESs are found to be suitable for various applications in the state, frameworks have been developed to estimate their potential in Uttarakhand. Also, past dissemination of solar and biomass based DRESs in Uttarakhand has been studied to assess their time-trend of diffusion in the state. Based on the understanding of 'Theory of Diffusion of Innovations', and the time-trend of diffusion of DRESs in Uttarakhand, the time periods required for the cumulative dissemination of DRESs to reach their estimated potential have been estimated. A survey of DRESs adopters and non-adopters has also been carried out in the study to assess the barriers to the dissemination of DRESs in the state as perceived by the potential and existing users. Considering the criticality of financial/economic barrier, an assessment of financial attractiveness of DRESs has also been carried out in the study.

Results of the study indicate that the state of Uttarakhand has large potential for domestic solar water heaters, solar lanterns and improved biomass cookstoves. Also, the state has substantial potential for solar home systems, solar cookers, solar dryers and family size biogas plants. The results also suggest relatively better suitability of soft loan provision for large scale dissemination of DRESs as it has bigger impact on improving the purchasing power of households compared to the provision of capital subsidy.

Assessment of the time-trend of diffusion of DRESs in Uttarakhand has indicated inconsistency in the promotion of various DRESs (except domestic solar water heaters). Time-trend or reported diffusion indicate that only domestic solar water heaters have received persistent subsidy support in the state reflected by sustained growth in annual subsidy allocated for its promotion. Time-trend of dissemination of DRESs also reflect dependence of diffusion on subsidy. A preliminary analysis of the time-trend of dissemination of DRESs in Uttarakhand based on the logistic growth curve indicate that as per the prevailing trend, it would take substantially long time period (around 200 years for most DRESs) for the cumulative dissemination of DRESs to reach the respective estimated utilization potentials.

Survey based study of adopters and non-adopters of DRESs in Uttarakhand has indicated that the following barriers are affecting their dissemination in the state of Uttarakhand: high capital cost, lack of access to capital / loan, availability of cheaper alternative fuel, unavailability of trained manpower for installation and maintenance, lack of user training for maintenance, unavailability of retail shops, and unavailability of spares as the major barriers. Other relevant barriers are inappropriateness of technology, poor resource availability, lack of adequate awareness, and lack of socio-cultural acceptability. Lack of adequate awareness has been considered more critical by the non-adopters whereas adopters of DRESs that require regular maintenance services such as solar home systems and family size biogas plants consider unavailability of trained manpower for installation and maintenance and unavailability of spare parts as more critical barriers. Survey of the status of adopted DRESs has indicated that a satisfied DRES adopter has recommended it to others and most (about 85%) of such recommendations have resulted in adoptions.

Assessment of financial attractiveness of DRESs has indicated that improved cookstoves, domestic solar water heaters, solar lanterns and solar home systems are the most suitable DRESs for promotion in the state. These are found to be financially viable under almost all scenarios even without capital subsidy. In case of dish type solar cookers, solar PV pumps and solar dryers, community usage has been found to be more viable compared to their household level applications. Results of financial assessment reaffirm the need for providing a fair market to DRESs either by withdrawal of direct and indirect subsidies being given on conventional energy supply or by providing suitable incentives to one or more of the stakeholders involved in the diffusion of DRESs.

## CONTENTS


| | | |
|---|---|---|
| **1.** | **Characteristics of Uttarakhand and its Implications for Renewable Energy** | **1** |
| | 1.1. State of Uttarakhand | 1 |
| | 1.1.1. Introduction | 1 |
| | 1.1.2. Topography and Climate | 2 |
| | 1.1.3. Demography | 3 |
| | 1.1.4. Economic Activities | 9 |
| | 1.1.5. Energy Scenario | 13 |
| | 1.1.5.1. Electricity | 13 |
| | 1.1.5.2. Energy for Cooking and Lighting | 13 |
| | 1.1.5.3. Pattern of Household Expenditure on Energy (Fuels and Light) | 22 |
| | 1.2. Renewable Energy Resource Availability in Uttarakhand | 23 |
| | 1.2.1. Solar Radiation | 23 |
| | 1.2.2. Wind | 25 |
| | 1.2.3. Biomass | 25 |
| | 1.2.4. Hydro | 25 |
| | 1.3. Critical Areas for Development of Uttarakhand | 26 |
| | 1.3.1. Energy | 26 |
| | 1.3.2. Water | 27 |
| | 1.3.3. Agriculture | 27 |
| | 1.3.4. Tourism | 28 |
| | 1.3.5. Roads | 28 |
| | 1.4. Implications for Renewable Energy Applications in Uttarakhand | 28 |
| | 1.5. Potential and Diffusion of DRESs in Uttarakhand | 32 |

**CONTENTS (continued…)**


| | | |
|---|---|---|
| | 1.6. Business Problem | 33 |
| | 1.7. Research Objective(s) | 34 |
| | 1.8. Organisation of the Thesis | 35 |
| **2.** | **Review of Barriers to the Dissemination of Decentralized Renewable Energy Systems** | **36** |
| | 2.1. Introduction | 36 |
| | 2.2. Identification and Classification of Barriers to the Diffusion of DRESs | 37 |
| | 2.2.1. Technical Barriers | 37 |
| | 2.2.1.1. Resource Availability | 39 |
| | 2.2.1.2. Technology – Design, Installation and Performance | 39 |
| | 2.2.1.3. Skill Requirement for Design and Development, Manufacturing, Installation, Operation and Maintenance | 41 |
| | 2.2.1.4. Potential Remedial Measures | 42 |
| | 2.2.2. Economic Barriers | 43 |
| | 2.2.2.1. Cost | 46 |
| | 2.2.2.2. Market | 48 |
| | 2.2.2.2.1. Market Structure | 48 |
| | 2.2.2.2.2. Fuel/Energy Pricing | 49 |
| | 2.2.2.2.3. Incentives/Taxes/Duties | 51 |
| | 2.2.2.2.4. Purchasing Power and Spending Priorities | 52 |
| | 2.2.2.2.5. Financial Issues | 52 |
| | 2.2.2.2.6. Awareness and Risk Perception | 53 |

**CONTENTS (continued…)**


| | | |
|---|---|---|
| | 2.2.2.3. Potential Remedial Measures | 54 |
| | 2.2.3. Institutional Barriers | 59 |
| | 2.2.3.1. Policy and Regulatory | 60 |
| | 2.2.3.2. Infrastructure | 60 |
| | 2.2.3.3. Administrative | 63 |
| | 2.2.3.4. Potential Remedial Measures | 63 |
| | 2.2.4. Socio-cultural Barriers | 68 |
| | 2.2.4.1. Societal Structure, Norms and Value System | 68 |
| | 2.2.4.2. Awareness and Risk Perception | 70 |
| | 2.2.4.3. Behavioral or Lifestyle Issues | 71 |
| | 2.2.4.4. Potential Remedial Measures | 72 |
| | 2.2.5. Environmental Barriers | 74 |
| | 2.2.5.1. Potential Remedial Measures | 75 |
| | 2.3. Concluding Remarks | 76 |
| **3.** | **Estimation of Potential of Decentralized Renewable Energy Systems in Uttarakhand** | **78** |
| | 3.1. Introduction | 78 |
| | 3.2. Frameworks for Estimation of Potential of using DRESs in Uttarakhand | 78 |
| | 3.2.1. Solar Energy based DRESs | 79 |
| | 3.2.1.1. Domestic Solar Water Heaters | 79 |
| | 3.2.1.2. Solar Home Systems | 81 |
| | 3.2.1.3. Solar Lanterns | 82 |
| | 3.2.1.4. Dish Type (Paraboloid) Solar Cookers | 84 |
| | 3.2.1.5. Solar Dryers | 85 |
| | 3.2.1.6. Solar PV Pumps | 86 |

**CONTENTS (continued…)**


3.2.2. Biomass based DRESs 87

3.2.2.1. Family Size Biogas Plants 87

3.2.2.2. Improved Biomass Cookstoves 89

3.3. Results and Discussion 89

3.3.1. Domestic Solar Water Heaters 89

3.3.2. Solar Home Systems 92

3.3.3. Solar Lanterns 94

3.3.4. Dish Type Solar Cookers 95

3.3.5. Solar Dryers 96

3.3.6. Solar PV Pumps 96

3.3.7. Family Size Biogas Plants 97

3.3.8. Improved Biomass Cookstoves 99

3.4. Concluding Remarks 100

**4. Theory of Diffusion of Innovation and Expected Trend of Dissemination of Decentralized Renewable Energy Systems in Uttarakhand 102**

4.1. Theory of Diffusion of Innovation 102

4.1.1. Innovation 102

4.1.2. Communication Channels 104

4.1.3. Time 104

4.1.4. Social System 111

4.2. Time-trend of Diffusion of DRESs in Uttarakhand 112

4.3. Technology Diffusion Models 119

4.4. Estimation of Time Required for the Cumulative Diffusion of DRESs to Reach their Estimated Utilization Potential 121

4.5. Concluding Remarks 124

CONTENTS (continued…)


| | | |
|---|---|---|
| **5.** | **Assessment of Barriers Faced by Decentralized Renewable Energy Systems Adopters and Non-Adopters in Uttarakhand** | **126** |
| | 5.1. Introduction | 126 |
| | 5.2. Sample Design for Survey | 126 |
| | 5.3. Results of Survey | 127 |
| | 5.4. Concluding Remarks | 136 |
| **6.** | **Assessment of Financial Attractiveness of Decentralized Renewable Energy Systems in Uttarakhand** | **137** |
| | 6.1. Introduction | 137 |
| | 6.2. Methodology | 137 |
| | 6.2.1. Expressions for Measures of Financial Performance | 138 |
| | 6.2.1.1. Discounted Payback Period | 138 |
| | 6.2.1.2. Net Present Value | 139 |
| | 6.2.1.3. Internal Rate of Return | 139 |
| | 6.2.1.4. Levelized Cost of Useful Energy | 139 |
| | 6.2.2. DRES Specific Expressions for Estimation of Monetary Value of Annual Benefits | 140 |
| | 6.2.2.1. Domestic Solar Water Heater | 140 |
| | 6.2.2.2. Family Size Biogas Plant | 141 |
| | 6.2.2.3. Improved Biomass Cookstove | 142 |
| | 6.2.2.4. Paraboloid (Dish) Type Solar Cooker | 142 |
| | 6.2.2.5. Solar Lantern | 143 |
| | 6.2.2.6. Solar Home System | 144 |
| | 6.2.2.7. Solar PV Pump | 144 |
| | 6.2.2.8. Solar Dryer | 145 |
| | 6.3. Results and Discussion | 146 |

**CONTENTS (continued…)**


6.3.1. Domestic Solar Water Heater 148

6.3.2. Family Size Biogas Plant 153

6.3.3. Improved Biomass Cookstove 155

6.3.4. Dish Type (Parabolic) Solar Cooker 157

6.3.5. Solar Lantern 160

6.3.6. Solar Home System 163

6.3.7. Solar PV Pump 164

6.3.8. Solar Dryer 167

6.4. Concluding Remarks 170

**7. Conclusions and Recommendations 172**

7.1. Conclusions 172

7.2. Limitations of the Study and Recommendations for Further Work 176

**References 177**

**Appendices 198**

Appendix I 198

Appendix II 199

# LIST OF FIGURES


| *Figure no.* | *Title* | *Page no.* |
|---|---|---|
| Figure 1.1 | Uttarakhand as a state in India | 4 |
| Figure 1.2 | Location of Uttarakhand | 5 |
| Figure 1.3 | Districts of Uttarakhand | 6 |
| Figure 1.4 | Percentage of rural and urban population in Uttarakhand | 8 |
| Figure 1.5 | Framing research objectives from research gaps | 35 |
| Figure 4.1 | Adopter categorization on the basis of innovativeness | 108 |
| Figure 4.2 | S-curve | 110 |
| Figure 4.3 | Curve fitting for DSWHs | 122 |
| Figure 4.4 | Curve fitting for FSBPs | 122 |
| Figure 4.5 | Curve fitting for solar cookers | 123 |
| Figure 4.6 | Curve fitting for solar lanterns | 123 |
| Figure 4.7 | Curve fitting for solar home systems | 124 |
| Figure 5.1 | Scree plot | 131 |

## LIST OF TABLES


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 1.1 | District-wise population, number of households and villages in Uttarakhand | 7 |
| Table 1.2 | Population and decadal growth rate by residence | 8 |
| Table 1.3 | Number of out-migrant per 1000 persons for Uttarakhand and average of all states in India | 9 |
| Table 1.4 | Gross State Domestic Product at factor cost by industry: 2004-05 to 2012-13 at current prices 15 Feb 2013 | 11 |
| Table 1.5 | Contribution of sector/sub-sector to Uttarakhand's Gross State Domestic Product at factor cost: 2004-05 to 2012-13 at current prices 15 Feb 2013 (in %) | 12 |
| Table 1.6 | Electrification of households in Uttarakhand | 14 |
| Table 1.7 | Energy consumption pattern: fuel used for cooking | 16 |
| Table 1.8 | Energy consumption pattern: fuel used for cooking (in %) | 18 |
| Table 1.9 | Fuels used for lighting in Uttarakhand | 20 |
| Table 1.10 | Percentage of households using various types of fuels for lighting | 21 |
| Table 1.11 | Monthly per capita quantity and monetary value of fuel consumption for Uttarakhand | 23 |
| Table 1.12 | Solar radiation data for districts of Uttarakhand | 24 |
| Table 1.13 | Characteristics of Uttarakhand and implications for renewable energy applications in the state | 29 |
| Table 1.14 | Resource-DRES-Task matrix | 33 |
| Table 1.15 | Potential and cumulative diffusion of DRESs in Uttarakhand | 34 |

## LIST OF TABLES (continued…)


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 2.1 | Classification of barriers to the diffusion of DRESs | 38 |
| Table 2.2 | Potential remedial measures suggested to overcome the sub-barriers of technical barrier | 45 |
| Table 2.3 | Potential remedial measures suggested to overcome the sub-barriers of economic barrier | 55 |
| Table 2.4 | Potential remedial measures suggested to overcome the sub-barriers of institutional barrier | 64 |
| Table 2.5 | Potential remedial measures suggested to overcome the sub-barriers of socio-cultural barrier | 73 |
| Table 2.6 | Potential remedial measures suggested to overcome the sub-barriers of environmental barrier | 76 |
| Table 3.1 | Estimation of number of households in Uttarakhand with perceived need for water heating | 90 |
| Table 3.2 | Input values and results for estimation of potential of 100 LPD ETC type DSWH in Uttarakhand | 93 |
| Table 3.3 | Input values and results for estimation of potential of SHS in Uttarakhand | 94 |
| Table 3.4 | Input values and results for estimation of potential of solar lantern in Uttarakhand | 95 |
| Table 3.5 | Classification of villages according to population range and estimation of potential of solar dryer in Uttarakhand | 96 |
| Table 3.6 | Suitable households for the usage of family size biogas plants in Uttarakhand | 98 |
| Table 3.7 | Input values and results for estimation of potential of family size biogas plant (1 $m^3$) in Uttarakhand | 99 |

## LIST OF TABLES (continued…)


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 3.8 | Input values and result for estimation of potential of improved biomass cookstoves in Uttarakhand | 100 |
| Table 3.9 | Summary of potential of DRESs in Uttarakhand | 101 |
| Table 4.1 | Activities involved in various stages in the innovation-decision process | 106 |
| Table 4.2 | Diffusion pattern of solar water heaters and associated subsidy expenditure | 115 |
| Table 4.3 | Diffusion pattern of FSBPs and associated subsidy expenditure | 116 |
| Table 4.4 | Diffusion pattern of solar cookers and associated subsidy expenditure | 117 |
| Table 4.5 | Diffusion pattern of solar lanterns and associated subsidy expenditure | 118 |
| Table 4.6 | Diffusion pattern of solar home systems and associated subsidy expenditure | 119 |
| Table 4.7 | Estimated time duration by which cumulative diffusion of DRESs will reach their potential | 124 |
| Table 5.1 | Case processing summary | 129 |
| Table 5.2 | Reliability statistics | 129 |
| Table 5.3 | KMO and Barlett’s Test | 129 |
| Table 5.4 | Total variance explained (Extraction method: Principal component analysis) | 130 |
| Table 5.5 | Rotated component matrix | 132 |
| Table 5.6 | Criticality of barriers to adoption in the opinion of adopters and non-adopters | 134 |

## LIST OF TABLES (continued…)


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 5.7 | Status of adopted DRESs and opinion and role of adopters | 135 |
| Table 6.1 | General input parameters for financial analysis of DRESs in Uttarakhand | 146 |
| Table 6.2 | Input values for financial analysis of 100 liters per day (LPD) DSWH | 148 |
| Table 6.3 | Measures of financial performance of DSWH with subsidized fuel and rebate in electricity bill | 150 |
| Table 6.4 | Measures of financial performance of DSWH with unsubsidized fuel and rebate in electricity bill | 151 |
| Table 6.5 | Breakeven values of CUF (in fraction) for DSWH with/without rebate | 152 |
| Table 6.6 | Breakeven values of fuel price for DSWH with/without rebate | 152 |
| Table 6.7 | Input values for financial analysis of 2 $m^3$ FSBP | 153 |
| Table 6.8 | Measures of financial performance of FSBP (2 $m^3$) | 154 |
| Table 6.9 | Breakeven values of number of days in a year during which FSBP satisfies full cooking need of the household and fuel price for replaced fuel | 155 |
| Table 6.10 | Input values for financial analysis of improved biomass cookstove (natural draft type) | 156 |
| Table 6.11 | Measures of financial performance of improved biomass cookstoves | 157 |
| Table 6.12 | Breakeven values for fuelwood price and number of days of improved biomass cookstove operation per year | 157 |

## LIST OF TABLES (continued…)


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 6.13 | Input values for financial analysis of household and community type solar cooker | 158 |
| Table 6.14 | Measures of financial performance of solar cooker | 159 |
| Table 6.15 | Breakeven values of number of meals cooked by solar cooker in a year and breakeven values of fuel price for replaced fuel | 160 |
| Table 6.16 | Input values for financial analysis of solar lantern | 161 |
| Table 6.17 | Measures of financial performance of solar lantern | 162 |
| Table 6.18 | Breakeven values of number of days of solar lantern usage per year and breakeven values of fuel price for replaced fuel | 162 |
| Table 6.19 | Input values for financial analysis of solar home system (Model II, 37 $W_p$) | 163 |
| Table 6.20 | Measures of financial performance of solar home system | 164 |
| Table 6.21 | Breakeven values of number of days of solar home system usage per year | 164 |
| Table 6.22 | Input values for financial analysis of 1800 $W_p$ submersible solar PV pump for community use | 165 |
| Table 6.23 | Measures of financial performance of solar PV pump | 166 |
| Table 6.24 | Breakeven values of number of days of solar PV pump usage per year, number of persons in a village, and fuel price for replaced fuel | 166 |
| Table 6.25 | Input values for financial analysis of solar dryer (household and community type) | 167 |

## LIST OF TABLES (continued…)


| *Table no.* | *Title* | *Page no.* |
|---|---|---|
| Table 6.26 | Measures of financial performance of solar dryer | 169 |
| Table 6.27 | Breakeven values of number of loadings per year (with drying time of 8 hours required per loading for chilli) and breakeven values of fuel price for replaced fuel | 170 |
| Table 7.1 | Summary of potential of DRESs in Uttarakhand | 173 |

# NOMENCLATURE

| | |
|---|---|
| $A_{sc}$ | Average number of community type solar cookers installed per school |
| AC | Total annual cost of DRES usage |
| $AC_C$ | Annualized capital cost |
| $AHS_{(r)}$ | Average household size in rural Uttarakhand |
| $AP_{vpri}$ | Average population of villages of Uttarakhand that are in the $i^{th}$ population range category |
| AUE | Annual useful energy delivered by DRES |
| a, b | Coefficients in equations representing various technology diffusion models |
| B | Annual benefit accrued to the DRES user as a result of fuel savings |
| BPL | Below poverty line |
| C | Annual operation and maintenance cost associated with DRES usage |
| $c_{pw}$ | Specific heat of water |
| $C_0$ | Capital cost of DRES |
| CUF | Capacity utilization factor |
| $CUF_{DSWH}$ | Annual capacity utilization factor of DSWH |
| $CV_f$ | Calorific value of fuel replaced by DRES |
| d | Discount rate |
| DNI | Direct normal irradiance |
| DPP | Discounted payback period |
| DRES | Decentralized renewable energy system |
| DSWH | Domestic solar water heater |
| ETC | Evacuated tube collector |

## NOMENCLATURE (continued…)

| | |
|---|---|
| $f$ | Annual operation and maintenance cost as a fraction of the capital cost of DRES |
| $f_{a(r)}$ | Fraction of households having access to solar radiation in rural areas of Uttarakhand |
| $f_{a(u)}$ | Fraction of households having access to solar radiation in urban areas of Uttarakhand |
| $f_{bch(r)}$ | Fraction of households in rural areas of Uttarakhand using biomass for cooking |
| $f_{bch(u)}$ | Fraction of households in urban areas of Uttarakhand using biomass for cooking |
| $f_{bp}$ | Fraction of annual useful energy required for domestic cooking met with biogas |
| $f_{h(r)}$ | Fraction of households in rural areas of Uttarakhand |
| $f_{h(u)}$ | Fraction of households in urban areas of Uttarakhand |
| $f_{hdswh(r)}$ | Fraction of households situated in locations suitable for domestic solar water heater usage in rural areas of Uttarakhand |
| $f_{hdswh(u)}$ | Fraction of households situated in locations suitable for domestic solar water heater usage in urban areas of Uttarakhand |
| $f_{ic}$ | Fraction of annual useful energy required for domestic cooking met with improved biomass cookstove |
| $f_{idh(r)}$ | Fraction of suitable households that may not have adequate cow dung due to inefficient collection |
| $f_{l(r)}$ | Fraction of rural households in Uttarakhand that have adequate land for biogas plant installation adjacent to their house |
| $f_{pa}$ | Fraction of households having the propensity to adopt a DRES |

## NOMENCLATURE (continued…)

| | |
|---|---|
| $f_{ppbp(r)}$ | Fraction of rural households in Uttarakhand having the purchasing power to adopt a family size biogas plant |
| $f_{ppdswh(r)}$ | Fraction of households having the purchasing power to adopt a domestic solar water heater in rural areas of Uttarakhand |
| $f_{ppdswh(u)}$ | Fraction of households having the purchasing power to adopt domestic solar water heater in urban areas of Uttarakhand |
| $f_{ppic(r)}$ | Fraction of households having the purchasing power to adopt improved cookstove in rural areas of Uttarakhand |
| $f_{ppic(u)}$ | Fraction of households having the purchasing power to adopt improved cookstove in urban areas of Uttarakhand |
| $f_{ppshs(r)}$ | Fraction of rural households in Uttarakhand having the purchasing power to adopt an SHS |
| $f_{ppsl(r)}$ | Fraction of households in rural areas of Uttarakhand having the purchasing power to adopt a solar lantern |
| $f_{ppsl(u)}$ | Fraction of households in urban areas of Uttarakhand having the purchasing power to adopt a solar lantern |
| $f_{sh(r)}$ | Fraction of households suitable for biogas plant in rural Uttarakhand |
| $f_{shs}$ | Fraction of annual lighting energy demand met by an SHS |
| $f_{sl}$ | Fraction of annual lighting energy demand met with solar lantern |
| $f_{sl(r)}$ | Fraction of electrified rural households of Uttarakhand that may prefer solar lantern for outdoor lighting |
| $f_{sp}$ | Fraction of annual water pumping energy requirement met by solar PV pump |
| $f_{spn}$ | Fraction of households whose perceived needs are fulfilled by improved biomass cookstoves |

## NOMENCLATURE (continued…)

| | |
|---|---|
| $f_{ueh(r)}$ | Fraction of un-electrified households in rural Uttarakhand |
| $f_{ueh(u)}$ | Fraction of un-electrified households in urban Uttarakhand |
| FPC | Flat plate collector |
| FSBP | Family size biogas plant |
| g | Acceleration due to gravity |
| GHI | Global horizontal irradiance |
| GSDP | Gross state domestic product |
| h | Head for water pumping |
| $h_{fg}$ | Enthalpy of evaporation of water at drying temperature |
| IRR | Internal rate of return |
| KVIC | Khadi and Village Industries Commission |
| LCUE | Levelized cost of useful energy |
| LPD | Liters per day |
| M | Estimated potential of a technology in a region |
| $M_{DSWH}$ | Daily water heating capacity of DSWH |
| $M_f$ | Final moisture content (in fraction) of crop on wet basis |
| $M_i$ | Initial moisture content (in fraction) of crop on wet basis |
| $M_{sd}$ | Capacity of solar dryer (mass of crop dried on wet basis) |
| MNRE | Ministry of New and Renewable Energy |
| MPCE | Monthly per capita expenditure |
| n | Useful life of DRES |
| $n_{hrld}$ | No. of hours of lighting per day |
| $n_l$ | No. of lamps replaced by an SHS |
| $n_{ly}$ | No. of loadings per year |
| $n_{mc}$ | Average no. of persons for whom meal is cooked |

## NOMENCLATURE (continued…)

| | |
|---|---|
| $n_{mcy}$ | No. of meals cooked by solar cooker per year |
| $n_{ph}$ | No. of persons per household |
| $n_{pv}$ | No. of persons in village |
| $N_h$ | No. of households in Uttarakhand |
| $N_{smdms}$ | No. of schools covered under mid-day meal scheme in Uttarakhand |
| $N_{uev}$ | No. of un-electrified villages in Uttarakhand |
| $N_{vpri}$ | No. of villages in Uttarakhand in the $i^{th}$ population range category |
| NASA | National Aeronautics and Space Administration |
| NPV | Net present value |
| NSSO | National Sample Survey Office |
| N(t) | Cumulative dissemination/adoptions of a technology upto $t^{th}$ year |
| $P_{bp}$ | Potential of family size biogas plant in Uttarakhand |
| $P_{dswh}$ | Potential of domestic solar water heater in Uttarakhand |
| $P_f$ | Unit price of fuel replaced by DRES |
| $P_{ic}$ | Potential of improved cookstove in Uttarakhand |
| $P_{pvp}$ | Potential of solar PV pump in Uttarakhand |
| $P_{sc}$ | Potential of community type solar cookers in Uttarakhand |
| $P_{sd}$ | Potential of community type solar dryer in Uttarakhand |
| $P_{shs}$ | Potential of solar home system in Uttarakhand |
| $P_{sl}$ | Potential of solar lantern in Uttarakhand |
| R | Annual rebate (if any) to the DRES user |
| s | Specific heat of wet crop |
| SFC | Specific fuel consumption of the lighting appliance replaced by solar lighting device |

## NOMENCLATURE (continued…)

| | |
|---|---|
| SHS | Solar home system |
| SWH | Solar water heater |
| $t$ | time period |
| $T_a$ | Ambient temperature |
| $T_d$ | Drying temperature |
| $T_1$ | Inlet temperature of water in DSWH |
| $T_2$ | Outlet temperature of water in DSWH |
| $UER_{mp}$ | Useful energy required per meal per person |
| $UER_{pd}$ | Useful cooking energy requirement per person per day |
| UREDA | Uttarakhand Renewable Energy Development Agency |
| $V_{wpd}$ | Volume of water required per person per day for various domestic activities |
| $\rho_w$ | Density of water |
| $\eta_{fu}$ | Efficiency of fuel utilization of the fuel replaced by DRES |
| $\eta_{ic}$ | Efficiency of improved biomass cookstove |
| $\eta_{tc}$ | Efficiency of traditional biomass cookstove |

# CHAPTER 1

# CHARACTERISTICS OF UTTARAKHAND AND ITS IMPLICATIONS FOR RENEWABLE ENERGY

## 1.1. State of Uttarakhand

### *1.1.1. Introduction*

Uttarakhand, formerly Uttaranchal, is a state in the Central Himalayan Region of India. On 9th November 2000, Uttarakhand was carved out of the state of Uttar Pradesh as 27th state of the Republic of India (GoU, n.d.). Geographically, Uttarakhand is situated in the northern part of India extending between 28° 43′ to 31° 27′ N latitude and 77° 34′ to 81° 02′ E longitude (Figures 1.1-1.2) (DES, 2014). The state has international boundaries with China (Tibet) in the north and Nepal in the east. In west and south, it is surrounded by Indian states of Himachal Pradesh and Uttar Pradesh respectively (Figure 1.3). It is largely a hilly state located at the foothills of the Himalayan mountain ranges. The state is rich in natural resources especially water and forests with many glaciers, rivers, dense forests and snow-clad mountain peaks. Due to its geography and strategic location, it has been provided special category status which entitles the state to special financial package from the Union Government of India (DIPP, 2003).

As per Census of India 2011, the state of Uttarakhand has a population of 1,01,16,752 (ORGCC, n.d.) with a total geographical area of 53,483 sq.km (DES, 2014). The state has 13 districts that are divided between two divisions namely Garhwal and Kumaon (Figure 1.3). Garhwal Division consists of Dehradun, Haridwar, Tehri Garhwal, Uttarkashi, Chamoli, Pauri Garhwal (commonly known as Garhwal) and Rudraprayag. Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udham Singh Nagar districts constitute Kumaon Division. Of these 13 districts, Dehradun and Nainital are foothill districts whereas Haridwar and Udham Singh Nagar have large areas in plains. The remaining 9 districts are classified as hill districts of Uttarakhand (Singh and Singh, n.d.; APF, n.d.; ENVIS, n.d.). The state has 16793 villages and 7555 gram panchayats (village level local governing bodies) (DES, 2014).

### *1.1.2. Topography and Climate*

The topography of Uttarakhand is characterized by hilly terrain, deep valleys, high peaks, swift streams and rivulets, rapid soil erosion, frequent landslides and widely scattered habitation (Planning Commission, 2009). Regions in the state of Uttarakhand exhibit altitudinal variation ranging from 210-7817 m above mean sea level (GoU, 2011). Out of the total geographical area of 53,483 sq.km, about 85% area (i.e., 46,035 sq.km) has hilly terrain (DES, 2014). With respect to ground slope, all the 9 hill districts of Uttarakhand are reported to have large areas of land having steep slopes with slope angle ≥ 20% (MoEF, n.d.). It is only the foothill districts of Dehradun and Nainital and the plain districts of Udham Singh Nagar and Hardwar which have land in plains with manageable slope (slope angle < 5%) (APF, n.d.). Two major rivers of India, Ganga and Yamuna emerge from the glaciers of Uttarakhand, and are fed by glacial melts and streams in the region. The high Himalayan ranges and glaciers form most of the northern parts of the state while the lower reaches are densely forested. The state is rich in vegetation with a forest cover of 34,651 sq.km (approximately 65% of the geographical area) (DES, 2014). The natural vegetation is mixed broad-level forest with oak and pine predominating. Hilly areas that form 85% of the state are characterized by loose soil and steep slopes that are highly susceptible to soil erosion during rains (MoEF, n.d.).

The state of Uttarakhand stretches from the foot hills in the south to the snow-clad peaks of Himadri outlining Indo-Tibetan boundary. Being situated centrally in the long sweep of Himalaya, Uttarakhand represents a transitional zone between the per-humid eastern and the dry to sub-humid western Himalaya (WMD, n.d.).

Climate wise, the state exhibits two distinct climatic regions: the predominant hilly terrain and the small plain region. Uttarakhand's climate varies greatly due to change in altitude and proximity towards Himalayas. The climatic condition of the plain areas of the state is tropical. Uttarakhand experiences three major seasons, namely, summers, winters, and monsoons (NP, n.d.). Summers are relatively hot and winters are cold with temperatures reaching sub-zero levels. The minimum and maximum temperatures recorded are -4.6 °C at Mukteshwar and 43.1 °C at Dehradun respectively (DES, 2014). With increased coverage of meteorological observatories, the maximum and minimum temperatures can further intensify. Uttarakhand receives an average rainfall varying from 920 mm in Srinagar to 2500 mm in Nainital (GoU, 2011). However, spatial distribution of the rainfall varies with generally higher rainfall in low mountainous regions like Nainital and Dehradun. Rainfall gradually decreases with increased elevation. Approximately 3/4$^{th}$ of the total rainfall is received during monsoon season (June-September) and remaining 1/4$^{th}$ occurs in the other seasons due to the western disturbances (GoU, 2011).

### *1.1.3. Demography*

Uttarakhand is predominantly a rural society with 69% of its population residing in rural areas and only 31% living in urban areas (Table 1.1) (ORGCC, n.d.). Population and household distribution and number of villages in rural and urban areas of the districts of Uttarakhand are depicted in Table 1.1. Apart from foothill districts of Dehradun and Nainital and plain districts of Udham Singh Nagar and Hardwar, all other nine districts of the state have large part (about 85% or more) of its population in rural areas. Dehradun is the only district of the state to have urban population higher than the rural population. Average household size in Uttarakhand is 5 and it is the same in urban and rural areas. The rural areas of the state have 16,793 villages in total (ORGCC, n.d.).

Rural Uttarakhand is predominantly hilly and doesn't support large scale agriculture (Mittal et al., 2008). In rural areas of the state, people generally practice subsistence agriculture. Scarcity of employment opportunities coupled with weak infrastructure in rural areas is fuelling rural to urban migration of


Figure 1.1: Uttarakhand as a state in India (MoI, n.d.)

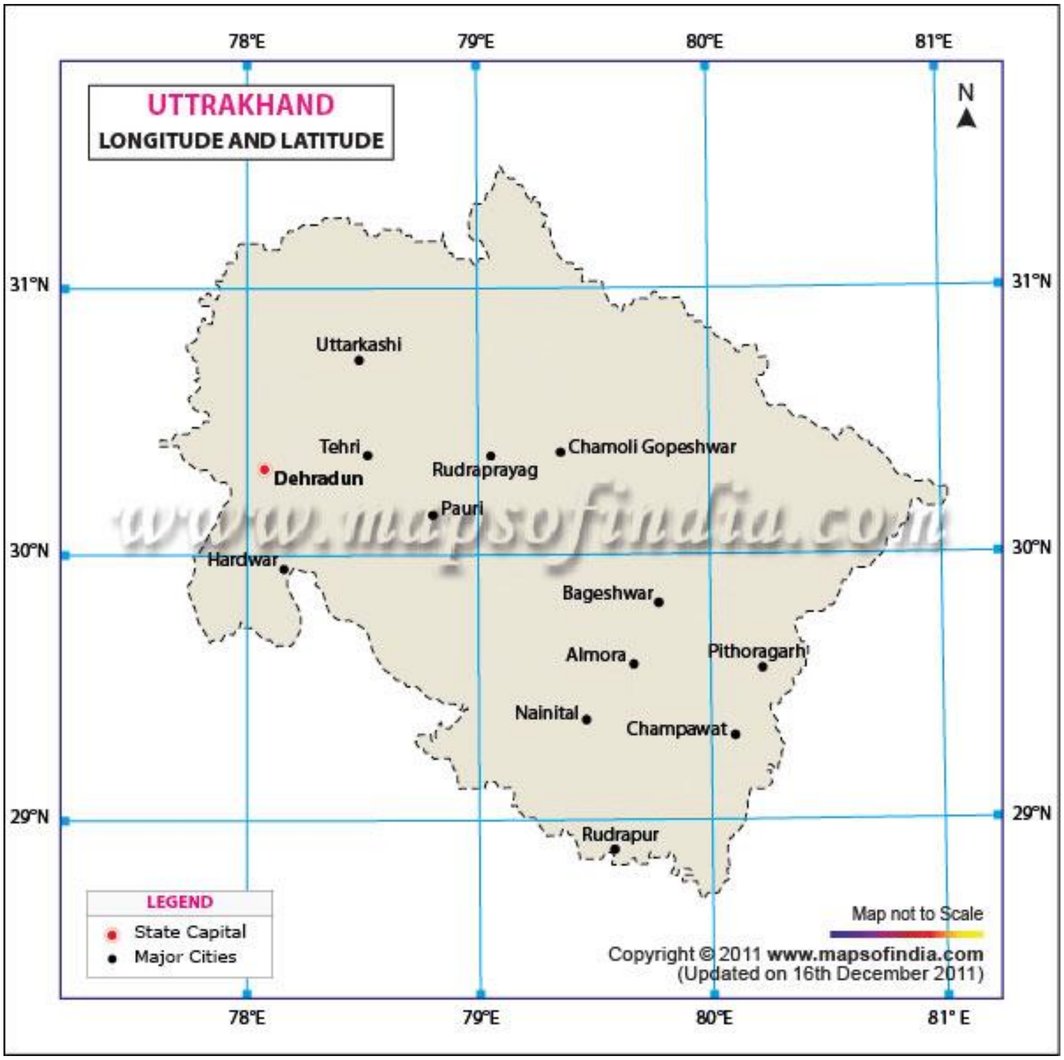


Figure 1.2: Location of Uttarakhand (MoI, n.d.)

people especially young men (Mittal et al., 2008). Hence, rural to urban migration is one of the critical challenges being faced by the state (Planning Commission, 2009). Table 1.2 presents the percentage decadal growth recoded in rural and urban areas of various districts of Uttarakhand during 2001-11. From the table, it is evident that during 2001-11, urban areas of most of the districts have registered higher decadal growth rates compared to rural areas. Uttarkashi and Champawat are the only two districts which have reported higher decadal growth rate of population in rural areas. The decadal growth rates in rural areas of Rudraprayag

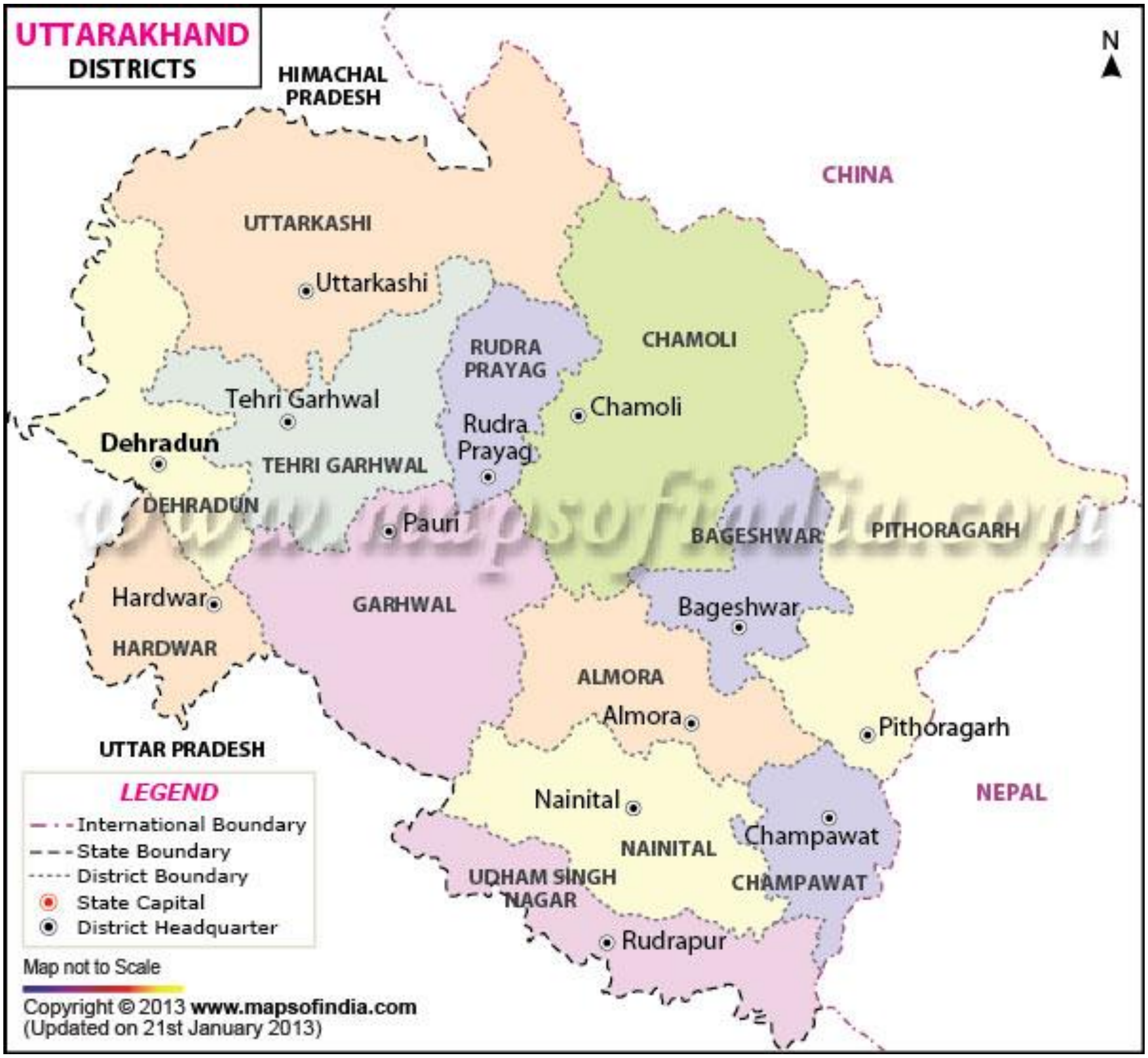


Figure 1.3: Districts of Uttarakhand (MoI, n.d.)

and Tehri Garhwal districts are almost negligible whereas the growth rates are relatively very high in its urban counterparts. Garhwal and Almora exhibit negative decadal growth rates in rural areas whereas the growth rates in its urban parts are positive and comparatively very high. Lower, negligible and negative decadal growth rates in rural areas depict the phenomenon of rural to urban migration. Because of the migration, the share of rural population of the state has decreased from 74.33% in 2001 to 69.45% in 2011 (Figure 1.4) (ORGCC, n.d.). Table 1.3 depicts the migration statistics of Uttarakhand released by National

Sample Survey Office (NSSO), India. The number of male out-migrants per 1000 persons for the rural areas of Uttarakhand is significantly higher than the

Table 1.1: District-wise population, number of households and villages in Uttarakhand (ORGCC, n.d.)

| *Uttarakhand/ Districts* | *Population* | | | *% of population* | | *No. of households* | | | *No. of villages* |
|---|---|---|---|---|---|---|---|---|---|
| | *Total* | *Rural* | *Urban* | *Rural* | *Urban* | *Total* | *Rural* | *Urban* | |
| Uttarakhand | 10116752 | 7025583 | 3091169 | 69 | 31 | 1997068 | 1404845 | 592223 | 16793 |
| Uttarkashi | 329686 | 305469 | 24217 | 93 | 07 | 66558 | 61149 | 5409 | 707 |
| Chamoli | 391114 | 332026 | 59088 | 85 | 15 | 85765 | 72744 | 13021 | 1246 |
| Rudraprayag | 236857 | 226939 | 9918 | 96 | 04 | 53492 | 51064 | 2428 | 688 |
| Tehri Garhwal | 616409 | 546354 | 70055 | 89 | 11 | 133494 | 116988 | 16506 | 1862 |
| Dehradun | 1698560 | 749000 | 949560 | 44 | 56 | 322700 | 137051 | 185649 | 748 |
| Garhwal | 686527 | 573847 | 112680 | 84 | 16 | 161688 | 137102 | 24586 | 3473 |
| Pithoragarh | 485993 | 416430 | 69563 | 86 | 14 | 111542 | 95130 | 16412 | 1675 |
| Bageshwar | 259840 | 250749 | 9091 | 97 | 03 | 57712 | 55748 | 1964 | 947 |
| Almora | 621927 | 559595 | 62332 | 90 | 10 | 139257 | 126476 | 12781 | 2289 |
| Champawat | 259315 | 220970 | 38345 | 85 | 15 | 52356 | 44386 | 7970 | 717 |
| Nainital | 955128 | 583237 | 371891 | 61 | 39 | 187108 | 112670 | 74438 | 1141 |
| Udham Singh Nagar | 1648367 | 1061841 | 586526 | 64 | 36 | 300052 | 194695 | 105357 | 688 |
| Hardwar | 1927029 | 1199126 | 727903 | 62 | 38 | 325344 | 199642 | 125702 | 612 |

average for rural areas of India (NSSO, 2010). For rural males, almost 85% (844 out of 1000 persons) of the out-migration has been a result of out-migration due to employment related activities whereas for females it is primarily due to marriage (NSSO, 2010). With increased migration of young men to urban areas for employment, more and more women in rural households of Uttarakhand are taking on the mantle of operational head of the household (Mittal et al., 2008).

Table 1.2: Population and decadal growth rate by residence (ORGCC, n.d.)

| *India/Uttarakhand/ Districts* | *Population in 2011* | | | *Percentage decadal growth (persons) 2001-2011* | | |
|---|---|---|---|---|---|---|
| | *Total* | *Rural* | *Urban* | *Total* | *Rural* | *Urban* |
| India | 1210193422 | 833087662 | 377105760 | 17.64 | 12.18 | 31.80 |
| Uttarakhand | 10116752 | 7025583 | 3091169 | 19.17 | 11.34 | 41.86 |
| Uttarkashi | 329686 | 305469 | 24217 | 11.75 | 12.27 | 5.67 |
| Chamoli | 391114 | 332026 | 59088 | 5.60 | 3.87 | 16.54 |
| Rudraprayag | 236857 | 226939 | 9918 | 4.14 | 0.99 | 263.03 |
| Tehri Garhwal | 616409 | 546354 | 70055 | 1.93 | 0.27 | 17.06 |
| Dehradun | 1698560 | 749000 | 949560 | 32.48 | 24.13 | 39.90 |
| Garhwal | 686527 | 573847 | 112680 | -1.51 | -5.49 | 25.37 |
| Pithoragarh | 485993 | 416430 | 69563 | 5.13 | 3.47 | 16.26 |
| Bageshwar | 259840 | 250749 | 9091 | 5.13 | 4.76 | 16.51 |
| Almora | 621927 | 559595 | 62332 | -1.73 | -3.24 | 14.36 |
| Champawat | 259315 | 220970 | 38345 | 15.49 | 15.83 | 13.52 |
| Nainital | 955128 | 583237 | 371891 | 25.20 | 18.10 | 38.22 |
| Udham Singh Nagar | 1648367 | 1061841 | 586526 | 33.40 | 27.53 | 45.53 |
| Hardwar | 1927029 | 1199126 | 727903 | 33.16 | 19.80 | 63.11 |

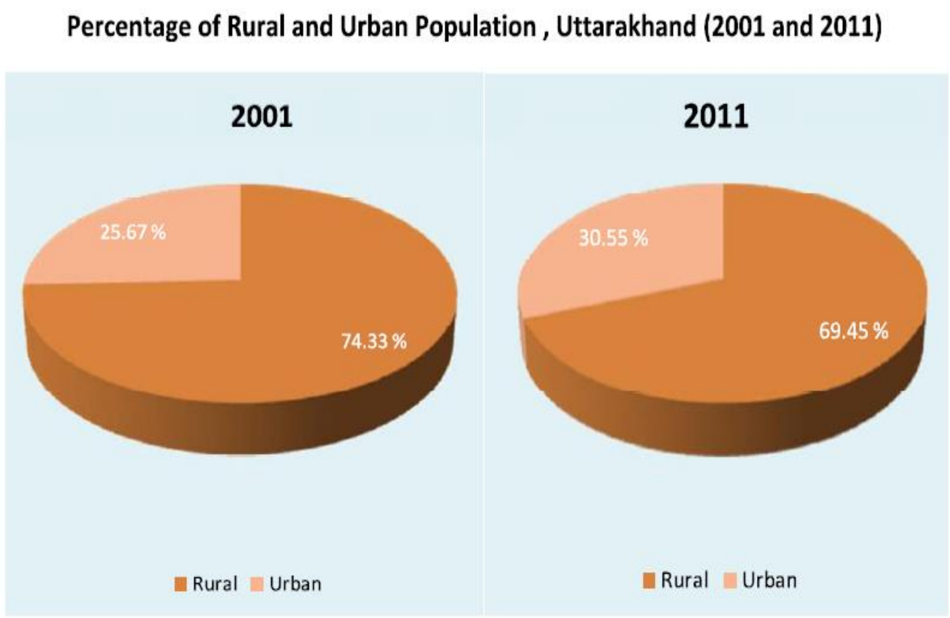


Figure 1.4: Percentage of rural and urban population in Uttarakhand (ORGCC, n.d.)

Table 1.3: Number of out-migrant per 1000 persons for Uttarakhand and average of all states in India (NSSO, 2010)

| *Gender* | *Uttarakhand* | | *India* | |
|---|---|---|---|---|
| | *Rural* | *Urban* | *Rural* | *Urban* |
| Male | 166 | 63 | 92 | 51 |
| Female | 207 | 106 | 166 | 110 |

### *1.1.4. Economic Activities*

The economic activities of the state of Uttarakhand are divided into three sectors – primary, secondary and tertiary. The sub-sectors under these three sectors are presented in Table 1.4. For livelihood, the state's population is largely dependent on primary sector. Sub-sectors of primary sector namely agriculture and allied activities (forestry, logging and fishing) provide livelihood to more than 70 per cent of the population of Uttarakhand (Planning Commission, 2009; WMD, n.d.). Though agriculture is one of the primary sources of livelihood, only 14% of the land area of the state is under cultivation as 85% of the state's land is hilly (Planning Commission, 2009; WMD, n.d.). Agriculture in Uttarakhand is largely rainfed and land holdings are small (AD, n.d.). Lack of institutional arrangements supporting pre and post harvesting activities results in low yields. This ultimately leads to subsistence agriculture with low and unstable income for the farmers (WMD, n.d.).

The trend of Uttarakhand's Gross State Domestic Product (GSDP) estimates suggests that Agriculture, Manufacturing, Construction and Trade, Hotels and Restaurants used to be the major contributing sectors (Table 1.5). During 1999-2000, agriculture used to be the major contributor to Uttarakhand's GSDP contributing 26.15% of the total share (Table 1.5). However, since 1999-2000, there has been continuous decrease in its share and it contributed only 9% during 2012-03. As per data for the year 2012-13, the share of primary, secondary and tertiary sectors in GSDP of Uttarakhand are 14%, 34% and 52% respectively.

Within tertiary sector, tourism related sub-sector named Trade, Hotels and Restaurants is the major contributor with a share of 23% in the GSDP of the state (Table 1.5) (DES, 2013).

Apart from agriculture and tourism, employment with the state government is the source of income to a population of 1,45,630 (DES, 2014). In addition to this, a significant population of Uttarakhand is employed in various defense establishments. Also, about 5,00,000 registered pensioners are receiving pension in the state from central/state government under various schemes (DES, 2014). Unsuitability of the state for large scale agriculture or other employment generating activities has resulted in wide spread poverty in the state. Uttarakhand has 36.5% of its population under the category of Below Poverty Line (BPL). Hilly areas are more affected by poverty that is reflected by a BPL population of 44% whereas the plain areas of the state have a BPL population of 19% (WMD, n.d.).

Table 1.4: Gross State Domestic Product at factor cost by industry: 2004-05 to 2012-13 at current prices 15 Feb 2013 (₹ Lacs) (DES, 2013)

| *S.No.* | *Sector/Sub-sector* | *2004-05* | *2005-06* | *2006-07* | *2007-08* | *2008-09* | *2009-10* | *2010-11* | *2011-12* | *2012-13* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Agriculture | 411370 | 420567 | 491405 | 507118 | 595515 | 734753 | 758791 | 847375 | 943617 |
| 2 | Forestry&Logging | 139751 | 163641 | 185764 | 199950 | 227127 | 256115 | 315402 | 362398 | 415364 |
| 3 | Fishing | 919 | 1053 | 1234 | 1275 | 1479 | 2158 | 2753 | 3562 | 4428 |
| *Agriculture and Allied* | | *552040* | *585261* | *678403* | *708343* | *824121* | *993026* | *1076946* | *1213335* | *1363409* |
| 4 | Mining&Quarrying | 29894 | 44591 | 50747 | 57538 | 45058 | 57784 | 73108 | 93615 | 103406 |
| *Sub-total of Primary Sector* | | *581934* | *629852* | *729150* | *765881* | *860179* | *1050810* | *1150054* | *1306950* | *1466815* |
| 5 | Manufacturing | 315559 | 483122 | 648360 | 983629 | 1271801 | 1610496 | 1859660 | 2045355 | 2293208 |
| 6 | Construction | 315686 | 368159 | 470989 | 460222 | 478218 | 587487 | 677562 | 792351 | 943193 |
| 7 | Electricity, Gas and Water Supply | 38445 | 41329 | 75221 | 155880 | 175158 | 217402 | 312985 | 350090 | 451949 |
| *Sub-total of Secondary Sector* | | *669690* | *892610* | *1194570* | *1599731* | *1925177* | *2415385* | *2850207* | *3187796* | *3688350* |
| 8 | Transport, Storage & Communication | 162784 | 192291 | 239102 | 293876 | 351386 | 452672 | 543297 | 639353 | 774165 |
| 9 | Trade, Hotels & Restaurants | 419564 | 551390 | 682256 | 920771 | 1195955 | 1633282 | 1975396 | 2194607 | 2486233 |
| 10 | Banking & Insurance | 93663 | 105378 | 124822 | 146611 | 179305 | 204636 | 259281 | 311518 | 376373 |
| 11 | Real Estate, Ownership of Dwellings & Business Services | 159893 | 178583 | 199883 | 238414 | 278405 | 336533 | 407807 | 470572 | 555761 |
| 12 | Public Administration | 133372 | 153922 | 176435 | 252589 | 369289 | 472270 | 531608 | 582843 | 684347 |
| 13 | Other Services | 257667 | 292727 | 333324 | 367691 | 433780 | 508046 | 574145 | 622533 | 722781 |
| *Sub-total of Tertiary Sector* | | *1226943* | *1474291* | *1755822* | *2219952* | *2808120* | *3607439* | *4291534* | *4821426* | *5599660* |
| *Gross State Domestic Product (GSDP)* | | *2478567* | *2996753* | *3679542* | *4585564* | *5602476* | *7073634* | *8291795* | *9316172* | *10754825* |
| State Population (in thousands) | | 9014 | 9160 | 9305 | 9451 | 9597 | 9742 | 9885 | 10027 | 10167 |
| *Per Capita GSDP (₹)* | | *27497* | *32716* | *39544* | *48519* | *58377* | *72610* | *83883* | *92911* | *105782* |

Table 1.5: Contribution of sector/sub-sector to Uttarakhand's Gross State Domestic Product at factor cost: 2004-05 to 2012-13 at current prices 15 Feb 2013 (in %) (DES, 2013)

| *S.No.* | *Sector/Sub-sector* | *2004-05* | *2005-06* | *2006-07* | *2007-08* | *2008-09* | *2009-10* | *2010-11* | *2011-12* | *2012-13* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Agriculture | 17 | 14 | 13 | 11 | 11 | 10 | 09 | 09 | 09 |
| 2 | Forestry&Logging | 06 | 05 | 05 | 04 | 04 | 04 | 04 | 04 | 04 |
| 3 | Fishing* | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| *Agriculture and Allied* | | *22* | *20* | *18* | *15* | *15* | *14* | *13* | *13* | *13* |
| 4 | Mining&Quarrying | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 | 01 |
| *Sub-total of Primary Sector* | | *23* | *21* | *20* | *17* | *15* | *15* | *14* | *14* | *14* |
| 5 | Manufacturing | 13 | 16 | 18 | 21 | 23 | 23 | 22 | 22 | 21 |
| 6 | Construction | 13 | 12 | 13 | 10 | 09 | 08 | 08 | 09 | 09 |
| 7 | Electricity, Gas and Water Supply | 02 | 01 | 2 | 03 | 03 | 03 | 04 | 04 | 04 |
| *Sub-total of Secondary Sector* | | *27* | *30* | *32* | *35* | *34* | *34* | *34* | *34* | *34* |
| 8 | Transport, Storage & Communication | 07 | 06 | 06 | 06 | 06 | 06 | 07 | 07 | 07 |
| 9 | Trade, Hotels & Restaurants | 17 | 18 | 19 | 20 | 21 | 23 | 24 | 24 | 23 |
| 10 | Banking & Insurance | 04 | 04 | 03 | 03 | 03 | 03 | 03 | 03 | 03 |
| 11 | Real Estate, Ownership of Dwellings & Business Services | 06 | 06 | 05 | 05 | 05 | 05 | 05 | 05 | 05 |
| 12 | Public Administration | 05 | 05 | 05 | 06 | 07 | 07 | 06 | 06 | 06 |
| 13 | Other Services | 10 | 10 | 09 | 08 | 08 | 07 | 07 | 07 | 07 |
| *Sub-total of Tertiary Sector* | | *50* | *49* | *48* | *48* | *50* | *51* | *52* | *52* | *52* |
| *Gross State Domestic Product (GSDP)* | | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* | *100* |

* The contribution of fishing is very small and thus approximately equal to zero.

### *1.1.5. Energy Scenario*

*1.1.5.1. Electricity*

In comparison to urban areas, rural areas have less access to electricity in Uttarakhand (Table 1.6). 17% of the rural households in Uttarakhand lack access to electricity. In rural areas of Uttarkashi, Almora, Champawat and Hardwar, more than 20% of households lack access to electricity (ORGCC, n.d.). As per the latest data, there are 107 un-electrified villages in Uttarakhand (CEA, 2015)**.** As per Uttarakhand Power Corporation Limited, the un-electrified villages are surrounded by dense forests, steep hills or are snowbound. Forests, steep hills and snowbound areas make grid electrification difficult and unviable (Chaudhuri, 2007; Nouni et al., 2008).

In addition to poor access to electricity in rural Uttarakhand, the state is also facing acute power shortage. During last year, monthly averaged daily energy (electricity) shortages in the state ranged from 8% - 46% with an annual mean of 30% (UPCL, 2015)**.** The state is addressing the energy shortage by purchasing energy through power trading (bilateral agreements and power exchange) and rostering (UPCL, 2015)**.** Thus, it can be inferred that the state does not have the power generation capacity to support further expansion of access to electricity.

*1.1.5.2. Energy for Cooking and Lighting*

As per Census of India 2011, more than 90% of the households in Uttarakhand utilize fire wood and LPG as major fuel for cooking (Tables 1.7-1.8) (ORGCC, n.d.). Almost half (48.68%) of the households in the state are using biomass as a fuel for cooking. In rural households of the state, the share of biomass in cooking further increases to 63.29%. This may be attributed to easy availability of biomass or agricultural residues at zero private cost from nearby forests or agricultural farms to rural households in Uttarakhand. Apart from biomass, LPG is also used widely for cooking in the state with 44.23% households dependent on LPG. The percentage of LPG using households in urban areas is 79.42% and for rural areas it is 29.40%. Among various renewable energy technologies, only biogas is being used for cooking by a very small fraction (0.47%) of households in the state. It is only in the rural areas of Nainital and Udham Singh Nagar where biogas is

Table 1.6: Electrification of households in Uttarakhand (ORGCC, n.d.)

| *State/District* | *No. of households* | | | *No. of electrified households* | | | *% of electrified households* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Total* | *Rural* | *Urban* | *Total* | *Rural* | *Urban* | *Total* | *Rural* | *Urban* |
| Uttarakhand | 1997068 | 1404845 | 592223 | 1738175 | 1166756 | 571419 | 87 | 83 | 96 |
| Uttarkashi | 66558 | 61149 | 5409 | 52621 | 47319 | 5302 | 79 | 77 | 98 |
| Chamoli | 85765 | 72744 | 13021 | 71524 | 58791 | 12733 | 83 | 81 | 98 |
| Rudraprayag | 53492 | 51064 | 2428 | 49182 | 46794 | 2388 | 92 | 92 | 98 |
| Tehri Garhwal | 133494 | 116988 | 16506 | 117239 | 100992 | 16247 | 88 | 86 | 98 |
| Dehradun | 322700 | 137051 | 185649 | 310726 | 129466 | 181260 | 96 | 94 | 98 |
| Garhwal | 161688 | 137102 | 24586 | 143963 | 119829 | 24134 | 89 | 87 | 98 |
| Pithoragarh | 111542 | 95130 | 16412 | 95421 | 79202 | 16219 | 86 | 83 | 99 |
| Bageshwar | 57712 | 55748 | 1964 | 47083 | 45172 | 1911 | 82 | 81 | 97 |
| Almora | 139257 | 126476 | 12781 | 109876 | 97337 | 12539 | 79 | 77 | 98 |
| Champawat | 52356 | 44386 | 7970 | 37725 | 30333 | 7392 | 72 | 68 | 93 |
| Nainital | 187108 | 112670 | 74438 | 169001 | 96746 | 72255 | 90 | 86 | 97 |
| Udham Singh Nagar | 300052 | 194695 | 105357 | 254802 | 156658 | 98144 | 85 | 80 | 93 |
| Hardwar | 325344 | 199642 | 125702 | 279012 | 158117 | 120895 | 86 | 79 | 96 |

utilized in more than 1% households. The best case of use of biogas is of rural Nainital where 4.27% of the households depend on biogas for cooking (ORGCC, n.d.).

For lighting, electricity is the main energy source being utilized in Uttarakhand households followed by kerosene with shares of 87.04% and 11.08% households respectively (Tables 1.9-1.10). The share of kerosene usage is higher in rural households with 14.53% rural households using it for lighting. Among renewable energy technologies for lighting, only solar energy usage is being reported. 1.22%

households of Uttarakhand are reported to be using solar lighting devices. In rural and urban areas of Uttarakhand, solar lighting is being used by 1.69% and 0.08% households respectively. In rural areas of Chamoli and Champawat, solar energy utilization for lighting score high with more than 5% of the households utilizing solar lighting (ORGCC, n.d.).

Table 1.7: Energy consumption pattern: fuel used for cooking (ORGCC, n.d.)

| *State/District* | *Type of area* | *No. of households* | *No. of households using various types of fuel for cooking* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Fire-wood* | *Crop residue* | *Cow dung* | *Coal/Lignite* | *Kerosene* | *LPG/PNG* | *Electricity* | *Biogas* | *Any other* | *No cooking* |
| Uttarakhand | Total | 1997068 | 972074 | 25430 | 63188 | 1211 | 35676 | 883286 | 806 | 9460 | 699 | 5238 |
| | Rural | 1404845 | 889073 | 21402 | 54979 | 801 | 12954 | 412972 | 584 | 8866 | 365 | 2849 |
| | Urban | 592223 | 83001 | 4028 | 8209 | 410 | 22722 | 470314 | 222 | 594 | 334 | 2389 |
| Uttarkashi | Total | 66558 | 43190 | 499 | 39 | 6 | 1167 | 21374 | 83 | 8 | 28 | 164 |
| | Rural | 61149 | 42979 | 485 | 35 | 5 | 843 | 16582 | 83 | 7 | 28 | 102 |
| | Urban | 5409 | 211 | 14 | 4 | 1 | 324 | 4792 | 0 | 1 | 0 | 62 |
| Chamoli | Total | 85765 | 55291 | 829 | 38 | 26 | 1384 | 27853 | 12 | 16 | 7 | 309 |
| | Rural | 72744 | 54017 | 790 | 33 | 25 | 737 | 16971 | 9 | 13 | 6 | 143 |
| | Urban | 13021 | 1274 | 39 | 5 | 1 | 647 | 10882 | 3 | 3 | 1 | 166 |
| Rudraprayag | Total | 53492 | 32047 | 736 | 30 | 16 | 678 | 19859 | 16 | 20 | 3 | 87 |
| | Rural | 51064 | 31881 | 735 | 29 | 16 | 354 | 17957 | 16 | 19 | 1 | 56 |
| | Urban | 2428 | 166 | 1 | 1 | 0 | 324 | 1902 | 0 | 1 | 2 | 31 |
| Tehri Garhwal | Total | 133494 | 78821 | 1093 | 77 | 41 | 1970 | 50929 | 147 | 47 | 11 | 358 |
| | Rural | 116988 | 78281 | 1064 | 75 | 33 | 791 | 36468 | 49 | 45 | 6 | 176 |
| | Urban | 16506 | 540 | 29 | 2 | 8 | 1179 | 14461 | 98 | 2 | 5 | 182 |
| Dehradun | Total | 322700 | 71123 | 1693 | 787 | 154 | 13322 | 233705 | 96 | 635 | 131 | 1054 |
| | Rural | 137051 | 59064 | 1027 | 401 | 78 | 3035 | 72422 | 60 | 521 | 30 | 413 |
| | Urban | 185649 | 12059 | 666 | 386 | 76 | 10287 | 161283 | 36 | 114 | 101 | 641 |
| Garhwal | Total | 161688 | 87128 | 1112 | 116 | 44 | 2072 | 70551 | 37 | 224 | 40 | 364 |
| | Rural | 137102 | 85141 | 1042 | 96 | 37 | 1362 | 48887 | 33 | 207 | 38 | 259 |
| | Urban | 24586 | 1987 | 70 | 20 | 7 | 710 | 21664 | 4 | 17 | 2 | 105 |
| Pithoragarh | Total | 111542 | 62721 | 873 | 83 | 29 | 2041 | 45365 | 20 | 143 | 16 | 251 |
| | Rural | 95130 | 62493 | 848 | 77 | 28 | 1103 | 30228 | 20 | 132 | 11 | 190 |
| | Urban | 16412 | 228 | 25 | 6 | 1 | 938 | 15137 | 0 | 11 | 5 | 61 |
| Bageshwar | Total | 57712 | 42658 | 709 | 75 | 32 | 717 | 13352 | 13 | 66 | 6 | 84 |
| | Rural | 55748 | 42520 | 702 | 74 | 32 | 566 | 11691 | 13 | 66 | 5 | 79 |
| | Urban | 1964 | 138 | 7 | 1 | 0 | 151 | 1661 | 0 | 0 | 1 | 5 |
| Almora | Total | 139257 | 95560 | 1344 | 100 | 84 | 1583 | 40199 | 27 | 69 | 37 | 254 |
| | Rural | 126476 | 95046 | 1318 | 95 | 82 | 1087 | 28534 | 27 | 68 | 32 | 187 |
| | Urban | 12781 | 514 | 26 | 5 | 2 | 496 | 11665 | 0 | 1 | 5 | 67 |
| Champawat | Total | 52356 | 32382 | 521 | 71 | 12 | 385 | 18785 | 11 | 106 | 11 | 72 |
| | Rural | 44386 | 30533 | 380 | 71 | 8 | 199 | 13057 | 10 | 79 | 11 | 38 |

Table 1.7: Energy consumption pattern: fuel used for cooking (ORGCC, n.d.) (continued…)

| *State/District* | *Type of area* | *No. of households* | *No. of households using various types of fuel for cooking* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Fire-wood* | *Crop residue* | *Cow dung* | *Coal/Lignite* | *Kerosene* | *LPG/PNG* | *Electricity* | *Biogas* | *Any other* | *No cooking* |
| | Urban | 7970 | 1849 | 141 | 0 | 4 | 186 | 5728 | 1 | 27 | 0 | 34 |
| Nainital | Total | 187108 | 76000 | 1360 | 302 | 74 | 4679 | 99021 | 55 | 4924 | 100 | 593 |
| | Rural | 112670 | 65764 | 993 | 212 | 42 | 1233 | 39229 | 44 | 4807 | 60 | 286 |
| | Urban | 74438 | 10236 | 367 | 90 | 32 | 3446 | 59792 | 11 | 117 | 40 | 307 |
| Udhamsingh Nagar | Total | 300052 | 164558 | 6805 | 5056 | 408 | 2807 | 116576 | 127 | 2841 | 162 | 712 |
| | Rural | 194695 | 131503 | 5303 | 4394 | 236 | 1015 | 48951 | 102 | 2697 | 73 | 421 |
| | Urban | 105357 | 33055 | 1502 | 662 | 172 | 1792 | 67625 | 25 | 144 | 89 | 291 |
| Hardwar | Total | 325344 | 130595 | 7856 | 56414 | 285 | 2871 | 125717 | 162 | 361 | 147 | 936 |
| | Rural | 199642 | 109851 | 6715 | 49387 | 179 | 629 | 31995 | 118 | 205 | 64 | 499 |
| | Urban | 125702 | 20744 | 1141 | 7027 | 106 | 2242 | 93722 | 44 | 156 | 83 | 437 |

Table 1.8: Energy consumption pattern: fuel used for cooking (in %) (ORGCC, n.d.)

| *State/District* | *Type of area* | *No. of households* | *Percentage of households using various types of fuel for cooking* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Fire-wood* | *Crop residue* | *Cow dung* | *Coal/Lignite* | *Kerosene* | *LPG/PNG* | *Electricity* | *Biogas* | *Any other* | *No cooking* |
| Uttarakhand | Total | 1997068 | 48.68 | 1.27 | 3.16 | 0.06 | 1.79 | 44.23 | 0.04 | 0.47 | 0.04 | 0.26 |
| | Rural | 1404845 | 63.29 | 1.52 | 3.91 | 0.06 | 0.92 | 29.40 | 0.04 | 0.63 | 0.03 | 0.20 |
| | Urban | 592223 | 14.02 | 0.68 | 1.39 | 0.07 | 3.84 | 79.42 | 0.04 | 0.10 | 0.06 | 0.40 |
| Uttarkashi | Total | 66558 | 64.89 | 0.75 | 0.06 | 0.01 | 1.75 | 32.11 | 0.12 | 0.01 | 0.04 | 0.25 |
| | Rural | 61149 | 70.29 | 0.79 | 0.06 | 0.01 | 1.38 | 27.12 | 0.14 | 0.01 | 0.05 | 0.17 |
| | Urban | 5409 | 3.90 | 0.26 | 0.07 | 0.02 | 5.99 | 88.59 | 0.00 | 0.02 | 0.00 | 1.15 |
| Chamoli | Total | 85765 | 64.47 | 0.97 | 0.04 | 0.03 | 1.61 | 32.48 | 0.01 | 0.02 | 0.01 | 0.36 |
| | Rural | 72744 | 74.26 | 1.09 | 0.05 | 0.03 | 1.01 | 23.33 | 0.01 | 0.02 | 0.01 | 0.20 |
| | Urban | 13021 | 9.78 | 0.30 | 0.04 | 0.01 | 4.97 | 83.57 | 0.02 | 0.02 | 0.01 | 1.27 |
| Rudraprayag | Total | 53492 | 59.91 | 1.38 | 0.06 | 0.03 | 1.27 | 37.13 | 0.03 | 0.04 | 0.01 | 0.16 |
| | Rural | 51064 | 62.43 | 1.44 | 0.06 | 0.03 | 0.69 | 35.17 | 0.03 | 0.04 | 0.00 | 0.11 |
| | Urban | 2428 | 6.84 | 0.04 | 0.04 | 0.00 | 13.34 | 78.34 | 0.00 | 0.04 | 0.08 | 1.28 |
| Tehri Garhwal | Total | 133494 | 59.04 | 0.82 | 0.06 | 0.03 | 1.48 | 38.15 | 0.11 | 0.04 | 0.01 | 0.27 |
| | Rural | 116988 | 66.91 | 0.91 | 0.06 | 0.03 | 0.68 | 31.17 | 0.04 | 0.04 | 0.01 | 0.15 |
| | Urban | 16506 | 3.27 | 0.18 | 0.01 | 0.05 | 7.14 | 87.61 | 0.59 | 0.01 | 0.03 | 1.10 |
| Dehradun | Total | 322700 | 22.04 | 0.52 | 0.24 | 0.05 | 4.13 | 72.42 | 0.03 | 0.20 | 0.04 | 0.33 |
| | Rural | 137051 | 43.10 | 0.75 | 0.29 | 0.06 | 2.21 | 52.84 | 0.04 | 0.38 | 0.02 | 0.30 |
| | Urban | 185649 | 6.50 | 0.36 | 0.21 | 0.04 | 5.54 | 86.88 | 0.02 | 0.06 | 0.05 | 0.35 |
| Garhwal | Total | 161688 | 53.89 | 0.69 | 0.07 | 0.03 | 1.28 | 43.63 | 0.02 | 0.14 | 0.02 | 0.23 |
| | Rural | 137102 | 62.10 | 0.76 | 0.07 | 0.03 | 0.99 | 35.66 | 0.02 | 0.15 | 0.03 | 0.19 |
| | Urban | 24586 | 8.08 | 0.28 | 0.08 | 0.03 | 2.89 | 88.12 | 0.02 | 0.07 | 0.01 | 0.43 |
| Pithoragarh | Total | 111542 | 56.23 | 0.78 | 0.07 | 0.03 | 1.83 | 40.67 | 0.02 | 0.13 | 0.01 | 0.23 |
| | Rural | 95130 | 65.69 | 0.89 | 0.08 | 0.03 | 1.16 | 31.78 | 0.02 | 0.14 | 0.01 | 0.20 |
| | Urban | 16412 | 1.39 | 0.15 | 0.04 | 0.01 | 5.72 | 92.23 | 0.00 | 0.07 | 0.03 | 0.37 |
| Bageshwar | Total | 57712 | 73.92 | 1.23 | 0.13 | 0.06 | 1.24 | 23.14 | 0.02 | 0.11 | 0.01 | 0.15 |
| | Rural | 55748 | 76.27 | 1.26 | 0.13 | 0.06 | 1.02 | 20.97 | 0.02 | 0.12 | 0.01 | 0.14 |
| | Urban | 1964 | 7.03 | 0.36 | 0.05 | 0.00 | 7.69 | 84.57 | 0.00 | 0.00 | 0.05 | 0.25 |
| Almora | Total | 139257 | 68.62 | 0.97 | 0.07 | 0.06 | 1.14 | 28.87 | 0.02 | 0.05 | 0.03 | 0.18 |
| | Rural | 126476 | 75.15 | 1.04 | 0.08 | 0.06 | 0.86 | 22.56 | 0.02 | 0.05 | 0.03 | 0.15 |
| | Urban | 12781 | 4.02 | 0.20 | 0.04 | 0.02 | 3.88 | 91.27 | 0.00 | 0.01 | 0.04 | 0.52 |
| Champawat | Total | 52356 | 61.85 | 1.00 | 0.14 | 0.02 | 0.74 | 35.88 | 0.02 | 0.20 | 0.02 | 0.14 |

Table 1.8: Energy consumption pattern: fuel used for cooking (in %) (ORGCC, n.d.) (continued…)

| *State/District* | *Type of area* | *No. of households* | *Percentage of households using various types of fuel for cooking* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Fire-wood* | *Crop residue* | *Cow dung* | *Coal/Lignite* | *Kerosene* | *LPG/PNG* | *Electricity* | *Biogas* | *Any other* | *No cooking* |
| | Rural | 44386 | 68.79 | 0.86 | 0.16 | 0.02 | 0.45 | 29.42 | 0.02 | 0.18 | 0.02 | 0.09 |
| | Urban | 7970 | 23.20 | 1.77 | 0.00 | 0.05 | 2.33 | 71.87 | 0.01 | 0.34 | 0.00 | 0.43 |
| Nainital | Total | 187108 | 40.62 | 0.73 | 0.16 | 0.04 | 2.50 | 52.92 | 0.03 | 2.63 | 0.05 | 0.32 |
| | Rural | 112670 | 58.37 | 0.88 | 0.19 | 0.04 | 1.09 | 34.82 | 0.04 | 4.27 | 0.05 | 0.25 |
| | Urban | 74438 | 13.75 | 0.49 | 0.12 | 0.04 | 4.63 | 80.32 | 0.01 | 0.16 | 0.05 | 0.41 |
| Udhamsingh Nagar | Total | 300052 | 54.84 | 2.27 | 1.69 | 0.14 | 0.94 | 38.85 | 0.04 | 0.95 | 0.05 | 0.24 |
| | Rural | 194695 | 67.54 | 2.72 | 2.26 | 0.12 | 0.52 | 25.14 | 0.05 | 1.39 | 0.04 | 0.22 |
| | Urban | 105357 | 31.37 | 1.43 | 0.63 | 0.16 | 1.70 | 64.19 | 0.02 | 0.14 | 0.08 | 0.28 |
| Hardwar | Total | 325344 | 40.14 | 2.41 | 17.34 | 0.09 | 0.88 | 38.64 | 0.05 | 0.11 | 0.05 | 0.29 |
| | Rural | 199642 | 55.02 | 3.36 | 24.74 | 0.09 | 0.32 | 16.03 | 0.06 | 0.10 | 0.03 | 0.25 |
| | Urban | 125702 | 16.50 | 0.91 | 5.59 | 0.08 | 1.78 | 74.56 | 0.04 | 0.12 | 0.07 | 0.35 |

Table 1.9: Fuels used for lighting in Uttarakhand (ORGCC, n.d.)

| *State / District* | *Type of area* | *No. of households* | *No. of households by main source of lighting* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *Kerosene* | *Solar energy* | *Other oil* | *Any other* | *No lighting* |
| Uttarakhand | Total | 1997068 | 1738175 | 221206 | 24267 | 3158 | 3880 | 6382 |
| | Rural | 1404845 | 1166756 | 204149 | 23789 | 2691 | 2750 | 4710 |
| | Urban | 592223 | 571419 | 17057 | 478 | 467 | 1130 | 1672 |
| Uttarkashi | Total | 66558 | 52621 | 11848 | 1691 | 134 | 103 | 161 |
| | Rural | 61149 | 47319 | 11758 | 1688 | 129 | 102 | 153 |
| | Urban | 5409 | 5302 | 90 | 3 | 5 | 1 | 8 |
| Chamoli | Total | 85765 | 71524 | 9396 | 4145 | 192 | 201 | 307 |
| | Rural | 72744 | 58791 | 9142 | 4138 | 168 | 201 | 304 |
| | Urban | 13021 | 12733 | 254 | 7 | 24 | 0 | 3 |
| Rudraprayag | Total | 53492 | 49182 | 3811 | 278 | 47 | 18 | 156 |
| | Rural | 51064 | 46794 | 3774 | 278 | 46 | 17 | 155 |
| | Urban | 2428 | 2388 | 37 | 0 | 1 | 1 | 1 |
| Tehri Garhwal | Total | 133494 | 117239 | 12552 | 2995 | 210 | 104 | 394 |
| | Rural | 116988 | 100992 | 12329 | 2989 | 201 | 91 | 386 |
| | Urban | 16506 | 16247 | 223 | 6 | 9 | 13 | 8 |
| Dehradun | Total | 322700 | 310726 | 10036 | 349 | 330 | 628 | 631 |
| | Rural | 137051 | 129466 | 6410 | 292 | 195 | 379 | 309 |
| | Urban | 185649 | 181260 | 3626 | 57 | 135 | 249 | 322 |
| Garhwal | Total | 161688 | 143963 | 14695 | 2249 | 238 | 91 | 452 |
| | Rural | 137102 | 119829 | 14331 | 2212 | 234 | 85 | 411 |
| | Urban | 24586 | 24134 | 364 | 37 | 4 | 6 | 41 |
| Pithoragarh | Total | 111542 | 95421 | 12957 | 2781 | 109 | 87 | 187 |
| | Rural | 95130 | 79202 | 12802 | 2770 | 101 | 77 | 178 |
| | Urban | 16412 | 16219 | 155 | 11 | 8 | 10 | 9 |
| Bageshwar | Total | 57712 | 47083 | 9062 | 1028 | 149 | 110 | 280 |
| | Rural | 55748 | 45172 | 9020 | 1027 | 145 | 110 | 274 |
| | Urban | 1964 | 1911 | 42 | 1 | 4 | 0 | 6 |
| Almora | Total | 139257 | 109876 | 25175 | 3545 | 263 | 64 | 334 |
| | Rural | 126476 | 97337 | 24978 | 3536 | 249 | 59 | 317 |
| | Urban | 12781 | 12539 | 197 | 9 | 14 | 5 | 17 |
| Champawat | Total | 52356 | 37725 | 11948 | 2293 | 108 | 94 | 188 |
| | Rural | 44386 | 30333 | 11460 | 2286 | 84 | 80 | 143 |

Table 1.9: Fuels used for lighting in Uttarakhand (ORGCC, n.d.) (continued…)

| *State / District* | *Type of area* | *No. of households* | *No. of households by main source of lighting* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *Kerosene* | *Solar energy* | *Other oil* | *Any other* | *No lighting* |
| | Urban | 7970 | 7392 | 488 | 7 | 24 | 14 | 45 |
| Nainital | Total | 187108 | 169001 | 15242 | 1827 | 265 | 220 | 553 |
| | Rural | 112670 | 96746 | 13409 | 1801 | 192 | 115 | 407 |
| | Urban | 74438 | 72255 | 1833 | 26 | 73 | 105 | 146 |
| Udhamsingh Nagar | Total | 300052 | 254802 | 41967 | 648 | 487 | 666 | 1482 |
| | Rural | 194695 | 156658 | 36023 | 397 | 393 | 330 | 894 |
| | Urban | 105357 | 98144 | 5944 | 251 | 94 | 336 | 588 |
| Hardwar | Total | 325344 | 279012 | 42517 | 438 | 626 | 1494 | 1257 |
| | Rural | 199642 | 158117 | 38713 | 375 | 554 | 1104 | 779 |
| | Urban | 125702 | 120895 | 3804 | 63 | 72 | 390 | 478 |

Table 1.10: Percentage of households using various types of fuels for lighting (ORGCC, n.d.)

| *State / District* | *Type of area* | *No. of households* | *Percentage of households by main source of lighting* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *Kerosene* | *Solar energy* | *Other oil* | *Any other* | *No lighting* |
| Uttarakhand | Total | 1997068 | 87.04 | 11.08 | 1.22 | 0.16 | 0.19 | 0.32 |
| | Rural | 1404845 | 83.05 | 14.53 | 1.69 | 0.19 | 0.20 | 0.34 |
| | Urban | 592223 | 96.49 | 2.88 | 0.08 | 0.08 | 0.19 | 0.28 |
| Uttarkashi | Total | 66558 | 79.06 | 17.80 | 2.54 | 0.20 | 0.15 | 0.24 |
| | Rural | 61149 | 77.38 | 19.23 | 2.76 | 0.21 | 0.17 | 0.25 |
| | Urban | 5409 | 98.02 | 1.66 | 0.06 | 0.09 | 0.02 | 0.15 |
| Chamoli | Total | 85765 | 83.40 | 10.96 | 4.83 | 0.22 | 0.23 | 0.36 |
| | Rural | 72744 | 80.82 | 12.57 | 5.69 | 0.23 | 0.28 | 0.42 |
| | Urban | 13021 | 97.79 | 1.95 | 0.05 | 0.18 | 0.00 | 0.02 |
| Rudraprayag | Total | 53492 | 91.94 | 7.12 | 0.52 | 0.09 | 0.03 | 0.29 |
| | Rural | 51064 | 91.64 | 7.39 | 0.54 | 0.09 | 0.03 | 0.30 |
| | Urban | 2428 | 98.35 | 1.52 | 0.00 | 0.04 | 0.04 | 0.04 |
| Tehri Garhwal | Total | 133494 | 87.82 | 9.40 | 2.24 | 0.16 | 0.08 | 0.30 |
| | Rural | 116988 | 86.33 | 10.54 | 2.55 | 0.17 | 0.08 | 0.33 |
| | Urban | 16506 | 98.43 | 1.35 | 0.04 | 0.05 | 0.08 | 0.05 |
| Dehradun | Total | 322700 | 96.29 | 3.11 | 0.11 | 0.10 | 0.19 | 0.20 |
| | Rural | 137051 | 94.47 | 4.68 | 0.21 | 0.14 | 0.28 | 0.23 |

Table 1.10: Percentage of households using various types of fuels for lighting (ORGCC, n.d.) (continued..)

| *State / District* | *Type of area* | *No. of households* | *Percentage of households by main source of lighting* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *Kerosene* | *Solar energy* | *Other oil* | *Any other* | *No lighting* |
| | Urban | 185649 | 97.64 | 1.95 | 0.03 | 0.07 | 0.13 | 0.17 |
| Garhwal | Total | 161688 | 89.04 | 9.09 | 1.39 | 0.15 | 0.06 | 0.28 |
| | Rural | 137102 | 87.40 | 10.45 | 1.61 | 0.17 | 0.06 | 0.30 |
| | Urban | 24586 | 98.16 | 1.48 | 0.15 | 0.02 | 0.02 | 0.17 |
| Pithoragarh | Total | 111542 | 85.55 | 11.62 | 2.49 | 0.10 | 0.08 | 0.17 |
| | Rural | 95130 | 83.26 | 13.46 | 2.91 | 0.11 | 0.08 | 0.19 |
| | Urban | 16412 | 98.82 | 0.94 | 0.07 | 0.05 | 0.06 | 0.05 |
| Bageshwar | Total | 57712 | 81.58 | 15.70 | 1.78 | 0.26 | 0.19 | 0.49 |
| | Rural | 55748 | 81.03 | 16.18 | 1.84 | 0.26 | 0.20 | 0.49 |
| | Urban | 1964 | 97.30 | 2.14 | 0.05 | 0.20 | 0.00 | 0.31 |
| Almora | Total | 139257 | 78.90 | 18.08 | 2.55 | 0.19 | 0.05 | 0.24 |
| | Rural | 126476 | 76.96 | 19.75 | 2.80 | 0.20 | 0.05 | 0.25 |
| | Urban | 12781 | 98.11 | 1.54 | 0.07 | 0.11 | 0.04 | 0.13 |
| Champawat | Total | 52356 | 72.05 | 22.82 | 4.38 | 0.21 | 0.18 | 0.36 |
| | Rural | 44386 | 68.34 | 25.82 | 5.15 | 0.19 | 0.18 | 0.32 |
| | Urban | 7970 | 92.75 | 6.12 | 0.09 | 0.30 | 0.18 | 0.56 |
| Nainital | Total | 187108 | 90.32 | 8.15 | 0.98 | 0.14 | 0.12 | 0.30 |
| | Rural | 112670 | 85.87 | 11.90 | 1.60 | 0.17 | 0.10 | 0.36 |
| | Urban | 74438 | 97.07 | 2.46 | 0.03 | 0.10 | 0.14 | 0.20 |
| Udhamsingh Nagar | Total | 300052 | 84.92 | 13.99 | 0.22 | 0.16 | 0.22 | 0.49 |
| | Rural | 194695 | 80.46 | 18.50 | 0.20 | 0.20 | 0.17 | 0.46 |
| | Urban | 105357 | 93.15 | 5.64 | 0.24 | 0.09 | 0.32 | 0.56 |
| Hardwar | Total | 325344 | 85.76 | 13.07 | 0.13 | 0.19 | 0.46 | 0.39 |
| | Rural | 199642 | 79.20 | 19.39 | 0.19 | 0.28 | 0.55 | 0.39 |
| | Urban | 125702 | 96.18 | 3.03 | 0.05 | 0.06 | 0.31 | 0.38 |

### *1.1.5.3. Pattern of Household Expenditure on Energy (Fuels and Light)*

Households incur expenditure on fuel consumption for domestic needs such as cooking, lighting, etc. As per a survey conducted by NSSO, ₹ 130.58/- and ₹ 140.50/- are the monthly per capita expenditure on fuel and light in rural and urban areas of Uttarakhand respectively (Table 1.11) (NSSO, 2014). In rural areas of the state, majority of expenditure on fuel and light is on firewood and chips followed by electricity. However, in urban areas, expenditure on LPG and electricity has the majority share in the amount spent on fuel and light. This indicates large scale biomass usage for cooking in rural areas of Uttarakhand as pointed by Census of India 2011.

Table 1.11: Monthly per capita quantity and monetary value of fuel consumption for Uttarakhand (NSSO, 2014)

| *Item description* | *Quantity* | | | *Value (₹)* | |
|---|---|---|---|---|---|
| | *Unit* | *Rural* | *Urban* | *Rural* | *Urban* |
| Coke | kg | 0.004 | 0.000 | 0.01 | 0.00 |
| Firewood and chips | kg | 36.959 | 6.451 | 56.88 | 14.02 |
| Electricity | kWh | 13.733 | 21.553 | 32.35 | 51.20 |
| Dung cake | NA | - | - | 2.08 | 1.29 |
| Kerosene – PDS | litre | 0.451 | 0.201 | 7.01 | 3.09 |
| Kerosene – Other sources | litre | 0.009 | 0.030 | 0.19 | 0.76 |
| Matches | box | 1.995 | 1.585 | 2.00 | 1.59 |
| Coal | kg | 0.007 | 0.012 | 0.01 | 0.01 |
| LPG | kg | 0.878 | 2.252 | 25.30 | 63.48 |
| Charcoal | kg | 0.000 | 0.006 | 0.00 | 0.03 |
| Candle | no. | 0.773 | 0.787 | 1.88 | 2.56 |
| Gobar gas | NA | - | - | 0.04 | 0.00 |
| Petrol (excluding conveyance) | litre | 0.001 | 0.000 | 0.05 | 0.00 |
| Diesel (excluding conveyance) | litre | 0.000 | 0.010 | 0.00 | 0.33 |
| Other fuel | NA | - | - | 2.78 | 2.15 |
| Total for Fuel and Light | NA | NA | NA | 130.58 | 140.50 |

- indicates very small values

## 1.2. Renewable Energy Resource Availability in Uttarakhand

### *1.2.1. Solar Radiation*

Most of the locations in the state of Uttarakhand receive sufficient solar radiation throughout the year (Ramachandra et al., 2011). Based on the latitude and longitude of the districts of Uttarakhand obtained from GP (n.d.), solar resource data has been obtained from Ministry of New and Renewable Energy (MNRE) and National Aeronautics and Space Administration (NASA) databases (MNRE, n.d.; NASA, n.d.). Solar resource data presented in Table 1.12 indicates that almost all districts of Uttarakhand receive annually averaged daily Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) ≥ 5 kWh/m$^2$/day. Areas having annual average daily value of solar radiation (GHI/DNI) of 5.00 kWh/m$^2$/day or more are considered suitable for solar applications (Ramachandra et al., 2011). Thus, it can be inferred that all districts of Uttarakhand are suitable for solar energy applications.

Table 1.12: Solar radiation data for districts of Uttarakhand (MNRE, n.d.; NASA, n.d.)

| | *MNRE data (kWh/m$^2$/day)* | | *NASA data (kWh/m$^2$/day)* | |
|---|---|---|---|---|
| *Districts* | *GHI* | *DNI* | *GHI* | *DNI* |
| Uttarkashi | 5.21 | 5.43 | 5.32 | 6.68 |
| Chamoli | 5.27 | 5.37 | 5.04 | 5.99 |
| Rudraprayag | 5.32 | 5.62 | 5.32 | 6.64 |
| Tehri Garhwal | 5.34 | 5.62 | 5.32 | 6.65 |
| Dehradun | 5.15 | 5.01 | 5.32 | 6.64 |
| Garhwal | 5.27 | 5.49 | 5.40 | 6.71 |
| Pithoragarh | 5.41 | 5.98 | 5.35 | 6.69 |
| Bageshwar | 5.35 | 5.93 | 5.36 | 6.67 |
| Almora | 5.36 | 5.98 | 5.36 | 6.65 |
| Champawat | 5.23 | 5.64 | 5.35 | 6.67 |
| Nainital | 5.06 | 5.02 | 5.36 | 6.63 |
| Udham Singh Nagar | 5.24 | 4.66 | 5.32 | 6.44 |
| Hardwar | 5.27 | 4.90 | 5.40 | 6.71 |

### *1.2.2. Wind*

Although few of the localized pockets in Uttarakhand have significant wind resource at high altitudes, the state generally has minimal wind resource with average wind speeds around typical turbine cut-in speed of 3 m/s (Lundquist et al., 2014). Wind speed data obtained from NASA database also reflects low annual average wind speeds (about 4 m/s) for all districts of Uttarakhand (NASA, n.d.). Thus, wind energy applications may not be suitable for the state of Uttarakhand.

### *1.2.3. Biomass*

The state of Uttarakhand is rich in vegetation with a forest cover of 34,651 sq.km (approximately 65% of total geographical area) (DES, 2014). Sub-sectors of primary sector namely agriculture and allied activities (forestry, logging and fishing) provide livelihood to more than 70 per cent of the population of Uttarakhand (Planning Commission, 2009; WMD, n.d.). Households involved in agricultural activities generally rear livestock for agricultural work and milk. In rural Uttarakhand, it is reported that there are 2066 cattles and 734 buffaloes per 1000 households (NSSO, 2006). Also, as per estimates, Uttarakhand has surplus biomass (agro, forest and wasteland biomass) availability of about 3700 KT/year (CGPL, n.d.). Hence, biomass based applications may be appropriate for the state of Uttarakhand.

### *1.2.4. Hydro*

Uttarakhand has a number of perennial streams that can be tapped through small hydro power projects (GoU, 2008). As per MNRE estimates, small hydro power has a potential of about 1708 MW in the state (MNRE, 2014). Thus, small hydro applications may be utilized to satisfy energy demand in the state of Uttarakhand.

## 1.3. Critical Areas for Development of Uttarakhand

In Uttarakhand, the hill region districts (9 out of total 13 districts) are less developed in terms of infrastructure, i.e., electricity, roads and water supply. As a result, majority of the rural population in the hills either survive on subsistence agriculture or migrates to other parts of the country for employment (GoU, 2011). The state of Uttarakhand is rich in flora and fauna and other natural resources such as solar radiation, hydro and biomass. All these point towards tremendous potential for sustainable growth and development in the state. Thus, sustainable development has been a key element in the state's growth strategy (TERI, 2008). Water, agriculture, forestry and energy are important elements of the state's strategy for future growth (WMD, n.d.; TERI, 2008). In addition, tourism is also very important for the growth of the state as it is a major (23%) contributor to the economy of Uttarakhand (DES, 2013). The following sections discuss the critical areas for development of the state: energy, water, agriculture, tourism and road.

### *1.3.1. Energy*

As discussed in section 1.1.5.1., the state is facing challenges in the electricity sector. Apart from about 17% un-electrified households in rural areas [Ref: Census of India 2011], the state is also experiencing electricity shortages of about 30% (UPCL, 2015). As reported, about 107 villages in Uttarakhand are yet to be electrified (CEA, 2015). In Uttarakhand, the un-electrified villages are generally surrounded by dense forests, steep hills or snow that make grid electrification difficult and unviable (UPCL, 2014; Chaudhuri, 2007; Nouni et al., 2008).

Cooking pattern in the state of Uttarakhand reflect large scale usage of biomass as a fuel. About 48.68% of the households in the state are using biomass as a fuel for cooking whereas in rural households the share of biomass is about 63.29% (ORGCC, n.d.). Lighting pattern of the state indicate that electricity is the main energy source being utilized in Uttarakhand households followed by kerosene

(ORGCC, n.d.). The share of kerosene usage is higher in rural households with 14.53% rural households using it for lighting (ORGCC, n.d.).

### *1.3.2. Water*

Uttarakhand is a hill state with about 85% of its geographic area as hilly and has no appreciable groundwater potential. It is the plain areas of the state (about 15% of the area of the state comprising 5263 $km^2$) where groundwater is developed (CGWB, 2013). Though Uttarakhand receives good rainfall during monsoons, due to hilly terrain of the state, water flows to the plain areas (Chauhan, 2010). Water scarcity is a major challenge for Uttarakhand and some areas of the state faces acute scarcity of drinking water (WBI and DEA, 2013). As per DES (2014), there is scarcity of drinking water in 02 villages and 7745 hamlets of the state. As per another report, 11 of the 13 districts in Uttarakhand face regular water shortage, particularly of drinking water (Chauhan, 2010). Sources of water in the mountains are usually at considerable distance from habitations and women spend 2-4 hours a day collecting and carrying water to and fro (Chauhan, 2010). As per WBI and DEA (2013), about 3-4 hours of time and labour is spent in collecting and carrying water by women in the areas facing water scarcity.

### *1.3.3. Agriculture*

About 70% of the population is engaged in primary sector of Uttarakhand economy i.e. agriculture and allied activities (WMD, n.d.). Large areas under forest cover (65% of total geographical area) and 85% of the state's land as hilly result in utilization of only 14.02% of total land of the state for cultivation (WMD, n.d.; AD, n.d.). Small landholding (average landholding is around 0.68 ha in the hills and 1.77 ha in plains) and dependence on rain water for irrigation (about 55% of the cultivated land is rainfed) lead to poor agricultural productivity (WMD, n.d.; AD, n.d.). The subsistence nature of agriculture leads to low and unstable incomes resulting in poverty and subsequent out-migration of male members from rural areas in search of employment  (WMD, n.d.).

### *1.3.4. Tourism*

Tourism (trade, hotels and restaurants) is one of the major economic activities of the state as it contributes 23% to the economy of Uttarakhand (DES, 2013). The state is known for its hill stations, pilgrimage, wild life (sanctuaries and national parks) and adventure sites. Some of its popular tourist destinations are: Gangotri, Yamunotri, Kedarnath, Badrinath, Mussoorie, Hardwar, Rishikesh, Lansdowne, Dhanaulti, Chamba, Auli, Pauri, Chopta, Chakrata, Nainital, Kausani, Almora, Ranikhet, Binsar, Mukteshwar, Jageshwar, Corbett Park and Bhimtal (UTDB, n.d.). In spite of so many tourist locations, only few locations such are popular among the tourists as others lack infrastructure facilities.  For up-gradation of such locations, improvement in local infrastructure facilities (electricity, accommodation, roads and water supply) has been recommended (MoT, 2012).

### *1.3.5. Roads*

About 40% of the villages in Uttarakhand are not connected by roads. In the state, 76% roads are maintained by Public Works Department and only 59% of them are all-weather surface roads (Planning Commission, 2009). In monsoon season, the road connectivity may deteriorate further making rural areas inaccessible.

## 1.4. Implications for Renewable Energy Applications in Uttarakhand

In earlier sections, characteristics and challenges of the state of Uttarakhand have been briefly presented. The characteristics may be used to infer about the utilization of renewable energy in the state. Table 1.13 presents the characteristics of Uttarakhand and its implications for renewable energy applications in Uttarakhand.

Table 1.13: Characteristics of Uttarakhand and implications for renewable energy applications in the state

| *Characteristics of Uttarakhand* | *Implications* |
|---|---|
| • 17% of the rural households are unelectrified (ORGCC, n.d.)<br>• 20% unelectrified rural households in Uttarkashi, Almora, Champawat and Hardwar (ORGCC, n.d.).<br>• 107 un-electrified villages in Uttarakhand (CEA, 2015).<br>• Monthly averaged daily energy (electricity) shortages ranging from 8% - 46% with an annual mean of 30% (UPCL, 2015).<br>• The state has a geographical area of 53,483 sq.km and about 65% of it is forest area (DES, 2014).<br>• Region is predominantly hilly (85% of geographical area) with steep slopes (slope angle ≥ 20%) and widely scattered habitation (DES, 2014; MoEF, n.d.). | • Challenges regarding access to electricity in rural areas<br>• Power shortage in Uttarakhand<br>• Dependent on import of power through power exchanges and rostering.<br>• Protected forests, steep hills and snowbound areas make construction of large power projects and grid electrification difficult and unviable.<br>• Because of scattered villages and lesser number of households per village, the villages may not have adequate demand for power to justify grid extension.<br>• Decentralized renewable energy systems (DRESs) may be used for electrification of rural areas. |
| • About 70% of the population is engaged in agriculture (WMD, n.d.).<br>• Small landholdings, subsistence agriculture, mainly rainfed agriculture due to scarcity of water (WMD, n.d.; AD, n.d.; WBI and DEA, 2013).<br>• Heavy rainfall during rainy season (1631 mm) but rainwater flows to plain areas because of hilly terrain (DES, 2014; Chauhan, 2010). | • Scarcity of water (for irrigation and drinking)<br>• Scope for water harvesting |

Table 1.13: Characteristics of Uttarakhand and implications for renewable energy applications in the state (continued…)

| *Characteristics of Uttarakhand* | *Implications* |
|---|---|
| • A number of perennial water streams in the state (GoU, 2008)<br>• Average solar radiation availability (both GHI and DNI) in almost all districts of Uttarakhand is ≥5.00 kWh/m$^2$/day (MNRE, n.d.; NASA, n.d.).<br>• Wind resource in Uttarakhand is not suitable for wind power generation (Lundquist et al., 2014).<br>• The state has 65% forest cover with predominantly rural population dependent on subsistence agriculture and availability of livestock at households is common (DES, 2014; ORGCC, n.d.; WMD, n.d.). | • Scope for small hydro power plants. However, sparsely populated and scattered villages may not justify SHP as it may involve power distribution.<br>• The state is suitable for solar energy applications.<br>• Wind energy systems not suitable for the state.<br>• Point towards availability of biomass and thus biomass based devices may be used |
| • Monthly mean minimum temperatures are < 20°C in hill districts for almost all months (NASA, n.d.).<br>• The share of kerosene usage for lighting in rural households of the state is 14.53% (ORGCC, n.d.).<br>• 1.22% of households in the state are using solar lighting devices (ORGCC, n.d.).<br>• In rural areas of Chamoli and Champawat, solar lighting devices are used by more than 5% of households (ORGCC, n.d.).<br>• Also, About 48.68% of the households in the state are using biomass as a fuel for cooking. In rural households of the state, the share is 63.29% (ORGCC, n.d.). | • Need for space and water heating. Solar water heaters may be used for water heating.<br>• Solar lighting options may replace kerosene usage for lighting.<br>• Scope for improved biomass cookstoves |

Table 1.13: Characteristics of Uttarakhand and implications for renewable energy applications in the state (continued…)

| *Characteristics of Uttarakhand* | *Implications* |
|---|---|
| • Agriculture, tourism, central and state government employment, and pensions are major sources of income (Planning Commission, 2009; DES, 2013).<br>• 36.5% of the population in the state is BPL and the share increases to 44% in the hill districts (DES, 2014).<br>• Monthly per capita expenditure on fuel and light (excluding conveyance) in rural and urban households of Uttarakhand are Rs 130.58 and Rs 140.50 respectively (NSSO, 2014). | • Need for innovative finance mechanisms for DRES |
| • Large scale rural to urban migration in the state (ORGCC, n.d.; WMD, n.d.).<br>• The state is known for its hill stations, pilgrimage, wild life and adventure sites but only few locations are popular among tourists as others lack infrastructural facilities i.e. roads, energy and water supply (UTDB, n.d.; MoT, 2012). | • Need for employment generation and development in rural areas<br>• Need for improvement in access and availability of energy (including electricity), roads and water supply. |

From Table 1.13, it can be inferred that employment generation (especially in rural areas), improvement in access to energy, roads and water supply are the major challenging tasks before the state of Uttarakhand. Energy (including electricity) as a common input factor to almost all economic or development activities, is critical to the development of Uttarakhand. As inferences drawn in Table 1.13 suggest unsuitability of centralized energy options in several areas of Uttarakhand, solar and biomass based decentralized renewable energy systems (DRESs) emerge as appropriate options for improving the access to energy of households in the state.

### 1.5. Potential and Diffusion of DRESs in Uttarakhand

Prima-facie, characteristics of Uttarakhand indicate significant potential for DRESs (solar and biomass based) in the state. Different types of DRESs can be used for fulfilling appropriate energy demand. Table 1.14 presents resource-DRES-task matrix indicating the tasks that can be fulfilled by DRESs. The DRESs that have been disseminated in Uttarakhand include solar water heater, family size biogas plant, solar cooker, solar lantern, solar home system, solar dryer, solar pump and improved cookstove. Table 1.15 presents the reported potential and cumulative diffusion of DRESs in the state.

It is evident from Table 1.15 that for most of the DRESs, estimates of the potential is unavailable. In case of family size biogas plants, only 16535 plants have been installed against an estimated potential of 83000 indicating a wide gap between potential and diffusion (MNRE, 2014a). Similarly, only 3118 solar cookers have been installed (with an average of 3 cookers per school) under mid-day meal scheme whereas there are 17978 schools under the scheme in Uttarakhand (UREDA, 2011; UREDA, 2012; MHRD, 2013). Similar trend may be expected in the case of diffusion of other DRESs in Uttarakhand. Such wide gaps may be attributed to the barriers that impede the diffusion of DRESs. Hence, there is a need to assess and identify the barriers to the dissemination of DRES in the state of Uttarakhand. Also, it is desired to estimate the utilization potential of DRESs and analyze the trend of diffusion of DRESs in the state of Uttarakhand.

### 1.6. Business Problem

From earlier sections, it can be inferred that despite having significant potential, dissemination of DRESs in Uttarakhand has been sluggish pointing toward existence of barriers. These barriers are hindering accelerated diffusion of DRESs in Uttarakhand resulting in opportunity losses for sustainable development.

Table 1.14: Resource-DRES-Task matrix

| *Resource* | *DRES* | *Task(s) performed* |
|---|---|---|
| Solar | Domestic solar water heating system | Water heating |
| | Solar home system | Electricity generation |
| | Solar lantern | Lighting |
| | Solar cooker (household/community) | Cooking |
| | Solar dryer (household/community) | Drying |
| | Space heating system | Space heating |
| | Solar PV pump | Water pumping |
| | Solar fence | Fencing |
| Biomass | Family size biogas plant | Cooking, lighting, |
| | Biogas engine | Electricity generation, mechanical work |
| | Improved cook-stove | Cooking |
| | Biomass gasifier | Electricity generation |
| Wind | Aero-generator | Electricity generation |
| | Wind-mill | Mechanical work |
| Hydro | Micro-hydel | Electricity generation |
| | Water-mill | Mechanical work |

Table 1.15: Potential and cumulative diffusion of DRESs in Uttarakhand (MNRE, 2014a; UREDA, n.d., 2005, 2007, 2011a, 2012a)

| *DRES* | *Unit* | *Diffusion reported till 31.03.2014* | *Remarks* |
|---|---|---|---|
| Solar water heater | liters per day | 1814500 | Except an estimated potential of 83000 for family size biogas plants, estimates are unavailable for the potential of DRES in Uttarakhand. |
| Family size biogas plant | no. | 16535 | |
| Solar cookers (under mid-day meal scheme) | no. | 3118 | |
| Solar lanterns | no. | 66964 | |
| Solar home systems | no. | 58830 | |
| Solar dryer, solar pump, improved cookstove | no. | Data unavailable | |

## 1.7. Research Objective(s)

Discussions in earlier sections have indicated the following issues or research gaps:

i. Unavailability of estimates for potential of DRESs in Uttarakhand
ii. Unavailability of information on barriers to the dissemination of DRESs in Uttarakhand

The above research gaps have been the motivation for this study. Based on the research gaps, appropriate research questions and research objectives have been framed. Figure presents the flow diagram representing the framing of objectives of the study from research gaps. The following are the research objectives of the study:

i. To estimate the potential of utilization of DRESs in Uttarakhand with the factors affecting its value internalized in the approach used for estimation
ii. To assess the time-trend of dissemination of DRESs in Uttarakand and to estimate the time required for the cumulative dissemination to reach their estimated utilization potential
iii. To identify and assess the barriers impeding the dissemination of DRESs in Uttarakhand

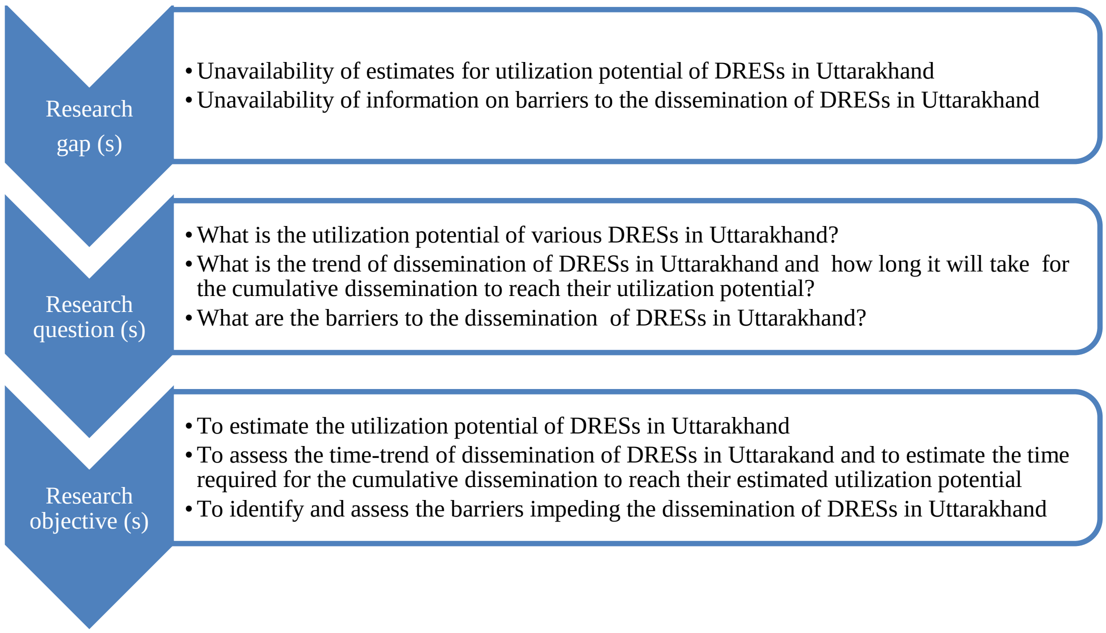


Figure 1.5: Framing research objectives from research gaps

## 1.8. Organization of the Thesis

The work presented in the thesis has been arranged in the following seven chapters:

i. Chapter 1: Characteristics of Uttarakhand and its implications for renewable energy
ii. Chapter 2: Review of barriers to the dissemination of DRESs
iii. Chapter 3: Estimation of potential of DRESs in Uttarakhand
iv. Chapter 4: Diffusion of innovation and time-trend of diffusion of DRESs in Uttarakhand
v. Chapter 5: Assessment of barriers faced by DRES adopters and non-adopters in Uttarakhand
vi. Chapter 6: Assessment of financial attractiveness of DRESs in Uttarakhand
vii. Chapter 7: Conclusions and recommendations

# CHAPTER 2

# REVIEW OF BARRIERS TO THE DISSEMINATION OF DECENTRALIZED RENEWABLE ENERGY SYSTEMS

## 2.1. Introduction

In view of energy security and climate change concerns, governments and policymakers are promoting increased dissemination[1] of renewable energy technologies. Increased share of renewable energy in the overall energy mix of countries would help the cause of sustainable development. Renewable energy systems are broadly classified into two categories: i) grid-connected (centralized) renewable energy system; ii) decentralized (off-grid) renewable energy system (DRES). DRESs such as solar lantern, solar home system, family size biogas plants, improved cook stoves, etc. have been disseminated worldwide for improving access to energy of the rural households. DRES is also an appropriate option for electrification of remote households located in difficult terrains (islands and hills) that may not be technically and financially feasible through grid extension (Nouni et al., 2008; Chaudhuri, 2007). Large scale diffusion and utilization of relatively newer technologies such as DRES face barriers. These barriers may put DRES at technical, economic, regulatory or institutional disadvantage in comparison to conventional energy systems (Beck and Martinot, 2004). Sometimes, the barriers may have inter-linkages that can have cascading impact on the diffusion of DRES. For example, lack of skills for installation and after sales services is a technical barrier that is a result of inadequate training institutions which is an institutional barrier. Thus, in order to address skill related technical barrier, it is necessary to set up relevant institutions. Hence, to

[1] Some authors restrict the term 'diffusion' to the spontaneous unplanned spread of ideas or innovation and use the concept of 'dissemination' for diffusion that is directed and managed. However, several studies have used them interchangeably (Rogers, 2003). In this study, these terms have been used interchangeably.

accelerate the diffusion of DRES, it is vital to understand the barriers and their inter-linkages. This would enable the policymakers and the implementing agencies to formulate plans and implement them in a more effective manner.

Based on an extensive review of published literature on barriers and relevant aspects, this study is a modest attempt to identify the barriers to the diffusion of DRESs and classify them based on their characteristics. It also suggests remedial measures to overcome them for enhanced diffusion of DRESs.

## 2.2. Identification and Classification of Barriers to the Diffusion of DRESs

A barrier to the diffusion of DRES may be defined as a factor that negatively affects its adoption and subsequent utilization, hampering its widespread diffusion (Jarach, 1989). Barriers to DRESs may often include technical, economic, institutional, socio-cultural or environmental aspects. In this study, barriers pertinent to DRESs have been identified through a literature review of published articles. In addition, relevant research papers have been referred to appreciate the impact of barriers on the diffusion of various DRESs across different geographic regions of the world. Based on the literature review, the identified barriers have been classified under five broad categories depending on the characteristics of the barrier - technical, economic, institutional, socio-cultural and environmental (Table 2.1). The following sections present a discussion on the categories and subcategories of barriers along with recommended remedial measures to accelerate the diffusion of DRESs.

### *2.2.1. Technical Barriers*

Technical or technological barriers to DRES generally include barriers associated with resource, technology and skill attributes of the system that limit full utilization of its theoretical potential (Mondal et al., 2010). Technical barrier has been widely reported as a critical barrier affecting diffusion of DRES (Jarach, 1989; Quadir et al., 1995; Rijal, 1986; Roessner, 1984; Agarwal, 1983;

Bakthavatsalam, 1999; Green, 1999; Jagadeesh, 2000; Oliver and Jackson, 1999; Barnett, 1990; Rijal, 1999; Bhatia, 1990; Painuly, 2001; Mirza et al. 2003; Pokharel, 2003; Reddy and Painuly, 2004; Green, 2004; Foxon et al., 2005; Pohekar et al., 2005; Patlitzianas et al., 2006; Owen, 2006; Pohekar and Ramachandran, 2006; Philibert, 2006; GNESD, 2007; Stangeland, 2007; Sahir and Qureshi, 2008; Srinivasan, 2008; Mirza et al., 2009; Nalan et al., 2009; Oikonomou et al., Hiremath et al., 2009; Purohit, 2009; Bhattacharya and Jana, 2009; Doukas et al., 2009; Pegels, 2010; Rao and Kishore, 2010; Wang and Chen, 2010; Martin and Rice, 2012; Krupa, 2012; Ahlborg and Hammar, 2011; Liu et al., 2013; Zhang et al., 2012; Allen et al., 2008). Technical barriers include sub-barriers pertaining to the following: a) resource availability; b) technology – design, installation and performance; c) skill requirement for design and development, manufacturing, installation, operation and maintenance. A brief summary of the published literature reporting different aspects of technical barriers affecting the adoption of DRES is presented in the following paragraphs.

Table 2.1: Classification of barriers to the diffusion of DRESs

| *Barrier* | *Sub-barriers* |
|---|---|
| Technical | Resource availability, technology – design, installation and performance, skill requirement for design and development, manufacturing, installation, operation and maintenance |
| Economic | Cost, market structure, energy pricing, incentives, purchasing power and spending priorities, financial issues, awareness and risk perception |
| Institutional | Policy and regulatory, infrastructure (institutions for research, design and after sales services), administrative |
| Socio-cultural | Societal structure, norms and value system, awareness and risk perception, behavioral or lifestyle issues |
| Environmental | Resources (land and water), pollution, aesthetics |

*2.2.1.1. Resource Availability*

Renewable energy resources (particularly solar and wind) are intermittent and/or variable in nature. Other renewable energy sources such as biomass and hydro may be inadequate at times to support capacity utilization of respective technologies at economical levels. Because of this intermittency and/or inadequacy, resource availability has been cited widely as an important barrier (Green, 1999; Bhatia, 1990; Pokharel, 2003; Pohekar et al., 2005; Philibert, 2006; Nalan et al., 2009; Oikonomou et al., 2009; Martin and Rice, 2012; Krupa, 2012; Ahlborg and Hammar, 2011; Chandrasekar and Kandpal, 2007; Trainer, 1984; Joseph and Burton, 1990; Fthenakis et al., 2009; Adams et al., 2011; Kennedy and Basu, 2013). For example, Chandrasekar and Kandpal (2007) have concluded that lack of resource availability is an important barrier to the diffusion of DRES such as family size biogas plant, box type solar cooker, domestic solar water heater, and solar photovoltaic lantern in India. In Turkey, uncertainty with respect to solar resource availability is reported to be hampering the adoption of solar water heaters (Nalan et al., 2009). Similarly, resource availability issues such as seasonal fluctuation of wind have been reported as barriers to diffusion of wind installations in Dodecanese islands (Greece) (Oikonomou et al., 2009).

*2.2.1.2. Technology – Design, Installation and Performance*

Generally, solar, wind and biomass powered renewable energy technologies suffer from lower energy flux as compared to fossil fuel fired technologies (Nalan et al., 2009). Additionally, intermittent nature of renewable energy sources necessitates usage of energy storage devices to improve the energy dispatch ability of concerned RETs and this puts them at a disadvantage (Nalan et al., 2009; Oikonomou et al., 2009; Rao and Kishore, 2010; Martin and Rice, 2012; Trainer, 1984).

Several studies have cited inappropriateness of technology or poor design as a significant technical barrier to the adoption of DRES (Quadir et al., 1995; Pohekar et al., 2005; Zhang et al., 2012; Chandrasekar and Kandpal, 2007; Adams et al., 2011; Prasertsan and Sajjakulnukit, 2006; Rijal, 1986a; Junfeng et al., 2002; Zyadin et al., 2014; Srinivasan, 2006). For example, it has been reported that failures due to application of too complex designs in early projects, lack of standardization and poor reliability are significant barriers to wind energy development in Tamil Nadu and Andhra Pradesh, India (Jagadeesh, 2000). Likewise, with poor design as a technical barrier, wind turbines have had limited success in Tanzania (Kassenga, 1997). In case of dissemination of improved biomass cookstoves, Agarwal (1983) has listed inadequate satisfaction of perceived needs such as space heating, inflexibility of the stove with respect to number and size of pots, and need of careful maintenance as primary barriers. Roessner (1984) has cited faulty design and improper installation of residential solar water heaters as the barriers to their diffusion in USA.

Installation and maintenance issues with respect to DRESs have also been highlighted as barriers in several studies (Jarach, 1989; Green, 2004; Sidiras and Koukios, 2004). For example, frequent need for repair and maintenance of biogas plants and variation of biogas production with factors such as ambient temperature have reportedly been detrimental to its adoption in Nepal (Rijal, 1986). Likewise, need for regular cleaning of photovoltaic panels has been cited as a barrier to the performance of solar pumps located at arid zone in India (Pande et al., 2003).

Reliability of DRES has also been an issue of concern for its potential adopters. Lack of standards and codes and certification for DRESs and consequent poor quality/reliability of these systems are important technical barriers to its diffusion (Oliver and Jackson, 1999; Painuly, 2001; GNESD, 2007; Mirza et al., 2009; Zhang et al., 2012; Prasertsan and Sajjakulnukit, 2006; Kinab and Elkhoury, 2012; Kennedy and Basu, 2013a; Radulovic, 2005; Margolis and Zuboy, 2006; Ohunakin et al., 2014; Adhikari et al., 2008). As per Bhattacharya and Jana (2009), absence of quality control, non-functionality and low capacity utilization are the barriers affecting improved cook stoves, family size biogas plants and small hydropower plants in India respectively. Also, low efficiency or quality of some renewable energy technologies and its insignificant utilization has been detrimental to its diffusion (Lidula et al., 2007). For example, solar dryers are reportedly facing the problem of low capacity utilization in India (Kumar and Kandpal, 2005). Low reliability of solar buildings in Kenya and the dependence of building designers on foreign designs have also been cited as barriers to diffusion of solar buildings in the country (Njuguna, 1997). On similar lines, Dorf (1984) has mentioned of the poor reliability and shorter expected life as the barriers to market development of solar water heating and space heating systems in USA. Also, past failures and poor reliability of DRESs such as solar thermal systems are reportedly discouraging its adoption among masses (Philibert, 2006).

#### *2.2.1.3. Skill Requirement for Design and Development, Manufacturing, Installation, Operation and Maintenance*

Availability of skilled manpower is critical to the successful dissemination of renewable energy technologies (Joseph and Burton, 1990). Lack of availability of skilled manpower for design and development, manufacturing, installation, operation and maintenance services has been often cited as a barrier to the diffusion of DRES (Mondal et al., 2010; Quadir et al., 1995; Roessner, 1984; Painuly, 2001; Foxon et al., 2005; Patlitzianas et al., 2006; Philibert, 2006; GNESD, 2007; Mirza et al., 2009; Martin and Rice, 2012; Krupa, 2012; Ahlborg and Hammar, 2011; Liu et al., 2013; Zhang et al., 2012; Zyadin et al., 2014; Kassenga, 1997; Kennedy and Basu, 2013a; Margolis and Zuboy, 2006; Ohunakin et al., 2014; Adhikari et al., 2008; Lidula et al., 2007; Al-Badi et al., 2009; Mezher et al., 2012; Balcombe et al., 2013; McCormick and Kaberger, 2007; Negro et al., 2012; Huacuz, 2001; Ruble and El-Khoury, 2013; Martinot, 1998). Beck and Martinot (2004) have discussed the negative impact of dearth of skilled manpower for installation, operation and maintenance on the diffusion of DRES. Similarly, lack of experience and awareness in technology and management of DRES has reportedly acted as barriers to its diffusion in ASEAN (Lidula et al., 2007). Lack of trained technicians has been reportedly hindering the growth of wind installations in Turkey (Nalan et al., 2009). For diffusion of DRES in Lebanon, non-existence of local manufacturers has been reported as a barrier (Kinab and Elkhoury, 2012). Green (1999) has deliberated that, in cross cultural technology transfer of sustainable energy systems it is important to address knowledge and skill barriers. Communication and training barriers due to language difference between field staff and local people have reportedly resulted in poor transfer of skills leading to the failure of solar battery charging programmes in Northern Thailand (Green, 2004). In addition, lack of knowledge of renewable energy technology operation and management has also been listed as a barrier by few studies (Bhatia, 1990; Doukas et al., 2009; Singh and Sooch, 2004).

*2.2.1.4. Potential Remedial Measures*

Several remedial measures have been suggested by researchers to overcome technical barriers to the diffusion of DRESs. Table 2.2 presents some of the suggested remedial measures to overcome technical barriers. In addition, appropriate responsibility centres that are expected to support and/or implement the suggested remedial measures are also listed in Table 2.2. It may be noted from Table 2.2 that research and development (R&D) institutions and academic institutions (universities and colleges) have major roles to play in overcoming technical barriers. Thus, such institutions need to be supported by both government and private sector to promote DRESs.

Apart from the frequently cited general remedial measures listed in Table 2.2, there are few other case-specific measures that have been recommended to overcome technical barriers. To overcome intermittency problem, Fthenakis et al. (2009) has recommended integrating photovoltaic with compressed air energy storage and increasing the thermal storage capability in concentrated solar power. Utilization of solar dryers at community level has been recommended to offset the problem of low capacity utilization associated with solar dryers (Kumar and Kandpal, 2005). Extensive testing of solar photovoltaic pump under similar climatic conditions has been advocated to ensure their reliability for drip irrigation in arid zones (Pande et al., 2003).

It may be noted that most of the remedial measures suggested to overcome technical barriers to the diffusion of DRESs point towards the establishment of appropriate institutional set-ups for: a) resource assessment, b) research and development, c) capacity building, and d) quality control and standardization.

### *2.2.2. Economic Barriers*

Diffusion of DRESs face economic and/or financial barriers (Jarach, 1989; Mondal et al., 2010; Quadir et al., 1995; Agarwal, 1983; Green, 1999; Jagadeesh, 2000; Oliver and Jackson, 1999; Rijal, 1999; Painuly, 2001; Pokharel, 2003; Reddy and Painuly, 2004; Green, 2004; Foxon et al., 2005; Pohekar and Ramachandran, 2006; Philibert, 2006; GNESD, 2007; Stangeland, 2007; Sahir and Qureshi, 2008; Mirza et al., 2009; Nalan et al., 2009; Oikonomou et al., 2009; Hiremath et al., 2009; Purohit, 2009; Doukas et al., 2009; Rao and Kishore, 2010; Wang and Chen, 2010; Chandrasekar and Kandpal, 2007; Adams et al., 2011; Kennedy and Basu, 2013; Al-Badi et al., 2009; McCormick and Kaberger, 2007; Martinot, 1998; Al-Badi et al., 2011; Rosch and Kaltschmitt, 1999). As per Chandrasekar and Kandpal (2007), financial and economic viability and awareness barriers are important economic barriers affecting the promotion of family size biogas plants, improved biomass cookstoves, box type solar cookers, domestic solar water heaters and solar photovoltaic lanterns. Several other research papers have discussed the following economic barriers - subsidies for competing conventional fuels, high initial capital cost, difficulty of fuel price risk assessment, high transaction costs of renewable energy projects, non-inclusion of environmental externalities in the cost of conventional energy, lack of access to capital and inadequate information (Beck and Martinot, 2004; Painuly, 2001; Patlitzianas et al., 2006; Owen, 2006; Mirza et al., 2009; Nalan et al., 2009; Mezher et al., 2012). Another study has listed high investment cost, long payback period, lack of purchasing power, uncertainty about benefits and availability of cheaper alternative fuels as economic barriers affecting the diffusion of family size biogas plants and solar cookers (Quadir et al., 1995). As per Mwirigi et al. (2009), high initial investment cost, negative image caused by failed biogas plants, limited private sector participation, lack of money and lack of awareness are the economic barriers hindering the adoption of biogas plants by farmers in Kenya. Lack of private sector investments due to profit uncertainties has also been reported as a critical economic barrier (Zyadin et al., 2014). It has also been argued that availability of highly subsidized conventional energy as well as inadequate fiscal incentives to DRES users are preventing the diffusion of DRESs in Oman (Al-Badi et al., 2009; Al-Badi et al., 2011). Economic barriers can be cost related or market related and further discussion in this section is presented under these two categories.

Table 2.2: Potential remedial measures suggested to overcome the sub-barriers of technical barrier

| *Sub-barrier* | *Remedial measure(s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| Resource availability | Accurate resource assessment | Institutions for resource assessment | Mondal et al., 2010; Quadir et al., 1995; Jagadeesh, 2000; Liu et al., 2013; Chandrasekar and Kandpal, 2007; Kinab and Elkhoury, 2012; Perlack et al., 1990. |
| Technology - design, installation and performance | Research and Development (R&D) | R&D institutions | Mondal et al., 2010; Quadir et al., 1995; Jagadeesh, 2000; Mirza et al., 2003; Foxon et al., 2005; Philibert, 2006; Martin and Rice, 2012; Junfeng et al., 2002; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Al-Badi et al., 2009; Perlack et al., 1990. |
| | International cooperation | R&D institutions, government organizations, academic institutions | Mirza et al., 2003; Patlitzianas et al., 2006; Mirza et al., 2009; Bhattacharya and Jana, 2009; Pegels, 2010; Liu et al., 2013; Kassenga, 1997; Lidula et al., 2007; Martinot, 1998. |
| | Indigenization of technology by studying local conditions and involving all stakeholders during product development | R&D institutions | Mondal et al., 2010; Quadir et al., 1995; Agarwal, 1983; Green, 1999; Jagadeesh, 2000; Barnett, 1990; Pohekar, 2005; Mirza et al., 2009; Rijal, 1986a; Perlack et al., 1990. |
| | Training for skill related to product development | R&D institutions, academic institutions | Mondal et al., 2010; Painuly, 2001; Mirza et al., 2003; Foxon et al., 2005; Philibert, 2006; GNESD, 2007; Mirza et al., 2009; Martin and Rice, 2012; Al-Badi et al., 2009; |

Table 2.2: Potential remedial measures suggested to overcome the sub-barriers of technical barrier (continued…)

| *Sub-barrier* | *Remedial measure(s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | | | Martinot, 1998; Perlack et al., 1990. |
| | Introduction of standards and regulations during product development | R&D institutions, quality assurance and quality control institutions | Mondal et al., 2010; Painuly, 2001; Pokharel, 2003; GNESD, 2007; Mirza et al., 2009; Junfeng et al., 2002; Sidiras and Koukios, 2004; Ohunakin et al., 2014; Dorf, 1984; Ruble and El-Khoury, 2013; Wamukonya, 2007. |
| | Deployment of mature, reliable, easy to maintain and long lasting technologies | R&D institutions | Barnett, 1990; Nalan et al., 2009. |
| Skill requirement for design and development, manufacturing, installation, operation and maintenance | Education and training | R&D institutions, NGOs, academic institutions | Beck and Martinot, 2004; Pokharel, 2003; Green, 2004; Krupa, 2012; Zhang et al., 2012; Prasertsan and Sajjakulnukit, 2006; Junfeng et al., 2002; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Kennedy and Basu, 2013a; Radulovic, 2005; Ohunakin et al., 2014; Adhikari et al., 2008; Njuguna, 1997; McCormick and Kaberger, 2007; Negro et al., 2012; Perlack et al., 1990; Wamukonya, 2007. |

### *2.2.2.1. Cost*

DRES often suffer from high upfront cost (Beck and Martinot, 2004; Jarach, 1989; Mondal et al., 2010; Quadir et al., 1995; Rijal, 1986; Green, 1999; Bhatia, 1990; Painuly, 2001; Mirza et al., 2003; Pokharel, 2003; Foxon et al., 2005; Patlitzianas et al., 2006; Philibert, 2006; GNESD, 2007; Mirza et al., 2009; Nalan et al., 2009; Bhattacharya and Jana, 2009; Doukas et al., 2009; Pegels, 2010; Rao and Kishore, 2010; Martin and Rice, 2012; Ahlborg and Hammar, 2011; Trainer, 1984; Joseph and Burton, 1990; Fthenakis et al., 2009; Kennedy and Basu, 2013; Prasertsan and Sajjakulnukit, 2006; Junfeng et al., 2002; Zyadin et al., 2014; Sidiras and Koukios, 2004; Kinab and Elkhoury, 2012; Margolis and Zuboy, 2006; Ohunakin et al., 2014; Adhikari et al., 2008; Lidula et al., 2007; Njuguna, 1997; Dorf, 1984; Mezher et al., 2012; Balcombe et al., 2013; Huacuz, 2001; Ruble and El-Khoury, 2013; Perlack et al., 1990; Mwirigi et al., 2009; Michalena and Angeon, 2009; Mills and Schleich, 2009; Sagie et al., 2001; Boyle, 1994; Arjunan et al., 2009; Jager-Waldau, 2007; Martinot, 1999; Finney et al., 2012). For example, it has been reported that cooking technologies based on biogas and solar energy have high initial cost that has limited their diffusion (Pohekar et al., 2005). Kassenga (1997) has mentioned that the cost of biogas plants is unaffordable for majority of poor people in rural areas. Similarly, high cost of solar water heaters in India has been pointed as a barrier to their diffusion (Bhattacharya and Jana, 2009). High cost has also been reported as a major barrier to the diffusion of solar PV systems (Oliver and Jackson, 1999; Pokharel, 2003; Purohit, 2009; Dorf, 1984; Wamukonya, 2007; Purohit and Michaelowa, 2008; Pillai and Banerjee, 2009; Muntasser et al., 2000). For example, as per experiences of a renewable energy company named Grameen Shakti in Bangladesh, high cost of solar PV module has been the main barrier to Bangladesh’s PV program (Barua, 2001).

In case of biomass gasifiers, high fuel cost, operation and maintenance costs, and taxes and insurance costs have been reported as barriers (Jarach, 1989). Additional burden on villagers due to operation and maintenance cost of PV battery charging stations for village electrification in Thailand has been cited as a barrier (Green, 2004). High operation and maintenance cost due to lack of technically skilled personnel has also been cited as a barrier for the diffusion of DRESs in Nigeria (Ohunakin et al., 2014). Similarly, few other studies have also reported high maintenance cost as a barrier (Zhang et al., 2012; Kennedy and Basu, 2013; Balcombe et al., 2013).

Often, smaller size of DRES projects lead to high transaction costs (cost incurred in various approvals, regulatory and administrative procedures) and the same has been reported as a barrier (Beck and martinet, 2004; Jagadeesh, 2000; Painuly, 2001; Patlitzianas et al., 2006; Owen, 2006; Mirza et al., 2009; Wang and Chen, 2010; Ahlborg and Hammar, 2011; Junfeng et al., 2002; Ohunakin et al., 2014; Mezher et al., 2012; Muntasser et al., 2000). For example, in Mexico, DRES projects have faced high project development cost as a barrier since these projects are typically smaller in size compared to its conventional counterparts (Huacuz, 2001). Similarly, high transaction cost has been cited by Srinivasan (Srinivasan, 2008) as a barrier to the utilization of domestic biogas plants. Solar PV systems are also reportedly suffering from high transaction costs in terms of sales, installation, etc., due to lack of conducive and enabling investment policies and a small market size (Muntasser et al., 2000). In addition, lack of awareness among customers and dealing with multiple stakeholders increases transaction costs for solar PV system projects (Radulovic, 2005). For bioenergy in United Kingdom, uncertain development and operation cost has been reported as a significant barrier (Adams et al., 2011).

*2.2.2.2. Market*

In comparison to conventional technologies, DRES has been facing economic

barriers due to existing market structure and its policies that favor conventional energy technologies through subsidies and other incentives.

*2.2.2.2.1. Market Structure*

Lack of competitiveness of DRES in comparison to conventional energy technologies in current market scenario is an important barrier (Jarach, 1989). Also, current market is reportedly biased against DRES and favors established technologies such as large scale fossil fired power plants (van der Gaast et al., 2009). Market related barriers have been highlighted by various studies (Jagadeesh, 2000; Painuly, 2001; Reddy and Painuly, 2004; Owen, 2006; Stangeland, 2007; Mirza et al., 2009; Oikonomou et al., 2009; Pegels, 2010; Ahlborg and Hammar, 2011; Adams et al., 2011; Junfeng et al., 2002; Zyadin et al., 2014; Mezher et al., 2012; Negro et al., 2012; Martinot, 1998; Perlack et al., 1990; Wamukonya, 2007). Lack of competition, trade barriers and inadequate information are the factors responsible for market barriers with respect to diffusion of DRES (Verbruggen et al., 2010). For example, state ownership of energy related enterprises has reportedly created market barriers in Thailand for the diffusion of DRES (Adhikari et al., 2008). Similarly, distortions in energy market are reported as one of the significant barriers to diffusion of DRES in India (Bakthavatsalam, 1999). Distortions in energy market are a result of policies that favor conventional technologies through various incentives (subsidies, tax rebates, etc) and discourage DRES utilization through trade barriers and non-internalization of externalities (Painuly, 2001). Small size of DRES market and subsequent lack of economies of scale has also been cited as an economic barrier (Mondal et al., 2010; Roessner, 1984; Painuly, 2001). In addition, Pillai and Banerjee (2009) have reported that 100% accelerated depreciation in the first year, capital subsidies and tax incentives for wind installations created market distortions in India that led to siting of wind turbines at sites with poor wind resource leading to project failures.

*2.2.2.2.2. Fuel/Energy Pricing*

Pricing and affordability issues reportedly reflect as financial barriers to the adoption of DRES (Pokharel, 2003). High cost of electricity from DRES for rural electrification is considered as an impediment to the diffusion of DRES (Liu et al., 2013; Puri, 2006). Failure to take into account all cost and benefits (particularly environment and health related) associated with both conventional energy and renewable energy is another barrier (Margolis and Zuboy, 2006). In addition, subsidies to fossil fuels and non-internalization of externalities in the energy cost are significant barriers impeding the diffusion of DRES (Beck and Martinot, 2004; Painuly, 2001; Patlitzianas et al., 2006; Philibert, 2006; Mirza et al., 2009; Oikonomou et al., 2009; Mezher et al., 2012; Huacuz, 2001; Boyle, 1994]. Owen (2006) has cited uncompetitive market price of renewable energy due to its lack of economies of scale and price distortion as a result of subsidies to its competitors (conventional energy sources) as barriers to its diffusion.

Subsidized conventional energy sources create market distortions favoring conventional energy sources (Bhatia, 1990; Ohunakin et al., 2014; Lidula et al., 2007; McCormick and Kaberger, 2007; Ruble and El-Khoury, 2013; Perlack et al., 1990; Martinot, 1999). For example, subsidies to oil and gas have been considered as a barrier to active solar systems for water or space heating in USA (Roessner, 1984; Dorf, 1984). Likewise, subsidies for conventional electricity sources have created a distorted market for solar PV discouraging its usage (Oliver and Jackson, 1999; Muntasser et al., 2000). In the state of Punjab in India, solar PV pumps have been unfairly put against pumps that operate on free electricity or subsidized diesel (Radulovic, 2005).

Non-inclusion of externalities in the cost of energy from fossil fuels is reported to have created imperfect market hindering the diffusion of DRES on large scale (Stangeland, 2007; McCormick and Kaberger, 2007; Sagie et al., 2001). Consequent availability of cheaper but less sustainable fossil fuel derived energy options has put renewable energy at disadvantage (Doukas et al., 2009). For example, abundance of fossil fuels and cheap electricity has been considered as a significant barrier to renewable energy in Australia (Martin and Rice, 2012). Likewise, easy availability of fuelwood at zero private cost has been cited as a barrier to the utilization of biogas in Nepal (Rijal, 1986).

Reportedly, non-monetary benefits such as time savings or reduction in consumption of freely available firewood are not motivating the potential user enough to adopt DRES such as a family type biogas plant (Barnett, 1990). Also, non-monetary benefits may not be considered for adoption of improved cook stoves in developing countries, especially where adoption decisions are taken by men whereas cooking is performed by women (Agarwal, 1983). Moreover, it is not easy to estimate future price of fossil fuels due to change in domestic and international prices. The difficulty of fuel price risk assessment (due to risk associated with fluctuation of future fossil fuel prices) has also been considered as a barrier to the development of DRES (Beck and Martinot, 2004; Mezher et al., 2012).

*2.2.2.2.3. Incentives/Taxes/Duties*

Government may support the diffusion of DRESs through incentives such as capital subidy, soft loan, carbon credit, etc. Also, reduction or waiver of taxes and duties on DRESs and associated projects may help the dissemination of DRESs. However, DRESs often receive inadequate incentives to promote its adoption among its potential users. Inadequate incentives to DRES users have been considered as a barrier to its diffusion (Oliver and Jackson, 1999; Liu et al., 2013; Adhikari et al., 2008; Lidula et al., 2007; Al-Badi et al., 2011). In Australia, dearth of incentives for renewable energy has been cited as a barrier (Martin and Rice, 2012). Similarly, lack of incentives to wind installations in Greece has been cited as a major barrier to its diffusion (Oikonomou et al., 2009). Conventional power generation technologies have been reaping the benefits of tariff support, tax holidays and other conducive policies since decades and this gives them significant edge over solar PV in the absence of conducive renewable energy policies in developing countries (Muntasser et al., 2000). Painuly (2001) has cited taxes on DRES as barriers that lead to market distortions. In addition, distortions in tariff policies on imported equipments are reportedly retarding the growth of DRES (Perlack et al., 1990). For example, import duty on solar PV systems has further worsened its competitiveness (Radulovic, 2005).

*2.2.2.2.4. Purchasing Power and Spending Priorities*

Poor purchasing power of potential users has been a significant hurdle to the diffusion of biogas, biomass and solar energy based cooking systems (Quadir et al., 1995; Pohekar et al., 2005). Poverty or affordability has been reported as a barrier to the promotion of DRES (Ahlborg and Hammar, 2011; Adhikari et al; 2008). Diffusion of solar water heating systems is also reported to be adversely affected by lack of purchasing power of potential households (Srinivasan, 2006; Ruble and El-Khoury, 2013). Similarly, low purchasing power of households due to poverty has been preventing usage of solar home systems in un-electrified areas of rural Bangladesh (Barua, 2001) and other countries (Radulovic, 2005). Other spending priority of households in Greece is also reported as a barrier to the diffusion of solar domestic hot water system in the country (Sidiras and Koukios, 2004).

*2.2.2.2.5. Financial Issues*

Lack of access to credit facilities has been widely reported as a critical barrier to the diffusion of DRESs (Beck and Martinot, 2004; Mondal et al., 2010; Quadir et al., 1995; Bhatia, 1990; Painuly, 2001; Patlitzianas et al., 2006; Owen, 2006; Mirza et al., 2009; Nalan et al., 2009; Doukas et al., 2009; Pegels, 2010; Martin and Rice, 2012; Krupa, 2012; Ahlborg and Hammar, 2011; Junfeng et al., 2002; Zyadin, 2014; Radulovic, 2005; Margolis and Zuboy, 2006; Lidula et al., 2007; Mezher et al., 2012; Ruble and El-Khoury, 2013; Martinot, 1998; Mwirigi et al., 2009). For example, limited access to financial resources and high cost of finance are preventing commercialization of DRES in India (Bakthavatsalam, 1999). Similarly, difficulties with financing and insuring biomass based projects in Europe have been reported as a barrier to their successful diffusion in the region

(Rosch and Kaltschmitt, 1999). As many of the potential users of improved cook stoves in rural areas of developing countries are very poor, need for access to subsidized credit has been stressed (Agarwal, 1983). Limited access to affordable credit facilities is also reported as a barrier to solar PV diffusion as it prevents entry of private sector in the industry (Oliver and Jackson, 1999; Muntasser et al., 2000). Lack of long-term financing and high interest rate for capital are important barriers to the diffusion of DRESs (Martinot, 1999; Painuly, 2001; Dorf, 1984). Lack of investment protection has also been cited as a barrier (Doukas et al., 2009). Moreover, lack of supportive investment climate in a country is also reported as a barrier as it may affect the growth of DRES industry in the country (Adhikari et al., 2008). Quadir et al. (1995) has cited long economic payback period as a barrier to the dissemination of biogas plants and solar cookers. Long payback period of DRES projects has also been cited as a barrier by several other studies (Painuly, 2001; Mirza et al., 2009; Zhang et al., 2012; Sidiras and Koukios, 2004; Kennedy and Basu, 2013a; Dorf, 1984; Finney et al., 2012).

*2.2.2.2.6. Awareness and Risk Perception*

Awareness among various stakeholders is a very important requirement for effective functioning of a market or economy. Lack of information has been cited in many studies as a barrier to the diffusion of DRES (Painuly, 2001; Owen, 2006; Srinivasan, 2008; Mirza et al., 2009; Martin and Rice, 2012; Allen et al., 2008; Kennedy and Basu, 2013; Kennedy and Basu, 2013a; Ohunakin et al., 2014; Balcombe et al., 2013; Ruble and El-Khoury, 2013; Rebane and Barham, 2011). For example, in the case of family size biogas plants in Kenya, lack of information is rated one of the most critical barrier affecting their adoption among the farmers (Mwirigi et al., 2009). On similar lines, Foxon et al. (2005) have mentioned that innovation systems for renewable energy technologies in United Kingdom are suffering due to lack of exchange of information among various stakeholders.

Perception of financial or investment risk is another challenge to the diffusion of DRESs (Owen, 2006; Mirza et al., 2009; Adams et al., 2011; Prasertsan and Sajjakulnukit, 2006; McCormick and Kaberger, 2007; Perlack et al., 1990; Martinot, 1999; Finney et al., 2012). In developing countries, public has general perception that new technologies such as DRESs are costlier compared to its conventional counterparts (van der Gaast et al., 2009). Increased risk perception regarding the performance and durability of DRESs results in higher desired rate of return on investment leading to less capital availability for DRES projects (Beck and Martinot, 2004).

### *2.2.2.3. Potential Remedial Measures*

Generally, most of the renewable energy policies attempt to address economic barriers (Beck and Martinot, 2004). Table 2.3 presents some of the suggested remedial measures to overcome the sub-barriers under economic barrier category. As indicated in Table 2.3, role of institutions including DRES related policymaking and implementation agency, R&D institutions, banks, NGOs and academic institutions is critical to surmount cost and market barriers. Besides supporting R&D for cost reduction, efforts should be made towards the development of a conducive market for DRESs through appropriate policy measures.

In addition to the generic broad based remedial measures listed in Table 2.3, there are few other case-specific measures that have been reportedly suggested to overcome economic barriers to DRESs. For promotion of alternative energy projects in developing countries, it has been recommended that the projects be designed to have low cost and short payback periods. Through a discussion on commercialization of solar technology in USA, Roessner (1984) has recommended matching of government’s commercialization strategy with the stage of evolution of the industry. Need for long-term fiscal incentives has also been stressed (Martin and Rice, 2012). Also, rationalization of subsidies has been recommended as large state subsidies in Thailand towards solar battery charging programmes for 15 years have reportedly destroyed market for private companies (Green, 2004). Developing PV schemes that prevents subsidy leakages to wealthy farmers has been recommended to improve diffusion of PV in Indian agricultural sector (Radulovic, 2005). Moreover, appropriate financial funding depending upon the relative maturity of solar water heating industry has also been recommended (Srinivasan, 2006). Local credit schemes need to be set up

Table 2.3: Potential remedial measures suggested to overcome the sub-barriers of economic barrier

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| Cost | Incentives to DRES users or consumers (subsidy, tax rebate) | DRES related policymaking and implementation agency | Beck and Martinot, 2004; Jarach, 1989; Rijal, 1986; Oliver and Jackson, 1999; Bhatia, 1990; Painuly, 2001; Mirza et al., 2003; Reddy and Painuly, 2004; Owen, 2006; Philibert, 2006; GNESD, 2007; Stangeland, 2007; Oikonomou et al., 2009; Martin and Rice, 2012; Krupa, 2012; Ahlborg and Hammar, 2011; Liu et al., 2013; Zhang et al., 2012; Chandrasekar and Kandpal, 2007; Joseph and Burton, 1990; Adams et al., 2011; Kassenga, 1997; Sidiras and Koukios, 2004; Kinab and Elkhoury, 2012; Ohunakin et al., 2014; Njuguna, 1997; Dorf, 1984; Al-Badi et al., 2009; Mezher et al., 2012; Balcombe et al., 2013; Ruble and El-Khoury, 2013; Perlack et al., 1990; Wamukonya, 2007; Al-Badi et al., 2011; Mills |

Table 2.3: Potential remedial measures suggested to overcome the sub-barriers of economic barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | | | and Schleich, 2009; Boyle, 1994; Jager-Waldau, 2007; Purohit and Michaelowa, 2008; Muntasser et al., 2000; Verbruggen et al., 2010 |
| | R&D for cost reduction | R&D institutions | Rijal, 1986; Jagadeesh, 2000; Liu et al., 2013; Fthenakis et al., 2009; Boyle, 1994; Pillai and Banerjee, 2009 |
| | Funds for R&D on DRES | DRES related policymaking and implementation agency | Jagadeesh, 2000; Mirza et al., 2003; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Lidula et al., 2007; Ruble and El-Khoury, 2013; Boyle, 1994 |
| | Reduction in transaction cost (learning by doing effect) | DRES related implementation agency and other relevant government agencies | Junfeng et al., 2002; Boyle, 1994; Verbruggen et al., 2010 |
| Market | Innovative financing schemes (soft loans, grants, revolving fund, fee for service delivery model) | DRES related policymaking and implementation agency, banks, energy service companies | Beck and Martinot, 2004; Jarach, 1989; Mondal et al., 2010; Jagadeesh, 2000; Oliver and Jackson, 1999; Bhatia, 1990; Painuly, 2001; Mirza et al., 2003; Reddy and Painuly, 2004; Owen, 2006; GNESD, 2007; Mirza et al., 2009; Chandrasekar and Kandpal, 2007; Junfeng et al., 2002; Kennedy and Basu, 2013a; Lidula et al., 2007; Balcombe et al., 2013; Perlack et al., 1990; Wamukonya, 2007; Sagie et al., 2001; Boyle, 1994 |

Table 2.3: Potential remedial measures suggested to overcome the sub-barriers of economic barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | Micro-credit facilities | Banks, NGOs, energy service companies | Mondal et al., 2010; Srinivasan, 2008; Kennedy and Basu, 2013a; Ohunakin et al., 2014; Wamukonya, 2007; Verbruggen et al., 2010 |
| | Internalization of externalities in cost of energy | Policymaking agencies related to energy sector | Reddy and Painuly, 2004; Owen, 2006; Stangeland, 2007; Srinivasan, 2008; Mirza et al., 2009; Oikonomou et al., 2009; Liu et al., 2013; Joseph and Burton, 1990; Junfeng et al., 2002; Zyadin et al., 2014; Kennedy and Basu, 2013a; Mezher et al., 2012; McCormick and Kaberger, 2007; Sagie et al., 2001; Boyle, 1994 |
| | Withdrawal of subsidies to fossil fuels | Policymaking agencies related to energy sector | Bhatia, 1990; pokharel, 2003; Owen, 2006; Mirza et al., 2009; Krupa, 2012; Joseph and Burton, 1990; Zyadin et al., 2014; Dorf, 1984; Mezher et al., 2012; Puri, 2006 |
| | Quotas for DRES usage | DRES related policymaking agency | Philibert, 2006; Wamukonya, 2007 |
| | Incentives (subsidies, tax break, reduced import duty) to private sector or entrepreneurs (acting as manufacturers/ project developers/ distributors/retailers) | DRES related policymaking agency | Bhatia, 1990; Mirza et al., 2003; Foxon et al., 2005; Philibert, 2006; Ahlborg and Hammar, 2011; Allen et al., 2008; Adams et al., 2011; Junfeng et al., 2002; Ohunakin et al., 2014; Adhikari et al., 2008; Dorf, 1984; Al-Badi et al., 2009; Muntasser et al., 2000 |
| | Market intermediation | Relevant | Pegels, 2010; Balcombe et al., |

Table 2.3: Potential remedial measures suggested to overcome the sub-barriers of economic barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | by government | government agency | 2013; Martinot, 1998; Martinot, 1999 |
| | Awareness or information dissemination programme | DRES related implementation agency, NGOs, academic institutions | Beck and Martinot, 2004; Painuly, 2001; Pokharel, 2003; Reddy and Painuly, 2004; Owen, 2006; GNESD, 2007; Mirza et al., 2009; Martin and Rice, 2012; Krupa, 2012; Joseph and Burton, 1990; Prasertsan and Sajjakulnukit, 2006; Zyadin et al., 2014; Kassenga, 1997; Sidiras and Koukios, 2004; Dorf, 1984; Ruble and El-Khoury, 2013; Perlack et al., 1990; Sagie et al., 2001; Charters, 2001 |

in rural areas to overcome cost barrier of DRES (Green, 1999). Soft loan schemes of Grameen Shakti in Bangladesh have been found to be very successful in overcoming affordability barriers associated with solar PV systems and its replication in other areas has been recommended (Barua, 2001). Creation of self-help groups among farmers to raise revolving funds for construction of biogas plants is also reported as a viable option for promotion of DRES in Kenya (Mwirigi et al., 2009).

As suggested above, overcoming economic barriers to DRES would need institutional support from government and DRES related policymaking and implementation agency for: a) setting up R&D institutions for cost reduction, b) market facilitation to DRES through various incentives, c) developing a fair energy pricing regime with internalization of externalities, and d) delivery of microfinance facilities to poor households for DRES adoption.

### *2.2.3. Institutional Barriers*

A large number of studies have reported the relevance of institutional barriers in preventing diffusion of DRES (Jarach, 1989; Quadir et al., 1995; Roessner, 1984; Green, 1999; Jagadeesh, 2000; Oliver and Jackson, 1999; Rijal, 1999; Painuly, 2001; Mirza et al., 2003; Pokharel, 2003; Reddy and Painuly, 2004; Foxon et al., 2005; Philibert, 2006; GNESD, 2007; Mirza et al., 2009; Nalan et al., 2009; Oikonomou et al., 2009; Doukas et al., 2009; Pegels, 2010; Martin and Rice, 2012; Ahlborg and Hammar, 2011; Zhang et al., 2012; Chandrasekar and Kandpal, 2007; Prasertsan and Sajjakulnukit, 2006; Kinab and Elkhoury, 2012; Njuguna, 1997; Al-Badi et al., 2009; Mezher et al., 2012; McCormick and Kaberger, 2007; Negro et al., 2012; Martinot, 1998; Al-Badi et al., 2011; Michalena and Angeon, 2009; Boyle, 1994; Jager-Waldau, 2007; Charters, 2001; Qiu et al., 1996). The sub-barriers that may be listed under the category of institutional barrier include - lack of agencies to disseminate information, uncertain government policies, lack of a legal/regulatory framework, tedious bureaucratic procedures, unstable macro-economic environment, lack of stakeholder participation in decision making, clash of interests among stakeholders, lack of R&D culture, insufficient professional institutions and lack of private sector participation (Painuly, 2001). For example, institutional barriers reported to be affecting family type biogas plants, improved cook stoves and solar cooker in developing countries are: lack of infrastructure, incompatibility with existing work organization, difficulties in obtaining loans from government, lack of coordination among various agencies, poor technology transfer and after-installation services, and differences in priority of policymaker and users (Quadir et al., 1995). Based on their characteristics, institutional barriers can be classified as: a) policy and regulatory; b) infrastructure; and c) administrative barriers.

*2.2.3.1. Policy and Regulatory*

Lack of consistent policies and regulations to support DRES (e.g., lack of incentives to consumers, difficult zoning and permitting processes, etc.) has been cited as a barrier to its diffusion (Oliver and Jackson, 1999; Rijal, 1999; Sahir and Qureshi, 2008; Krupa, 2012; Ahlborg and Hammar, 2011; Zhang et al., 2012; Adams et al., 2011; Prasertsan and Sajjakulnukit, 2006; Junfeng et al., 2002; Zyadin et al., 2014; Margolis and Zuboy, 2006; Lidula et al., 2007; Puri, 2006). Worldwide, policies are reportedly biased towards fossil fuels and nuclear energy (Krupa, 2012; Boyle, 1994). Lack of suitable legal and regulatory framework for dissemination of DRES is also a major institutional barrier (Beck and Martinot, 2004; Jarach, 1989; Jagadeesh, 2000; Patlitzianas et al., 2006; Philibert, 2006; Hiremath, 2009; Liu et al., 2013; Zhang et al., 2012; Adams et al., 2011; Kennedy and Basu, 2013a; Adhikari et al., 2008; Dorf, 1984; Huacuz, 2001; Ruble and El-Khoury, 2013; Rosch and Kaltschmitt, 1999; Martinot, 1999; Charters, 2001). Wind turbines, rooftop solar water heaters, photovoltaic installations, etc face opposition from urban planning agencies due to lack of established procedures for siting and installation of household DRESs (Beck and Martinot, 2004; Patlitzianas et al., 2006). The opposition may be based upon height, aesthetics, noise, or safety (Beck and Martinot, 2004). While excessive/inefficient/outdated regulation is reported to be hindering the development of DRESs (Owen, 2006), the risk of change of legislation has been found to be a major institutional barrier to the development of DRES in South Africa (Pegels, 2010).

*2.2.3.2. Infrastructure*

For development of DRES friendly environment, the institutions involved in its dissemination are expected to be effective in the following roles – planning at central, federal and local level, programme implementation, quality control and standardization, performance monitoring, human resource development, technology development and transfer, awareness generation and information dissemination, and market development (Chandrasekar and Kandpal, 2007). However, many studies have pointed that the institutional infrastructure may not have evolved enough to effectively support the dissemination of DRES. For example, in China, underdeveloped market support infrastructure for DRES has reportedly acted as an institutional barrier (Junfeng et al., 2002). Lack of institutional, financial and technical structures to promote DRES has been found to be detrimental to its diffusion in ASEAN (Lidula et al., 2007). In another study, Martinot (1998) has observed that ineffective market and contract institutions and lack of institutional framework are the major institutional barriers in Russia. Also, multiplicity of agencies for wind energy in India has been reported as a barrier as it has resulted in lack of coordination and unnecessary delays (Jagadeesh, 2000). Lack of organizational structure for installation, sales, repair and maintenance of DRESs is also cited as a barrier to their diffusion (Bhatia, 1990). As per a study on Europe, lack of infrastructure to support market introduction and subsequent dissemination of biomass based DRES has been a significant barrier (Rosch and Kaltschmitt, 1999). Echoing similar observation, service infrastructure for the promotion, distribution, sales, technical assistance and maintenance of solar PV systems is poorly developed and has been hindering their diffusion in many parts of the world (Oliver and Jackson, 1999). Mismatch between organizational aspects of DRES and adopters also lead to unsuccessful diffusion (e.g., DRES requiring frequent maintenance and services generally fail in rural areas of developing countries as these areas suffer from inaccessibility and lack of skilled workforce) (Green, 1999).

Availability of infrastructure for after sales services is also crucial for accelerated diffusion of DRES. Underdeveloped extension services for spare parts supply and maintenance services are reportedly hindering dissemination of renewable energy technologies for decentralized applications in rural areas (Rijal, 1986; Jagadeesh, 2000; Oliver and Jackson, 1999; Painuly, 2001; Mirza et al., 2003; Pokharel, 2003; Mirza et al., 2009; Bhattacharya and Jana, 2009; Ahlborg and Hammar, 2011; Zhang et al., 2012; Chandrasekar and Kandpal, 2007; Joseph and Burton, 1990; Junfeng et al., 2002; Radulovic, 2005; Adhikari et al., 2008; Dorf, 1984; Perlack et al., 1990). In developing countries, poor extension and after-installation services have resulted in slow dissemination of family type biogas plants, improved cook stoves and box type solar cookers (Quadir et al., 1995). For example, Barnett (1990) has noted that lack of maintenance services has been the major factor behind the failure of biomass gasifiers in Philippines. Lack of technical support for installation and maintenance is also reported as a barrier impeding the dissemination of solar home systems in Africa (Wamukonya, 2007).

Institutional support to ensure easy availability of spare parts is necessary to ensure effective maintenance services for DRESs. Limited availability of spare parts and maintenance expertise has been cited as a barrier to the growth of DRESs (Doukas et al., 2009; Kassenga, 1997). For example, as most of the renewable energy systems are imported in Pakistan, non-availability of spare parts is reported to be an important technical barrier to their diffusion in the country (Mirza et al., 2009). Similarly, frequent failure of mantle lamps of biogas plants and its unavailability as spare part has led to non-usage of biogas plants in Nepal (Rijal, 1986).

As renewable energy sources are site specific, reliable resource availability data is essential for selection of favorable site for renewable energy projects. However, diffusion of DRES is reportedly facing barrier due to lack of reliable resource availability data (Mirza et al., 2009; Prasertsan and Sajjakulnukit, 2006; Kassenga, 1997; Kinab and Elkhoury, 2012; Lidula et al., 2007; Al-Badi et al., 2009). According to Al-badi et al. (2009), lack of accurate data on resource availability, and inadequate support to research are hindering development of DRESs in Oman. Similarly, Mirza et al. (2009) has cited lack of detailed renewable energy resource assessments and data banks as barriers hindering diffusion of DRESs in Pakistan. Accurate and reliable resource assessment would need institutional infrastructure for strong coordination between government agencies and education and research institutions.

### *2.2.3.3. Administrative*

Administrative barriers limit effective implementation of renewable energy programme. Lack of coordination between various stakeholders has been frequently cited as a major administrative barrier to the diffusion of DRESs (Mondal et al., 2010; Adams et al., 2011; Prasertsan and Sajjakulnukit, 2006; Kennedy and Basu, 2013a; Radulovic, 2005; Margolis and Zuboy, 2006; Njuguna, 1997; McCormick and Kaberger, 2007). For example, dearth of good coordination between various ministries and agencies, and dependence of renewable energy budget on national budget has been acting as barriers to DRES development in Bangladesh (Mondal et al., 2010). In addition, few studies have cited poor monitoring and evaluation as a significant barrier to the diffusion of DRESs (Bhattacharya and Jana, 2009; Qiu et al., 1996). For example, large scale implementation of improved biomass cookstoves with poor monitoring and evaluation lead to failure of early programmes in China (Qiu et al., 1996). Similarly, poor monitoring and evaluation and subsidy driven nature of National Programme on Improved Cookstoves has been instrumental in limiting the impact of the programme in India (Bhattacharya and Jana, 2009). Tedious administrative and documentation procedures involved in approval of DRES projects also hinder the diffusion of DRESs (Mondal et al., 2010; Doukas et al., 2009; Michalena and Angeon, 2009; Puri, 2006). Few studies have also cited bureaucratic administrative procedures of government institutions as barriers impeding the growth of DRESs (Zyadin et al., 2014; Adhikari et al., 2008).

### *2.2.3.4. Potential Remedial Measures*

Institutional barriers can be addressed through several measures. Table 2.4 presents the suggested remedial measures to overcome the sub-barriers listed under institutional barrier. From the table, it may be noted that the role of DRES related policymaking agency is important to overcome institutional barriers due to inappropriate policy and regulatory framework. Worldwide, conducive regulatory frameworks have been enacted to accelerate the diffusion of DRES. For example, through a regulation introduced in 1980, Israel achieved 80% coverage of the roofs of residential households with solar water heaters (Philibert, 2006). To promote solar energy utilization in buildings, building code of Florida (USA) mandates all new educational buildings to include passive solar design (Beck and Martinot, 2004). Similarly, through renewable access laws in some countries, property owners are provided the right to continued access to a renewable resource (Beck and Martinot, 2004). The access is ensured through voluntary contracts between neighbors or covenant laws (Beck and Martinot, 2004).

Table 2.4: Potential remedial measures suggested to overcome the sub-barriers of institutional barrier

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| Policy and regulatory | Conducive long-term policies for all stakeholders | DRES related policymaking agency | Quadir et al., 1995; Mirza et al., 2003; Pokharel, 2003; Reddy and Painuly, 2004; Foxon et al., 2005; GNESD, 2007; Sahir and Qureshi, 2008; Ahlborg and Hammar, 2011; Liu et al., 2013; Prasertsan and Sajjakulnukit, 2006; Junfeng et al., 2002; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Kennedy and Basu, 2013a; Lidula et al., 2007; Balcombe et al., 2013; McCormick and Kaberger, 2007; Negro et al., 2012; Ruble and El-Khoury, 2013; Finney et al., 2012; Puri, 2006 |
| | Conducive regulatory | DRES related policymaking | Beck and Martinot, 2004; Oliver and Jackson, 1999; Rijal, 1999; Painuly, |

Table 2.4: Potential remedial measures suggested to overcome the sub-barriers of institutional barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | framework | agency | 2001; Owen, 2006; Philibert, 2006; Hiremath et al., 2009; Bhattacharya and Jana, 2009; Liu et al., 2013; Zhang et al., 2012; Allen et al., 2008; Junfeng et al., 2002; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Ohunakin, 2014; Lidula et al., 2007; Njuguna, 1997; Martinot, 1998; Al-Badi et al., 2011; Finney et al., 2012 |
| | Integration of DRES policies with developmental programmes | DRES related policymaking agency and other participating government agencies | GNESD, 2007; Junfeng et al., 2002 |
| | Policy involving incentives for DRES utilization | DRES related policymaking agency | Liu et al., 2013; Al-Badi et al., 2009; Al-Badi et al., 2011; Charters, 2001 |
| | Private sector participation | DRES related policymaking agency | Mondal et al., 2010; Bhattacharya and Jana, 2009; Ahlborg and Hammar, 2011; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Dorf, 1984 |
| Infrastructure | Specialized institutions for R&D, financing, capacity building, marketing and commercialization of DRES | DRES related policymaking and implementation agency, R&D institutions, banks, NGOs and academic institutions | Mondal et al., 2010; Jagadeesh, 2000; Painuly, 2001; Junfeng et al., 2002 |
| | After sales | DRES related | Rijal, 1986; Pokharel, 2003; Green, |

Table 2.4: Potential remedial measures suggested to overcome the sub-barriers of institutional barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | services infrastructure for training and extension programmes | implementation agency, energy services companies, NGOs and academic institutions | 2004; Zhang et al., 2012; Radulovic, 2005; Perlack et al., 1990; Wamukonya, 2007 |
| Administrative | Strong coordination between various agencies and stakeholders | DRES related implementation agency and other relevant government agencies such as municipal corporations | Foxon et al., 2005; Patlitzianas et al., 2006; Mirza et al., 2009; Martin and Rice, 2012; Krupa, 2012; Prasertsan and Sajjakulnukit, 2006; Kennedy and Basu, 2013a; McCormick and Kaberger, 2007; Huacuz, 2001; Rosch and Kaltschmitt, 1999 |
| | Involvement of local stakeholders in planning and implementation of DRES programme | DRES related implementation agency | Mondal et al., 2010; Rijal, 1999; Oikonomou et al., 2009; Ahlborg and Hammar, 2011; Zyadin et al., 2014; Kennedy and Basu, 2013a; Ohunakin et al., 2014; McCormick and Kaberger, 2007 |
| | Simplified approval procedures or single window clearance | DRES related implementation agency | Philibert, 2006; Rosch and Kaltschmitt, 1999; Puri, 2006 |
| | Support and facilitation by government from R&D to commercializa- | DRES related policymaking and implementation agency | Painuly, 2001; Reddy and Painuly, 2004; Ahlborg and Hammar, 2011; Liu et al., 2013; Adams et al., 2011; Junfeng et al., 2002; Kennedy and Basu, 2013a; Radulovic, 2005; Ohunakin, 2014; Lidula et al., 2007; |

Table 2.4: Potential remedial measures suggested to overcome the sub-barriers of institutional barrier (continued…)

| *Sub-barrier* | *Remedial measure (s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | tion of DRES | | Boyle, 1994; Charters, 2001 |
| | Effective project monitoring and evaluation | DRES related implementation agency | Mondal et al., 2010; Bhatia, 1990; Jager-Waldau, 2007; Martinot, 1999; Qiu et al., 1996 |

Apart from the generic remedial measures listed in Table 2.4, there are few other case-specific measures that have been recommended to overcome institutional barriers. Rather than just focusing on number of installations, Bhatia (1990) has advocated meticulous planning and in-depth socio-economic evaluation studies for improved diffusion of biogas engines in India. Market intermediation by Russian government for securing support of government officials, securing funds, obtaining necessary licenses and approvals, and managing, monitoring and evaluating projects to promote renewable energy in the country has been recommended (Martinot, 1999). Creation of an umbrella organization for monitoring, regulating and capacity building is recommended to overcome institutional barriers in Bangladesh (Mondal et al., 2010). For Turkey, it is recommended that DRES be promoted as unique products with attributes such as least cost and environmental and social benefits (Nalan et al., 2009). Appropriate institutional infrastructure to plan and implement well-coordinated programme at all levels and simplified time-bounded administrative procedure for various approvals and clearances are suggested to promote wind installations in India (Jagadeesh, 2000). Learning from the success of China's diffusion programme of improved biomass stoves, Qiu et al. (1996) advocates working in the best areas first, regular, systematic and consistent monitoring and evaluation, and promotion of rural energy companies.

It can be concluded that in addition to framing conducive long-term policies and a favorable regulatory framework for diffusion of DRESs, DRES related policymaking agency is also expected to create conducive environment for development of specialized institutions for R&D, financing, capacity building, marketing and commercialization (including awareness generation and quality control) of DRESs. Effective project monitoring and evaluation is also recommended to ensure the success of DRES projects.

### *2.2.4. Socio-cultural Barriers*

The category of socio-cultural barriers is another important impediment that affects the diffusion of DRESs (Stangeland, 2007). Social/socio-cultural/cultural barriers have been extensively reported with reference to diffusion of DRESs (Jarach, 1989; Quadir et al., 1995; Agarwal, 1983; Green, 1999; Rijal, 1999; Painuly, 2001; Green, 2004; Pohekar and Ramachandran, 2006; Philibert, 2006; Stangeland, 2007; Mirza et al., 2009; Nalan et al., 2009; Oikonomou, 2009; Purohit, 2009; Doukas et al., 2009; Krupa, 2014; Ahlborg and Hammar, 2011; Chandrasekar and Kandpal, 2007; Junfeng et al., 2002; Kassenga, 1997; Ohunakin et al., 2014; Njuguna, 1997; Michalena and Angeon, 2009; van der Gaast et al., 2009; Verbruggen et al., 2010; Sovacool, 2009; Alit, 1990; Pohl and Gisler, 2003; Kaldellis, 2005). Moreover, negative impacts of socio-economic, socio-political and political barriers on diffusion of DRES have also been discussed in Rijal (1999), Sahir and Qureshi (2008) and Green (1999) respectively. Socio-cultural barriers may arise as a result of the following: a) societal structure, norms and value system, b) awareness and risk perception, c) behavioral or lifestyle issues (Verbruggen et al., 2010).

#### *2.2.4.1. Societal Structure, Norms and Value System*

A socio-cultural barrier may exist due to - lack of satisfaction of perceived needs of the user and non-integration of the technology within the social structure and disharmony with prevailing values and ideology (Quadir et al., 1995). For example, in many rural societies, traditional cook stoves satisfy lighting, space heating, pest control, drying, etc needs of the household in addition to cooking. Improved cook stoves, though having higher efficiency in cooking, do not satisfy the other above-mentioned perceived needs of the user and thus have not been adopted (Quadir et al., 1995). Lack of understanding about the needs of the users primarily contributed to the failure of early Chinese biogas program (Barnett, 1990). A biogas project failed in Indonesia because it was incompatible with the local belief which considered rice fields as holy and installation of biogas units on it was considered a taboo (Alit, 1990). In Nepal, many households did not accept improved cook stoves and continued with open fire cooking as they believed that their family spirit resided in it (Agarwal, 1983). For family size biogas plants, improved cook stoves and box type solar cookers, socio-cultural acceptability factor is reported to be relatively more important as compared to solar water heating systems and solar photovoltaic technologies (Chandrasekar and Kandpal, 2007). This reflects better socio-cultural acceptance of non-cooking devices such as solar water heating and photovoltaic technologies.

Green (1999) has reported that diffusion faces hurdles when there are cultural differences between donor and receiver. In Turkey, wind energy installations have reportedly faced opposition due to its weak social compatibility (Nalan et al., 2009). Likewise, for preservation of natural resources and cultural heritage in Crete Island (Greece), local population opposed wind energy projects (Michalena and Angeon, 2009).

Psychological barriers and conservative rural traditions also act as hindrances to successful diffusion of DRES (Michalena and Angeon, 2009). In USA, psychological attributes such as comfort, freedom, control, trust, social status, ritual, and habit are reportedly impeding the diffusion of DRES in the country (Sovacool, 2009). Cooking is generally done by women, but gender bias leading to lack of women participation in decision making and inadequate access to credit has reportedly hindered adoption of improved cook stoves (Agarwal, 1983). Nonownership of house is a psychological barrier to diffusion of domestic solar water heater in Greece as it creates a condition of split incentives for the developer/owner and tenant (Sidiras and Koukios, 2004). Philibert (2006) has also reported problem of split incentives with respect to diffusion of solar thermal technologies.

#### *2.2.4.2. Awareness and Risk Perception*

Lack of information or awareness is a widely reported socio-economic barrier impeding diffusion of DRES (Beck and Martinot, 2004; Jarach, 1989; Mondal et al., 2010; Oliver and Jackson, 1999; Rijal, 1999; Painuly, 2001; Reddy and Painuly, 2004; Pohekar et al., 2005; Patlitzianas et al., 2006; Owen, 2006; Philibert, 2006; GNESD, 2007; Srinivasan, 2008; Mirza et al., 2009; Oikonomou, 2009; Martin and Rice, 2012; Ahlborg and Hammar, 2011; Chandrasekar and Kandpal, 2007; Prasertsan and Sajjakulnukit, 2006; Zyadin et al., 2014; Kinab and Elkhoury, 2012; Radulovic, 2005; Lidula et al., 2007; Dorf, 1984; Mezher et al., 2012; McCormick and Kaberger, 2007; Huacuz, 2001; Matinot, 1998; Mwirigi et al., 2009; Martinot, 1999; Muntasser et al., 2000; van der Gaast et al., 2009; Verbruggen et al., 2010; Rebane and Barham, 2011). Because of lack of awareness, DRESs are often perceived as inferior technologies in terms of utility and user comfort (Reddy and Painuly, 2004). For example, for wind parks in Dodecanese Islands of Greece, public opinion on its aesthetic harmful effect and insufficient information on social benefits are acting as social barriers (Oikonomou et al., 2009). As per a survey conducted in Greece, respondents consider opinion of friends as a barrier to the diffusion of domestic solar water heaters in the country (Sidiras and Koukios, 2004).

Negative perception about DRES is another issue that is hindering its diffusion. Generally, DRES suffer from perceptions of greater technical risk than conventional technologies because of lack of visible installations and familiarity with the system (Beck and Martinot, 2004). Perceived technology performance uncertainty, poor reliability and associated risks have also been cited by other studies reflecting on barriers to DRES (Quadir et al., 1995; Bakthavatsalam, 1999; Jagadeesh, 2000; Reddy and Painuly, 2004; Foxon et al., 2005; Pohekar et al., 2005; Patlitzianas et al., 2006; Srinivasan, 2008; Bhattacharya and Jana, 2009; Kennedy and Basu, 2013a; Mezher et al., 2012; Balcombe et al., 2013; McCormick and Kaberger, 2007; Perlack, et al., 1990). Also, many societies have the perception that DRES negatively affects community social structures and thus resist them (Doukas et at., 2009). Negative impression created by failure of DRES projects in the past also hinder diffusion of technically sound DRES (Green, 1999; Philibert, 2006; van der Gaast, 2009). For example, negative image caused by failed biogas plants in Kenya has been reported as a major barrier to its diffusion (Mwirigi et al., 2009). Moreover, failure of DRES in raising the standard of living has developed negative perception about DRES among potential users (Green, 2004; Joseph and Burton, 1990). Past failures have increased the risk perception regarding DRESs among public, politician and local authorities that are reportedly impeding diffusion of DRES (Painuly, 2001; Rosch and Kaltschmitt, 1999; Boyle, 1994). Lack of demonstration of DRES utility among potential users aggravates risk perception (Martinot, 1999). Mirza et al. (2003) have also pointed that inadequate demonstration of utility of solar energy devices is a significant barrier affecting their diffusion in Pakistan.

#### *2.2.4.3. Behavioral or Lifestyle Issues*

Preference for traditional energy sources and resistance to change has reportedly created behavioral barriers that may impede diffusion of DRES (Painuly, 2001; Reddy and Painuly, 2004; Verbruggen et al., 2010). Few studies have cited behavioral or lifestyle issues impeding the diffusion of DRES (cooking technologies) (Quadir et al., 1995; Pohekar et al., 2005; Pohekar and Ramachandran, 2006; Philibert, 2006; van der Gaast et al., 2009). Behavioral barriers are not limited to cooking devices. Power engineers and others working in large energy supply companies are also reportedly resisting innovations such as DRES (van der Gaast, 2009). In United Kingdom, inconvenience and subsequent behavioral changes involved in adoption of DRES is reportedly preventing its adoption (Balcombe et al., 2013).

*2.2.4.4. Potential Remedial Measures*

For successful diffusion of DRES, it is necessary to address socio-cultural barriers faced by it. Suggested remedial measures and corresponding responsibility center(s) to address socio-cultural barriers are presented in Table 2.5.

In addition to the generic remedial measures listed in Table 2.5, few other case-specific remedial measures have been recommended to overcome socio-cultural barriers. For example, installation of solar home systems for public view in neighborhood of potential users has been advocated to increase awareness regarding the system in rural Nicaragua (Rebane and Barham, 2011). Similarly, Painuly (2001) has recommended demonstration programmes of DRES to reduce its risk perception among users. For Russia, Martinot (1999) recommends market intermediation and joint ventures with foreign corporations for enhanced information dissemination and demonstration experiences. It is also suggested that the policymakers should strive to improve public understanding of renewable energy systems (Sovacool, 2009). Increased women participation and adequate consideration of social equity for poor and marginalized mountain population are recommended for improved DRES dissemination programmes in mountainous areas of China, India, Nepal and Pakistan (Rijal, 1999).

From the above suggestions, we can conclude that surmounting socio-cultural barriers associated with the diffusion of DRES would need institutional support for participative and indigenous R&D, demonstration and awareness generation. Government may support these activities through academic and R&D institutions and NGOs.

Table 2.5: Potential remedial measures suggested to overcome the sub-barriers of socio-cultural barrier

| *Sub-barrier* | *Remedial measure(s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| Societal structure, norms and value system | Comprehensive assessment of the perceived needs of the end user | R&D institutions | Quadir et al., 1995; Agarwal, 1983; Green, 1999; Barnett, 1990 |
| | Involvement of local stakeholders in planning and promotion of DRES | DRES related policymaking and implementation agency | Mondal et al., 2010; Pohekar et al., 2005; Patlitzianas et al., 2006; Oikonomou et al., 37; Sidiras and Koukios, 2004; Radulovic, 2005; Rosch and Kaltschmitt, 1999; Michalena and Angeon, 2009 |
| Awareness and perception | Awareness generation or information dissemination programmes | DRES related implementation agency, NGOs and academic institutions | Beck and Martinot, 2004; Mondal et al., 2010; Rijal, 1999; Painuly, 2001; Owen, 2006; Pohekar and Ramachandran, 2006; Philibert, 2006; GNESD, 2007; Srinivasan, 2008; Mirza, 2009; Doukas et al., 2009; Martin and Rice, 2012; Krupa, 2012; Prasertsan and Sajjakulnukit, 2006; Zyadin et al., 2014; Kassenga, 1997; Sidiras and Koukios, 2004; Kennedy and Basu, 2013a; Ohunakin et al., 2014; Adhikari et al., 2008; Dorf, 1984; |

Table 2.5: Potential remedial measures suggested to overcome the sub-barriers of socio-cultural barrier (continued…)

| *Sub-barrier* | *Remedial measure(s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| | | | McCormick and Kaberger, 2007; Huacuz, 2001; Ruble and El-Khoury, 2013; Rosch and Kaltschmitt, 1999; Mwirigi et al., 2009; Michalena and Angeon, 2009; Muntasser et al., 2000; Kaldellis, 2005 |
| | Demonstration programmes | DRES related implementation agency, NGOs and academic institutions | Beck and Martinot, 2004; Owen, 2006; Philibert, 2006; Liu et al., 2013; Prasertsan and Sajjakulnukit, 2006; Adhikari et al., 2008; Njuguna, 1997 |
| Behavioral or lifestyle issues | Demonstration programmes | DRES related implementation agency, NGOs and academic institutions | Owen, 2006; Philibert, 2006; Njuguna, 1997 |

### *2.2.5. Environmental Barriers*

In comparison to conventional energy technologies, most of the renewable energy technologies are relatively better in terms of environmental emissions and are expected to promote environmental sustainability. However, environmental impacts of DRESs must be analyzed for their large scale diffusion (Sidiras and Koukios, 2004).

Environmental barriers with respect to DRES involve competition for natural resources (e.g., water and land for biomass and solar power) and pollution (e.g., noise and visual pollution in case of wind energy) (Painuly, 2001). For example, non-availability of water has been reported to be one of the significant barriers to biogas engine utilization in India (Bhatia, 1990). A study on solar desalination plants in Israel has listed large land requirement as a major barrier (Sagie et al., 2001). Land issues affecting DRES have also been reported from Nigeria (Ohunakin, 2014). Environmental barrier is also significant to biomass gasifiers as it involves combustion, gasification and pyrolysis that release pollutants in the atmosphere (Jarach, 1989). Similarly, biogas and wind energy systems are also reported to have environmental concerns (Jarach, 1989). For example, leakage of biogas (mixture of methane, carbondioxide and hydrogen sulphide) pollutes

atmosphere and leads to global warming. Also, noise and odor have been reportedly hindering the usage of bioenergy technologies in United Kingdom (Adams et al., 2011). Wind energy installations are also facing environmental barriers as it negatively affects ecosystem (damage to flora and displacement of fauna such as migratory birds) (Oikonomou et al., 2009). Other environmental issues hindering wind energy are microwave interference, possibility of climate modification, noise, aesthetic (landscape) impact, bird collision and change of land use (Jarach, 1989; Nalan et al., 2009; Oikonomou et al., 2009; Krupa, 2012). Few other studies have also noted that aesthetic issues or its perception with respect to DRESs are acting as barriers (Zhang et al., 2012; Adams et al., 2011; Sidiras and Koukios, 2004; Margolis and Zuboy, 2006; Balcombe et al., 2013).

*2.2.5.1. Potential Remedial Measures*

Environmental barriers need to be assessed and addressed for improved diffusion of DRESs. Table 2.6 presents the suggested remedial measures and relevant responsibility center to address environmental barrier. Life cycle analysis (LCA)

Table 2.6: Potential remedial measures suggested to overcome the sub-barriers of environmental barrier

| *Sub-barrier* | *Remedial measure and reference(s)* | *Responsibility center(s)* | *Relevant reference(s)* |
|---|---|---|---|
| Resources (land and water), pollution, aesthetics | Life cycle analysis of the project | Environment protection agency | Stangeland, 2007 |
| | R&D for development of efficient systems with minimum possible footprint | R&D institutions | Jarach, 1989 |
| | Awareness generation among stakeholders | DRES related implementation agency, NGOs and academic institutions | Sidiras and Koukios, 2004 |

has been recommended for assessment of environmental impact of various DRES (Stangeland, 2007). For a given energy project, based on the results of LCA, the cleaner technology must be selected from a set of competing DRESs. Research for development of efficient technologies with minimum possible footprint and awareness generation campaigns regarding environmental/aesthetic issues of DRES are also recommended. Institutions that deal with environmental protection and R&D as well as academic institutions can play a major role in addressing environmental concerns associated with DRES projects.

## 2.3. Concluding Remarks

Diffusion of DRES may face variety of technical, economic, institutional, socio-cultural and environmental barriers. As DRESs are off-grid systems that are generally adopted and used directly by the adopters, barriers corresponding to personal adoption decision are more critical. Therefore, inappropriateness of technology, unavailability of skilled manpower for maintenance, unavailability of spare parts, high cost, lack of access to credit, poor purchasing power and other spending priorities, unfair energy pricing, lack of information or awareness, and lack of operation and maintenance training are the most critical barriers impeding the dissemination of DRESs. Long-term conducive policies, appropriate regulatory framework, financial incentives (capital subsidies and soft loans) to users, technology and skill development, inclusion of externalities in the cost of energy, withdrawal of subsidies to fossil fuels, development of specialized institutions, cooperation with international agencies, participation of local community and awareness generation are the frequently prescribed measures for increased dissemination of DRES. It may be concluded that for accelerated diffusion of DRES, appropriate institutional arrangements are required to facilitate R&D, capacity building, conducive market, credit facilities and awareness generation. Role of DRES related policymaking and implementation agency, R&D institutions, NGOs and academic institutions would be crucial to overcome barriers to the promotion of DRES.

# CHAPTER 3

# ESTIMATION OF POTENTIAL OF DECENTRALIZED RENEWABLE ENERGY SYSTEMS IN UTTARAKHAND

## 3.1. Introduction

The characteristics of the state of Uttarakhand in India have already been discussed in detail in Chapter 1. Characteristics of the state indicate that the conditions in most areas of the state are not favorable for centralized power plants and grid extension because of hilly terrain, large forest cover and scattered and thinly populated villages. However, solar and biomass based DRESs may be the suitable options to fulfill energy demand in such areas of the state. In rural areas of the state, repair and maintenance concerns may support those DRESs that are either easy to maintain or are almost maintenance free. Based on ease of operation and maintenance and the characteristics of the state of Uttarakhand, it may be inferred that solar water heater, solar home system, solar lantern, solar cooker, solar dryer, solar PV pump, family size biogas plant and improved cookstove are the DRESs that could have significant potential in the state. An attempt to estimate the potential of using DRESs in the state has been made in this chapter.

## 3. 2. Frameworks for Estimation of Potential of using DRESs in Uttarakhand

This section presents frameworks developed for estimating the potential of some of the DRESs namely solar water heater, solar home system, solar lantern, solar cooker, solar dryer and solar PV pump, family size biogas plant and improved cookstove in Uttarakhand. The potential of these DRESs in Uttarakhand would depend on factors such as resource availability, perceived energy need and socio-economic conditions of the adopter households such as purchasing power and awareness. Possibility of changes in: a) resource availability due to varying weather or climatic conditions, b) purchasing power due to higher income, provision of capital subsidy or soft loan, c) awareness levels of potential adopters indicate dynamic aspects of potential estimates. In this study, prevailing conditions with respect to climate, household income, capital subsidy and soft loan schemes have been considered for potential estimation of DRESs in Uttarakhand. Resource availability and energy need aspects have been discussed in subsequent sections as these are DRES specific. However, the impact of purchasing power and awareness on the adoption of all DRESs is more generic. Rural households in Uttarakhand have lesser purchasing power than their urban counterparts. Thus, in this study, the two (rural and urban households) have been considered separately. While developing the framework it has also been assumed that all potential users may not have the propensity to adopt (buy) a DRES because of differences in awareness, spending priorities, etc. and thus a factor of propensity to adopt ($f_{pa}$) has been included in the framework to accommodate the same.

### *3.2.1. Solar Energy based DRESs*

As discussed in Chapter 1, in almost all districts of the state of Uttarakhand both the values of annual average GHI and DNI are greater than 5 kWh/m$^2$/day. Hence, with sufficient resource availability, solar energy based DRES such as domestic solar water heater, solar home system, solar lantern, solar cooker, solar dryer and solar PV pump may be considered for use at almost all locations of the state. However, there may be issues with respect to access to solar radiation particularly in urban areas of the state with higher population density and more number of multi-storeyed buildings compared to the rural areas. On the other hand, houses in rural areas are scattered and seldom multi-storeyed and thus most of the rural households may have access to solar radiation.

#### *3.2.1.1. Domestic Solar Water Heaters*

Domestic solar water heaters (DSWHs) are used by households to meet their hot water requirements for bathing and sometimes for cloth and dish washing as well. In India, people generally take bath during early morning hours. Areas having low ambient temperature during early morning hours and good solar radiation availability throughout the year are suitable for the usage of domestic solar water heaters. The following assumptions have been made in the study for estimating the utilization potential of domestic solar water heater in Uttarakhand:

i. It is assumed that a household in Uttarakhand would take bath during 6-9 am.
ii. Ambient temperatures are the lowest during the early morning hours (IMD, n.d.). As water has high specific heat compared to air, the stored water temperature would lag behind ambient air temperature after sunrise. Thus, it has been assumed in the study that the temperature of water stored in overhead tank between 6-9 am is same as the minimum ambient air temperature. Hence, water heating requirement at a location is gauged from the minimum ambient air temperature recorded for that place.
iii. It is assumed that the areas in Uttarakhand that have monthly average minimum temperature less than 20 °C would need water heating during that month.
iv. It is also assumed that the households located in the areas of the state that have monthly average minimum ambient air temperature less than 20 °C for seven months or more per year are potential users of DSWH [assumption based on Chandrasekar and Kandpal (2004)].
v. The households of the state that have average monthly per capita expenditure (MPCE) higher than the MPCE required to adopt a DSWH are considered as the potential adopters. It is also assumed that such households would have houses (roof structure) and overhead water storage tanks that are suitable for the usage of DSWH.

With the above assumptions, the potential of DSWH in the state of Uttarakhand can be estimated using the following framework:

$$P_{dswh} = N_h \times \left[\left(f_{h(u)} \times f_{hdswh(u)} \times f_{a(u)} \times f_{ppdswh(u)}\right) + \left(f_{h(r)} \times f_{hdswh(r)} \times f_{a(r)} \times f_{ppdswh(r)}\right)\right] \times f_{pa} \qquad \text{(Eqn. 3.1)}$$

where $N_h$ represents the number of households in Uttarakhand, $f_h$ the fraction of households in urban/rural areas of the state, $f_{hdswh}$ the fraction of households situated in locations suitable for DSWH usage in urban/rural areas, $f_a$ the fraction of households having access to solar radiation in urban/rural areas, $f_{ppdswh}$ the fraction of households having the purchasing power to adopt DSWH in urban/rural areas, and $f_{pa}$ the fraction of households having the propensity to adopt a DRES. Subscripts (u) and (r) are used in the framework to represent urban and rural areas respectively.

*3.2.1.2. Solar Home Systems*

Solar home systems (SHSs) can be used to meet basic lighting and other demands in un-electrified households located in remote places with difficulty in grid extension. In Uttarakhand, about 17% and 4% households are un-electrified in rural and urban areas respectively (ORGCC, n.d.). Such un-electrified households may adopt solar home systems. The following are the assumptions used in the study to estimate the potential of solar home system in Uttarakhand:

i. As urban areas generally have better access to grid compared to rural areas, lack of access to grid electricity in urban households may not be due to grid unavailability. It may be due to regulatory issues related to the construction of the house or due to poor purchasing power of the household. Thus, un-electrified households in urban areas may prefer to opt for grid electricity whenever possible as against making an investment in SHS.

ii. In rural areas, un-electrified households may not have electricity due to lack of access to grid infrastructure. Also, due to remote location and difficult terrain (forest, snow and hilly land) in rural areas of Uttarakhand, grid extension to the un-electrified villages may not be viable and thus they may not be electrified in near future. Thus, these un-electrified rural households are potential adopters of solar home systems.

iii. The un-electrified rural households that have average MPCE higher than the MPCE required to adopt an SHS are considered as the potential adopters.

In view of the above, the potential of SHS in the state of Uttarakhand can be expressed as:

$$P_{shs} = N_h \times f_{h(r)} \times f_{ueh(r)} \times f_{a(r)} \times f_{ppshs(r)} \times f_{pa} \qquad \text{(Eqn. 3.2)}$$

where $f_{ueh(r)}$ is the fraction of un-electrified households in rural Uttarakhand and $f_{ppshs(r)}$ the fraction of rural households having the purchasing power to adopt an SHS.

*3.2.1.3. Solar Lanterns*

A solar lantern can either be used for lighting in un-electrified households or as a back-up lighting source in electrified households. As solar lantern is mobile, it can also be used for lighting during outdoor activities. To estimate the potential of solar lanterns in Uttarakhand, the following assumptions have been used in the study:

i. As an un-electrified household may adopt either SHS or solar lantern or both, it is necessary to avoid overlapping among the two. Thus, it is assumed that only those un-electrified rural households would adopt SHS that would have the purchasing power to buy an SHS. Among the rest, only those that have the purchasing power to buy a solar lantern would adopt the lantern.

ii. In un-electrified urban households, due to availability of grid infrastructure in vicinity, the household would be more interested in getting grid electricity as it is economical compared to electricity generated from SHS. Till the time it happens, it may consider adopting solar lantern as it is much cheaper compared to an SHS.

iii. The rural areas of Uttarakhand may not have sufficient street lighting and thus venturing outdoors during night may be difficult for the people residing in such areas. In such cases, battery powered torch and solar lantern may be used for outdoor lighting. In this study, it is assumed that a small fraction of the total electrified rural households may prefer solar lantern as a mobile light source for outdoor activities during night.

iv. Also, the electrified households in both urban and rural areas that face erratic power supply may consider adopting solar lantern as a backup lighting device. However, to avoid double counting of potential adopter households (electrified rural households may adopt solar lantern for outdoor lighting and/or to counter erratic power supply), this has not been considered in the study.

v. All the households of the state (both rural and urban) that may adopt solar lantern and also have average MPCE higher than the MPCE required to adopt a solar lantern are considered as the potential adopters.

With the above assumptions, the potential of solar lantern in the state of Uttarakhand can be expressed as:

$$P_{sl} = N_h \times \left[ \left( f_{h(u)} \times f_{ueh(u)} \times f_{a(u)} \times f_{ppsl(u)} \right) + \left( f_{h(r)} \times f_{ueh(r)} \times f_{a(r)} \times \left(1 - f_{ppshs(r)}\right) \times f_{ppsl(r)} \right) + \left( f_{h(r)} \times \left(1 - f_{ueh(r)}\right) \times f_{sl(r)} \times f_{a(r)} \times f_{ppsl(r)} \right) \right] \times f_{pa} \quad \text{(Eqn. 3.3)}$$

where $f_{ueh}$ is the fraction of unelectrified households in urban/rural areas, $f_{ppsl}$ the fraction of households in urban/rural areas having the purchasing power to adopt solar lantern and $f_{sl(r)}$ the fraction of electrified rural households that may prefer solar lantern for outdoor lighting.

### *3.2.1.4. Dish Type (Paraboloid) Solar Cookers*

A dish type solar cooker uses the direct component of solar radiation to meet the heat energy demand for cooking. Solar cookers are likely to be more suitable to cook lunch. Solar cookers are available in different sizes to satisfy a household or community cooking energy needs. In India, solar cookers have been used for boiling type cooking activities. However, modern day Scheffler solar cookers can perform all types of cooking (both boiling and frying) but they are costlier. Usage of paraboloid solar cooker at households may involve the following challenges: a) lifestyle changes (cooking outdoor under sun); b) inconvenience and complexity as the cooker need to track the sun; c) cooker can’t be used for preparing meal in the evening and night due to lack of solar radiation; d) restrictions with respect to type of cooking (frying may not be performed in all solar cookers). Also, urban households may not have the required space and/or access to solar radiation. Similarly, rural households cooking with low cost fuel wood may not see solar cooker as a viable option. Above all, even if households (both urban and rural) adopt solar cooker, they need to necessarily have a complimentary cooking device to meet cooking energy needs during the period when solar radiation is low or unavailable. Due to these challenges, individual households may be reluctant to adopt solar cookers. However, solar cooker enthusiasts can utilize it at household level for cooking rice, lentils and vegetable and preparing tea and coffee during daytime.

In India, usage of solar cooker at community level has been reported from several temples and schools e.g. Shri Saibaba Sansthan, Shirdi, Maharashtra (MEDA, n.d.). Government of India has been running mid-day meal scheme in primary and secondary schools for several years. The meal prescribed involves rice, lentil and egg and all these involve boiling. The prescribed meal time is also around noon time. With requirement of boiling type cooking around noon time, mid-day meal scheme provide a suitable opportunity for usage of solar cooker at community level. Teachers or staff of the school can take care of the tracking requirements associated with solar cooker. Moreover, usage of solar cooker at schools would have demonstration effect on the students that may encourage them to promote solar cooker among their friends and relatives. Thus, the study focusses on the use of solar cookers at schools in Uttarakhand and assumes that all mid-day meal serving schools of the state are potential adopters of solar cooker. Thus, the expression used to estimate the potential of solar cookers (community) in Uttarakhand is:

$$P_{sc} = N_{smdms} \times A_{sc} \qquad \text{(Eqn. 3.4)}$$

where $N_{smdms}$ represents the number of schools covered under mid-day meal scheme in the state and $A_{sc}$ the average number of solar cooker installed per school.

*3.2.1.5. Solar Dryers*

Solar dryers are used for crop drying to improve its shelf life as with reduced moisture content, it can be preserved for longer period. With about 70% of the rural population of Uttarakhand engaged in agriculture (as main or marginal worker) and sufficient solar radiation (GHI) availability, solar dryers have significant potential in the state. However, due to small landholdings per household, household dryers may face low capacity utilization and thus may not be economical. This study considers potential adoption of solar dryers at community level in Uttarakhand and the assumptions used for estimation of its potential are:

i. A community solar dryer would be used per 25 households in the villages of Uttarakhand.
ii. As villages have been classified as per population range, average population of the villages and average household size would be considered for the estimation of number of households in the villages.

iii. Only one solar dryer would be used if the number of households in a village is less than 25. For other cases, the number of dryers in a village would be rounded off to the nearest whole number.

iv. The issue pertaining to purchasing power has not been considered in this case since for community scale use, other appropriate financing modalities could be adopted.

With the above mentioned assumptions, the potential of solar dryer (community) in the state of Uttarakhand is estimated as:

$$P_{sd} = \sum_i N_{vpr_i} \times \frac{AP_{vpr_i}}{AHS_{(r)} \times 25} \qquad \text{(Eqn. 3.5)}$$

where $N_{vpr_i}$ is the number of villages in the i$^{th}$ population range category, $AP_{vpr_i}$ the average population of villages in i$^{th}$ population range category and $AHS_{(r)}$ the average household size in rural Uttarakhand.

*3.2.1.6. Solar PV Pumps*

As solar PV pump is a costly device (₹ 3 lakhs for a 2 HP pump with 1800 $W_p$ PV system) (Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014), these may not be used by individual households in electrified areas. Even in un-electrified areas (generally remote rural areas), due to its high cost and low purchasing power of households, it may not be preferred by households for personal use. However, in un-electrified remote areas, it may be utilized for community managed domestic use or irrigation water supply. As domestic use of water (including drinking) is of higher priority, in this study community usage of solar PV pump for domestic water supply in un-electrified areas has been considered. The assumptions used to estimate the potential of solar PV pump in Uttarakhand are:

i. As per UPCL, the un-electrified villages in Uttarakhand have difficult terrain and are surrounded by dense forests, steep hills or snowbound areas. It is assumed that such villages would have a natural water stream or an artificial water reservoir (created by rain water harvesting).

ii. With sufficient solar radiation availability, a solar pump in the un-electrified villages would supply water from the stream/reservoir to the households.

iii. As solar PV pump would be dedicated to community drinking water supply, the issue pertaining to purchasing power has not been considered in the study as for community usage, other appropriate financing modalities could be adopted.

In view of above assumptions, the potential of solar PV pump in Uttarakhand can be expressed as:

$$P_{pvp} = N_{uev} \quad \text{(Eqn. 3.6)}$$

where $N_{uev}$ is the number of un-electrified villages in the state.

### *3.2.2. Biomass based DRESs*

In Chapter 1, characteristics of Uttarakhand with respect to forest cover, engagement or rural population in agriculture, cattle holding per household and usage of biomass for cooking in rural households indicate adequate biomass availability in Uttarakhand. Thus, biomass based DRESs such as family size biogas plants and improved cookstoves may be promoted among the households in the state of Uttarakhand.

#### *3.2.2.1. Family Size Biogas Plants*

Family size biogas plants (FSBPs) are generally used in rural households that have adequate cattle holding to feed cattle dung to the plant and sufficient open land adjacent to the house for the installation of the biogas plant. Also, it has been reported that biogas generation falls significantly at low temperatures and biogas plants are reported to be unviable in low temperature regions (annual mean temperature < 20 °C) (GTZ, n.d.). It is also reported that minimum of 2-3 cattle are required to generate sufficient cow dung for satisfactory operation of a family size biogas plant (Singh and Sooch, 2004). The following are the assumptions used in the study to estimate the potential of family size biogas plant in Uttarakhand:

i. The locations in Uttarakhand that have annual mean temperature ≥ 20 °C are suitable locations for installation of biogas plant.
ii. The rural households that are located in the suitable locations and have a minimum cattle holding of 2-3 cattle are the potential users of family size biogas plants.
iii. All the potential users may adopt family size biogas plants provided they have sufficient land for installation of the plant and average MPCE higher than the MPCE required to adopt it.
iv. As the hilly areas of Uttarakhand are ruled out for biogas plant usage due to low annual mean temperatures, it is also assumed that all potential users of family size biogas plants (generally located in plain areas of Uttarakhand) have sufficient water availability to prepare slurry for family size biogas plants.

In view of above considerations, the potential of family size biogas plants in Uttarakhand can be expressed as:

$$P_{bp} = N_{h(r)} \times f_{sh(r)} \times f_{l(r)} \times \left(1 - f_{idh(r)}\right) \times f_{ppbp(r)} \times f_{pa} \quad \text{(Eqn. 3.7)}$$

where $f_{sh(r)}$ is the fraction of suitable households in rural areas that satisfy both temperature and cattle holding criteria, $f_{l(r)}$ the fraction of rural households that have adequate land adjacent to the house, $f_{idh(r)}$ the fraction of suitable households that may not have adequate cow dung due to inefficient collection, and $f_{ppbp(r)}$ the fraction of rural households having the purchasing power to adopt a family size biogas plant.

#### *3.2.2.2. Improved Biomass Cookstoves*

In comparison to traditional biomass cookstoves, improved biomass cookstoves have higher thermal efficiency and thus consumes lesser biomass as fuel. It is convenient for a traditional cookstove user to switch to improved cookstove as it wouldn't require any lifestyle changes. Unlike other DRESs, apart from its primary function (cooking), traditional biomass cookstoves may also be fulfilling other perceived needs of the users such as room heating, lighting, mosquito control, etc. Hence, satisfaction of perceived needs of the users is critical to the adoption of improved biomass cookstoves. Thus, it is assumed that all the households currently using biomass (firewood and crop residue) for cooking may switch to improved biomass cookstoves provided it satisfies the perceived needs of the potential users and the users have the purchasing power to adopt it. The potential of improved cookstoves in Uttarakhand can be expressed as:

$$P_{ic} = N_h \times \left[\left(f_{h(u)} \times f_{bch(u)} \times f_{ppic(u)}\right) + \left(f_{h(r)} \times f_{bch(r)} \times f_{ppic(r)}\right)\right] \times f_{spn} \times f_{pa} \quad \text{(Eqn. 3.8)}$$

where $f_{bch}$ represents the fraction of households in urban/rural areas of the state using biomass for cooking, $f_{ppic}$ the fraction of households having the purchasing power to adopt improved cookstove in urban/rural areas and $f_{spn}$ the fraction of households whose perceived needs are fulfilled by improved biomass cookstoves.

## 3.3. Results and Discussion

Using the framework outlined earlier, the potential of aforementioned DRESs in Uttarakhand have been estimated. Results and analysis regarding the potential estimation of the DRESs have been presented in this section.

### ***3.3.1. Domestic Solar Water Heaters***

Uttarakhand is a hilly state and the elevation levels of locations vary significantly from one location to another. Varying elevation levels impact the ambient temperature of the location. As hot water demand for bathing is assumed to depend on monthly averaged minimum ambient temperature, this study has collected temperature data at sub-district (tehsil) level of the state to internalize the impact of elevation on ambient temperature. List of sub-districts in Uttarakhand has been taken from Census of India, 2011. Based on the latitude and longitude of sub-districts (tehsil), monthly average minimum ambient temperature of the locations has been obtained from (NASA, n.d.). Table 3.1 presents the sub-districts of Uttarakhand that have monthly average minimum ambient temperature less than 20 °C for seven months or more in a year. The number of households located in areas suitable for DSWH usage are presented in Table 3.1 and the same has been used to estimate the values of $f_{hdswh(u)}$ and $f_{hdswh(r)}$. The approach followed to estimate the fraction of rural and urban households having the purchasing power to adopt a DRES like DSWH is presented in Appendix I.

Table 3.1: Estimation of number of households in Uttarakhand with perceived need for water heating (ORGCC, n.d.)

| *District* | *Suitable sub-districts* | *Rural households* | *Urban households* |
|---|---|---|---|
| Uttarkashi | Puraula | 6521 | 0 |
| Uttarkashi | Mori | 7473 | 0 |
| Uttarkashi | Rajgarhi | 12103 | 1509 |
| Uttarkashi | Dunda | 12493 | 0 |
| Uttarkashi | Chiniyalisaur | 9974 | 0 |
| Uttarkashi | Bhatwari | 13350 | 4179 |
| Chamoli | Joshimath | 7610 | 4748 |
| Chamoli | Chamoli | 16328 | 5914 |
| Chamoli | Pokhari | 8244 | 0 |
| Chamoli | Karnaprayag | 9220 | 3984 |
| Chamoli | Tharali | 19739 | 0 |
| Chamoli | Gairsain | 13177 | 0 |
| Rudraprayag | Ukhimath | 18227 | 297 |
| Rudraprayag | Rudraprayag | 19134 | 2363 |
| Rudraprayag | Jakholi | 13521 | 0 |
| Tehri Garhwal | Ghansali | 25127 | 0 |
| Tehri Garhwal | Devprayag | 21397 | 913 |
| Tehri Garhwal | Pratapnagar | 14773 | 0 |
| Tehri Garhwal | Jakhanidhar | 7955 | 0 |
| Tehri Garhwal | Tehri | 18773 | 8146 |
| Tehri Garhwal | Dhanaulti | 12409 | 0 |
| Tehri Garhwal | Narendra Nagar | 15257 | 7964 |

Table 3.1: Estimation of number of households in Uttarakhand with perceived need for water heating (ORGCC, n.d.) (continued…)

| *District* | *Suitable sub-districts* | *Rural households* | *Urban households* |
|---|---|---|---|
| Dehradun | Chakrata | 5399 | 759 |
| Dehradun | Tyuni | 4715 | 0 |
| Dehradun | Kalsi | 6421 | 0 |
| Dehradun | Dehradun | 144112 | 202889 |
| Dehradun | Rishikesh | 28284 | 26233 |
| Garhwal | Srinagar | 8159 | 4669 |
| Garhwal | Pauri | 27830 | 6304 |
| Garhwal | Thailisain | 19679 | 0 |
| Garhwal | Dhoomakot | 9600 | 0 |
| Garhwal | Lansdowne | 17632 | 1200 |
| Garhwal | Satpuli | 8106 | 0 |
| Garhwal | Chaubattakhal | 9539 | 0 |
| Garhwal | Yamkeshwar | 8759 | 1085 |
| Pithoragarh | Munsiari | 11285 | 0 |
| Pithoragarh | Dharchula | 13002 | 1712 |
| Pithoragarh | Didihat | 17613 | 2011 |
| Pithoragarh | Berinag | 12386 | 0 |
| Pithoragarh | Gangolihat | 16412 | 0 |
| Pithoragarh | Pithoragarh | 26273 | 14036 |
| Bageshwar | Kapkot | 13909 | 0 |
| Bageshwar | Kanda | 6342 | 0 |
| Bageshwar | Bageshwar | 20549 | 2054 |
| Bageshwar | Garud | 15192 | 0 |
| Almora | Bhikiasain | 16994 | 0 |
| Almora | Chaukhutiya | 10832 | 0 |
| Almora | Sult | 12778 | 0 |
| Almora | Ranikhet | 17556 | 4760 |
| Almora | Dwarahat | 12419 | 668 |
| Almora | Almora | 26417 | 9940 |
| Almora | Someshwar | 9697 | 0 |
| Almora | Jainti | 6349 | 0 |
| Almora | Bhanoli | 12167 | 0 |
| Champawat | Champawat | 10730 | 1172 |
| Champawat | Pati | 8467 | 0 |
| Champawat | Lohaghat | 16603 | 1846 |
| Champawat | Poornagiri | 9941 | 5194 |
| Nainital | Kosya Kutauli | 6480 | 0 |
| Nainital | Betalghat | 4357 | 0 |
| Nainital | Nainital | 18748 | 12842 |
| Nainital | Dhari | 13836 | 0 |
| Nainital | Haldwani | 24263 | 50012 |
| Nainital | Kaladhungi | 10585 | 1431 |
| Udham Singh Nagar | Bajpur | 26137 | 8186 |
| Total suitable households | | 1029359 | 399020 |

Input values used to estimate the potential of DSWH and the results have been presented in Table 3.2. For estimation, evacuated tube collector (ETC) based DSWH has been considered as it is comparatively cheaper and the current adoption trend in Uttarakhand indicates that ETC DSWH has been preferred over flat plate cFollector (FPC) type. By using the input values and the relevant framework (equation 3.1), the potential of ETC based 100 liters per day (LPD) DSWH has been estimated. Results indicate that DSWH has significant potential in Uttarakhand. It may also be noted from Table 3.2 that in comparison to capital subsidy, soft loan mode of financial support is more effective for large scale adoption of DSWH as the households can repay in smaller installments spread over 5 years. Thus, soft loan improves the purchasing power of households and its impact on purchasing power is very prominent in rural households that generally have lower purchasing power. Hence, it can be inferred that in comparison to capital subsidy mode, soft loan would be more effective in promoting large scale diffusion of DSWH.

### *3.3.2. Solar Home Systems*

As per the framework, equation 3.2 has been used to estimate the potential of SHS in Uttarakhand. In addition to the input values of $N_h$, $f_{h(r)}$, $f_{a(r)}$ and $f_{pa}$ that has been used in earlier section, other relevant input values and the results have been presented in Table 3.3. In Uttarakhand, during the year 2014-15, capital subsidy on SHS and solar lantern has been revised to 30% of the benchmark cost from erstwhile 90% capital subsidy (MNRE, 2014b). As expected, the current scheme of 30% capital subsidy on SHS has significantly reduced its potential users. Results also indicate that soft loan is a better financing option to promote widespread usage of SHS.

Table 3.2: Input values and results for estimation of potential of 100 LPD ETC type DSWH in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference / assumption / estimation* |
|---|---|---|---|
| Total number of households ($N_h$) | Number | 1997068 | ORGCC, n.d. |
| Fraction of households in urban areas ($f_{h(u)}$) | Fraction | 0.30 | ORGCC, n.d. |
| Fraction of households in rural areas ($f_{h(r)}$) | Fraction | 0.70 | ORGCC, n.d. |
| Fraction of suitable households in urban areas ($f_{hdswh(u)}$) | Fraction | 0.67 | Estimation |
| Fraction of suitable households in rural areas ($f_{hdswh(r)}$) | Fraction | 0.73 | Estimation |
| Fraction of urban households having access to solar radiation ($f_{a(u)}$) | Fraction | 0.75 | Assumption |
| Fraction of rural households having access to solar radiation ($f_{a(r)}$) | Fraction | 1.00 | Assumption |
| Fraction of urban households having the purchasing power to adopt an ETC based DSWH with capital subsidy (60% on benchmark cost) ($f_{ppdswh(u)}$) | Fraction | 0.30 | Estimation |
| Fraction of rural households having the purchasing power to adopt an ETC based DSWH with capital subsidy (60% on benchmark cost) ($f_{ppdswh(r)}$) | Fraction | 0.07 | Estimation |
| Fraction of urban households having the purchasing power to adopt an ETC based DSWH with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppdswh(u)}$) | Fraction | 0.50 | Estimation |
| Fraction of rural households having the purchasing power to adopt an ETC based DSWH with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppdswh(r)}$) | Fraction | 0.26 | Estimation |
| Fraction of households having propensity to adopt DRES ($f_{pa}$) | Fraction | 0.70 | Assumption |
| Potential of ETC type DSWH with capital subsidy | Number | 113284 | Estimation |
| Potential of ETC type DSWH with soft loan | Number | 292086 | Estimation |

Table 3.3: Input values and results for estimation of potential of SHS in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference / assumption / estimation* |
|---|---|---|---|
| Fraction of un-electrified households in rural areas ($f_{ueh(r)}$) | Fraction | 0.17 | ORGCC, n.d. |
| Fraction of rural households having the purchasing power to adopt an SHS with capital subsidy (30% on benchmark cost) ($f_{ppshs(r)}$) | Fraction | 0.07 | Estimation |
| Fraction of rural households having the purchasing power to adopt an SHS with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppshs(r)}$) | Fraction | 0.47 | Estimation |
| Fraction of rural households having the purchasing power to adopt an SHS with capital subsidy (90% on benchmark cost) ($f_{ppshs(r)}$) | Fraction | 0.75 | Estimation |
| Potential of SHS with capital subsidy (30% on benchmark cost) | Number | 12157 | Estimation |
| Potential of SHS with soft loan | Number | 78055 | Estimation |
| Potential of SHS with capital subsidy (90% on benchmark cost) | Number | 124326 | Estimation |

### *3.3.3. Solar Lanterns*

In accordance with the framework, equation 3.3 has been used to estimate the potential of solar lantern in Uttarakhand. Apart from the relevant input values cited earlier, other desired values and the results have been presented in Table 3.4. The study has estimated the potential of solar lantern with current capital subsidy scheme (30% of benchmark cost), erstwhile capital subsidy of 90% on benchmark cost and with soft loan. Interestingly, the potential of solar lantern decreases with attractive subsidy schemes (increase in capital subsidy or soft loan). This is due to the fact that both solar lantern and SHS compete with each other as a lighting option and with more attractive financing schemes that applies to both, SHS becomes affordable to more number of households. Thus, it is expected that an un-electrified household in rural area would prefer SHS over solar lantern once SHS becomes affordable. The preference to SHS may be due to its ability to support wider range of electrical/electronic appliances.

Table 3.4: Input values and results for estimation of potential of solar lantern in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference / assumption / estimation* |
|---|---|---|---|
| Fraction of un-electrified households in urban areas ($f_{ueh(u)}$) | Fraction | 0.04 | ORGCC, n.d. |
| Fraction of electrified rural households that may prefer solar lantern for outdoor lighting ($f_{sl(r)}$) | Fraction | 0.10 | Assumption |
| Fraction of urban households having the purchasing power to adopt a solar lantern with capital subsidy (30% on benchmark cost) ($f_{ppsl(u)}$) | Fraction | 1.00 | Estimation |
| Fraction of rural households having the purchasing power to adopt a solar lantern with capital subsidy (30% on benchmark cost) ($f_{ppsl(r)}$) | Fraction | 1.00 | Estimation |
| Fraction of urban households having the purchasing power to adopt a solar lantern with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppsl(u)}$) | Fraction | 1.00 | Estimation |
| Fraction of rural households having the purchasing power to adopt a solar lantern with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppsl(r)}$) | Fraction | 1.00 | Estimation |
| Fraction of urban households having the purchasing power to adopt a solar lantern with capital subsidy (90% on benchmark cost) ($f_{ppsl(u)}$) | Fraction | 1.00 | Estimation |
| Fraction of rural households having the purchasing power to adopt a solar lantern with capital subsidy (90% on benchmark cost) ($f_{ppsl(r)}$) | Fraction | 1.00 | Estimation |
| Potential of solar lantern with capital subsidy (30% on benchmark cost) | Number | 247120 | Estimation |
| Potential of solar lantern with soft loan | Number | 181222 | Estimation |
| Potential of solar lantern with capital subsidy (90% on benchmark cost) | Number | 134952 | Estimation |

### *3.3.4. Dish Type Solar Cookers*

In Uttarakhand, about 17978 schools run mid-day-meal schemes that serve lunch to a total of about 860139 students (average of 48 students per school) for a minimum number of 239 days per year (MHRD, 2013). As per Uttarakhand Renewable Energy Development Agency (UREDA), in the schools covered under mid-day meal scheme in Uttarakhand, generally 2-4 solar cookers have been installed per school (UREDA, 2011; UREDA, 2012). As per equation 3.4, with $N_{smdms}$ equal to 17978 and $A_{sc}$ as 3, Uttarakhand has a potential of 53934 solar cookers.

### *3.3.5. Solar Dryers*

In line with the framework, with $AHS_{(r)}$ value of 5 (ORGCC, n.d.) and other input values ($N_{vpr}$ and $AP_{vpr}$) as presented in Table 3.5, potential of solar dryer has been estimated by using equation 3.5. Results presented in Table 3.5 indicate that community type solar dryer has significant potential in the state of Uttarakhand.

Table 3.5: Classification of villages according to population range and estimation of potential of solar dryer in Uttarakhand (ORGCC, n.d.)

| *Number of villages in Uttarakhand ($N_{vpr}$)* | *Population range category (i)* | *Population range* | *Assumed average population ($AP_{vpr}$)* | *Estimated number of community solar dryers (@ 25 households per solar dryer)* |
|---|---|---|---|---|
| 7823 | 1 | < 200 | 100 | 7823 |
| 4684 | 2 | 200 – 499 | 350 | 13115 |
| 1826 | 3 | 500 – 999 | 750 | 10956 |
| 824 | 4 | 1000 – 1999 | 1500 | 9888 |
| 471 | 5 | 2000 – 4999 | 3500 | 13188 |
| 96 | 6 | 5000 – 9999 | 7500 | 5760 |
| 21 | 7 | ≥ 10000 | 15000 | 2520 |
| Potential of solar dryer in Uttarakhand | | | | 63250 |

### *3.3.6. Solar PV Pumps*

As per CEA (2015), there are about 107 un-electrified villages ($N_{uev}$) in state of Uttarakhand. About 79% of the villages in Uttarakhand have population up to 500 and about 91% of the villages have a population of 999 (ORGCC, n.d.). Average domestic water need per person per day is about 70 liters (Kandpal and Garg, 2003). Thus villages with an average population of 750 persons are considered in the study for estimation of potential of solar PV pump. Such villages would need about 52500 liters water per day for various domestic needs. As per MNRE specifications, a 1800 $W_p$ solar PV pump can supply 57000 liters of water per day from a total head of 30 m with solar radiation of 5.5 kWh/m$^2$/day (MNRE, 2013). As solar radiation availability is sufficient in Uttarakhand, 1800 $W_p$ solar PV pumps can satisfy the domestic water needs of un-electrified villages in the state. Thus, as per equation 3.6, $N_{uev}$ value of 107 represents the potential of solar PV pump in the state of Uttarakhand.

### *3.3.7. Family Size Biogas Plants*

As per the framework outlined (equation 3.7) for the estimation of potential of family size biogas plants in Uttarakhand, rural households of the state that are located in places that have annual mean temperature ≥ 20 °C along with an average cattle (cow or buffalo) holding size ≥ 2-3 are considered as the suitable households that may adopt family size biogas plant provided they have the required purchasing power and propensity to adopt. List of sub-districts (tehsils) in Uttarakhand has been taken from Census of India, 2011. Based on the latitude and longitude of sub-districts attained from GP (n.d.), annual mean temperature of the sub-districts has been obtained from NASA (n.d.). District-wise average cattle holding size of the households has been taken from DAH (2007). This study considers two cases: Case I considers households having average cattle holding size ≥ 3 as suitable households whereas Case II considers households with average cattle holding size ≥ 2 as suitable households for usage of family size biogas plants. For both the cases, estimated number of suitable households has been presented in Table 3.6.

Table 3.6: Suitable households for the usage of family size biogas plants in Uttarakhand

| *Case I* | | | *Case II* | | |
|---|---|---|---|---|---|
| *Sub-districts satisfying both temperature and ≥3 cattle size criteria* | *District* | *No. of rural households in sub-district* | *Sub-districts satisfying both temperature and ≥2 cattle size criteria* | *District* | *No. of rural households in sub-district* |
| Srinagar | Garhwal | 8159 | Devprayag | Tehri Garhwal | 21397 |
| Satpuli | Garhwal | 8106 | Kalsi | Dehradun | 6421 |
| Kotdwara | Garhwal | 26876 | Vikas Nagar | Dehradun | 51355 |
| Bhikiasain | Almora | 16994 | Rishikesh | Dehradun | 28284 |
| Poornagiri | Champawat | 9941 | Srinagar | Garhwal | 8159 |
| Betalghat | Nainital | 4357 | Satpuli | Garhwal | 8106 |
| Haldwani | Nainital | 24263 | Kotdwara | Garhwal | 26876 |
| Ramnagar | Nainital | 19294 | Bhikiasain | Almora | 16994 |
| Kaladhungi | Nainital | 10585 | Poornagiri | Champawat | 9941 |
| Lalkuan | Nainital | 17391 | Betalghat | Nainital | 4357 |
| Number of suitable households in rural Uttarakhand | | 145966 | Haldwani | Nainital | 24263 |
| | | | Ramnagar | Nainital | 19294 |
| | | | Kaladhungi | Nainital | 10585 |
| | | | Lalkuan | Nainital | 17391 |
| | | | Kashipur | Udham Singh Nagar | 27184 |
| | | | Jaspur | Udham Singh Nagar | 21064 |
| | | | Kichha | Udham Singh Nagar | 30465 |
| | | | Gadarpur | Udham Singh Nagar | 27623 |
| | | | Sitarganj | Udham Singh Nagar | 32014 |
| | | | Khatima | Udham Singh Nagar | 34158 |
| | | | Roorke | Hardwar | 108928 |
| | | | Hardwar | Hardwar | 59160 |
| | | | Laksar | Hardwar | 36389 |
| | | | Number of suitable households in rural Uttarakhand | | 630408 |

In addition to the values of input parameters discussed earlier, the values of remaining parameters and the results have been presented in Table 3.7. Results point that family size biogas plants have significant potential in Uttarakhand. Also, soft loan scheme emerges as a better option for widespread adoption of family size biogas plants in Uttarakhand.

Table 3.7: Input values and results for estimation of potential of family size biogas plant (1 $m^3$ fixed dome type) in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference / assumption / estimation* |
|---|---|---|---|
| Fraction of suitable households in rural areas for Case I ($f_{sh(r)}$) | Fraction | 0.10 | Estimation |
| Fraction of suitable households in rural areas for Case II ($f_{sh(r)}$) | Fraction | 0.45 | Estimation |
| Fraction of rural households having the required land (15 $m^2$) adjacent to their household ($f_{l(r)}$) | Fraction | 0.90 | Assumption |
| Fraction of suitable rural households that may not have adequate cowdung to feed the biogas plant in Case I ($f_{idh(r)}$) | Fraction | 0.05 | Assumption |
| Fraction of suitable rural households that may not have adequate cowdung to feed the biogas plant in Case II ($f_{idh(r)}$) | Fraction | 0.40 | Estimation |
| Fraction of rural households having the purchasing power to adopt a family size biogas plant of 1 $m^3$ capacity with capital subsidy (50% on benchmark cost) ($f_{ppbp(r)}$) | Fraction | 0.26 | Estimation |
| Fraction of rural households having the purchasing power to adopt a family size biogas plant of 1 $m^3$ capacity with soft loan (20% margin money, loan on 80% of cost at 5% interest rate for 5 years) ($f_{ppbp(r)}$) | Fraction | 0.36 | Estimation |
| Potential of family size biogas plant with capital subsidy (50% on benchmark cost) in Case I | Number | 22714 | Estimation |
| Potential of family size biogas plant with soft loan in Case I | Number | 31450 | Estimation |
| Potential of family size biogas plant with capital subsidy (50% on benchmark cost) in Case II | Number | 61956 | Estimation |
| Potential of family size biogas plant with soft loan in Case II | Number | 85786 | Estimation |

### *3.3.8. Improved Biomass Cookstoves*

Apart from the input values of $N_h$, $f_{h(u)}$, $f_{h(r)}$ and $f_{pa}$ that have been cited in earlier sections, values of other input parameters and the result of potential estimation has been presented in Table 3.8. As improved cookstove is a low cost DRES (about ₹ 1500) (Project Officer of UREDA, Personal Communication, May 11, 2014), and with capital subsidy, the DRES is affordable to almost all rural and urban households. By putting input values in equation 3.8, result has been obtained that indicates that about 208757 households are the potential users of improved biomass cookstoves in Uttarakhand.

Table 3.8: Input values and result for estimation of potential of improved biomass cookstoves in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference / assumption / estimation* |
|---|---|---|---|
| Fraction of urban households using biomass for cooking ($f_{bch(u)}$) | Fraction | 0.15 | ORGCC, n.d. |
| Fraction of rural households using biomass for cooking ($f_{bch(r)}$) | Fraction | 0.65 | ORGCC, n.d. |
| Fraction of urban households having the purchasing power to adopt an improved cookstove with capital subsidy (50% on benchmark cost) or soft loan ($f_{ppic(u)}$) | Fraction | 1.00 | Estimation |
| Fraction of rural households having the purchasing power to adopt an improved cookstove with capital subsidy (50% on benchmark cost) or soft loan ($f_{ppic(r)}$) | Fraction | 1.00 | Estimation |
| Fraction of households whose perceived needs are fulfilled by improved biomass cookstoves ($f_{spn}$) | Fraction | 0.30 | Assumption |
| Estimated potential of improved cookstove (with capital subsidy or soft loan) | Number | 208757 | Estimation |

## 3.4. Concluding Remarks

Frameworks for the estimation of potential of some DRESs in Uttarakhand have been developed. Using the framework, potential of the DRESs has been estimated. Estimations point that domestic solar water heater, solar home system, solar lantern, solar cooker, solar dryer, solar PV pump, family size biogas plant and improved biomass cookstove have significant potential in the state of Uttarakhand (Table 3.9). As soft loan scheme has greater impact on the purchasing power of households in Uttarakhand than the prevailing subsidy scheme, estimated values of potential of DRESs in Uttarakhand are generally higher with soft loans (Table 3.9). This reflects the effectiveness of soft loan as a financial tool in comparison to capital subsidy for promoting the usage of DRESs.

Table 3.9: Summary of potential of DRESs in Uttarakhand

| *DRES* | *Estimated potential* | | *Remark(s)* |
|---|---|---|---|
| | *with capital subsidy* | *with soft loan* | |
| Domestic solar water heater | 113284 | 292086 | Soft loan increases the purchasing power of households, thereby significantly increasing the estimated value of potential |
| Solar home system | 12157 | 78055 | |
| Solar lantern | 247120 | 181222 | Estimated potential decreases with soft loan provision as some potential users of solar lantern achieve the purchasing power to become potential users of solar home system |
| Solar cooker | 53934 | 53934 | Adopted in community mode with funding from government or other agencies, and thus purchasing power issue is assumed to be insignificant reflecting similar values for estimated potential with capital subsidy and with soft loan. |
| Solar dryer | 63250 | 63250 | |
| Solar PV pump | 107 | 107 | |
| Family size biogas plant | 61956 | 85786 | Soft loan increases the purchasing power of households, thereby significantly increasing the estimated value of potential |
| Improved biomass cookstove | 208757 | 208757 | As the capital cost is low, all households have the purchasing power to adopt it in capital subsidy mode or soft loan mode and thus the values are similar for capital subsidy and soft loan modes. |

# CHAPTER 4

# THEORY OF DIFFUSION OF INNOVATION AND EXPECTED TREND OF DISSEMINATION OF DECENTRALIZED RENEWABLE ENERGY SYSTEMS IN UTTARAKHAND

## 4.1. Theory of Diffusion of Innovation

New technologies or ideas (innovations) such as DRESs have to successfully undergo diffusion process for its large scale utilization. Diffusion is a process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). The four main elements of diffusion are: innovation, communication channels, time and social system.

### *4.1.1. Innovation*

‘An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption. It matters little, so far as human behavior is concerned, whether or not an idea is objectively new as measured by the lapse of time since its first use or discovery. If an idea seems new to the individual, it is an innovation’ (Rogers, 2003).

All innovations should not be assumed as equivalent units of analysis as they exhibit different rates of adoption. The most important characteristics of innovations are relative advantage, compatibility, complexity, trialability and observability. Innovations that are perceived to have greater relative advantage, compatibility, trialability, and observability, and less complexity are expected to be adopted faster than other innovations.

i. Relative advantage is the degree to which an innovation is perceived as superior than the innovation it displaces. Relative advantage may be measured in economic terms, but it may also include factors such as social prestige, convenience, and satisfaction. Perception regarding relative advantage rather than objectivity is more important in diffusion of innovation. The greater the perceived relative advantage of an innovation, the more will be its rate of adoption.

ii. Compatibility is the degree to which an innovation is perceived as being consistent with the existing morals and values of the individual's social system while satisfying the needs of the potential adopters. An idea that is contrary to the values and norms of a social system will not be adopted as readily as an innovation that is coherent with the social system.
iii. Complexity is the perceived degree of difficulty in understanding and usage of an innovation. Some innovations are readily understood by most members of a social system whereas others are more complicated and the adopter is required to develop new skills and understanding prior to its usage. Such complicated innovations are adopted slowly.
iv. Trialability is the degree to which an innovation may be used for a short time on experimental basis. Innovations that can be tried on installment plan are expected to be adopted rapidly.
v. Observability is the degree to which the results of an innovation are visible to others. The more visible are the results of an innovation, the more is the likelihood of its adoption. Such visibility stimulates peer discussion about the innovation as individuals in the adopter's network often enquire about the experience of the adopter with the innovation.

Innovations that are perceived to have greater relative advantage, compatibility, trialability, and observability, and less complexity are expected to be adopted faster than other innovations. Past research indicates that these five attributes of an innovation are the most important factors affecting its rate of adoption among which the first two attributes, relative advantage and compatibility, are particularly very important (Rogers, 2003).

### *4.1.2. Communication Channels*

Diffusion is a special type of communication in which the message is concerned with a new idea. The communication with respect to diffusion involves (a) an innovation, (b) an individual or other unit of adoption having knowledge or experience of the innovation, (c) another individual or other unit unaware of the innovation, and (d) a communication channel connecting the two units. Mass media (radio, television, newspapers) and interpersonal channels are the most common communication channels through which messages are conveyed among different units.

For awareness generation among potential adopters regarding an innovation, mass media channels are usually the most rapid and efficient tool. Interpersonal channels (word of mouth) are found be to be more effective in persuading an individual for adopting an innovation.

### *4.1.3. Time*

Time is the third element in the diffusion process. It is involved in diffusion in: (a) the innovation-decision process in which an individual consumes time from first knowledge of an innovation to its adoption or rejection, (b) the innovativeness (relative earliness) of an individual or other unit of adoption compared with other members of a system, and (c) an innovation's rate of adoption in a system, typically measured as the number of adoptions of the innovation in a given time period.

Innovation-decision process is the process through which an individual (or other decision–making unit) passes from awareness (initial knowledge) regarding an innovation, to development of an attitude toward the innovation, to a decision on adoption or rejection, to implementation and use of the innovation, and to confirmation of this decision. The abovementioned steps involved in innovation-decision process are conceptualized as: knowledge, persuasion, decision, implementation, and confirmation (Table 4.1).

Knowledge is attained when an individual (or other decision-making unit) is aware of the existence of the innovation and has some understanding of its functioning. The innovation-decision process is essentially an information-seeking and information-processing activity in which an individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation. The three types of knowledge involved are: a) awareness-knowledge; b) how-to knowledge; c) principles knowledge. Awareness-knowledge refers to the information that an innovation exists. Awareness-knowledge may motivate an individual to seek how-to knowledge and principles knowledge. How-to knowledge consists of information necessary to use an innovation properly. In case of innovations that are relatively complex, the amount of how-to knowledge needed for adoption is much greater than in the case of less complex ones. And when an adequate level of how-to knowledge is not obtained prior to the trial and adoption of an innovation, rejection and discontinuance are likely to result. Principles knowledge consists of information dealing with the functioning principles underlying how an innovation works. It is usually possible to adopt an innovation without principles knowledge, but the danger of misusing a new idea is greater and discontinuance may result (Rogers, 2003).

In persuasion stage, an individual forms a favorable/unfavorable attitude toward the innovation. Whereas the mental activity at the knowledge stage was mainly cognitive (or knowing), the main type of thinking at the persuasion stage is affective (or feeling). At the persuasion stage the individual becomes more psychologically involved with the innovation. He or she actively seeks information about the new idea, decides what messages he or she regards as credible, and decides how he or she interprets the information that is received. Thus, selective perception is important in determining the individual’s behavior at the persuasion stage, for it is at the persuasion stage that a general perception of the innovation is developed. Such perceived attributes of innovations such as their

Table 4.1: Activities involved in various stages in the innovation-decision process (Rogers, 2003)

| *Stages in the Innovation-Decision Process* | *Activities in the Innovation-Decision Process* |
|---|---|
| Knowledge stage | • Recall of information<br>• Comprehension of messages<br>• Knowledge or skill for effective adoption of the innovation |
| Persuasion stage | • Liking the innovation<br>• Discussion of the new behavior with others<br>• Acceptance of the message about the innovation<br>• Formation of a positive image of the message and the innovation<br>• Support for the innovative behavior from the system |
| Decision stage | • Intention to seek additional information about the innovation<br>• Intention to try the innovation |
| Implementation stage | • Acquisition of additional information about the innovation<br>• Use of the innovation on a regular basis<br>• Continued use of the innovation |
| Confirmation stage | • Recognition of the benefits of using the innovation<br>• Integration of the innovation into one’s ongoing routine<br>• Promotion of the innovation to others |

relative advantage, compatibility, and complexity are especially important at this stage. The main outcome of the persuasion stage in the innovation-decision process is a favorable or unfavorable attitude toward the innovation. It is assumed that such persuasion will lead to a subsequent change in overt behavior (that is, adoption or rejection) consistent with the individual's attitude.

During the process of decision, an individual engages in activities that result in decision about adoption or rejection of the innovation. Adoption is a decision to make full use of an innovation as the best course of action available. Rejection is a decision not to adopt an innovation. The innovation-decision process can just as logically lead to a rejection decision as to adoption.

Implementation occurs when an individual (or other decision-making unit) puts an innovation to use. Until the implementation stage, the innovation-decision process has been a strictly mental exercise of thinking and deciding. But implementation involves overt behavior change as the new idea is actually put into practice. The implementation stage may continue for a lengthy period of time, depending on the nature of the innovation. Eventually a point is reached at which the new idea becomes institutionalized as a regularized part of an adopter's ongoing operations. The innovation loses its distinctive quality as the separate identity of the new idea disappears. This point is considered the end of the implementation stage.

During confirmation, an individual assesses his/her experience regarding usage of the innovation and seeks reinforcement of the adoption decision which may be reversed if the individual is not satisfied with the innovation.  If the adopter's experience is not good, the adopter may go for discontinuance of the innovation. Discontinuance is a decision to reject an innovation after having previously adopted it.

The innovation-decision period is the time duration of the innovation-decision process. Different individuals exhibit different innovation-decision periods as some people require many years to adopt an innovation while others may adopt quickly. Innovativeness is the degree of relative earliness with which an individual adopts an innovation in comparison to other members of the system.

On the basis of innovativeness, the members of a social system may be classified as: (a) innovators, (b) early adopters, (c) early majority, (d) late majority, and (e) laggards. Figure 4.1 depicts the normal frequency distribution among five adopter categories. In the figure, approximate percentage of individuals included in each category is plotted on a normal distribution curve. The first 2.5% of the individuals in a system to adopt an innovation are innovators followed by early adopters which constitute 13.5% of the system. The subsequent 34% of the adopters fall into early majority category followed by another 34% tagged as late majority. The last 16% to adopt are categorized as laggards.

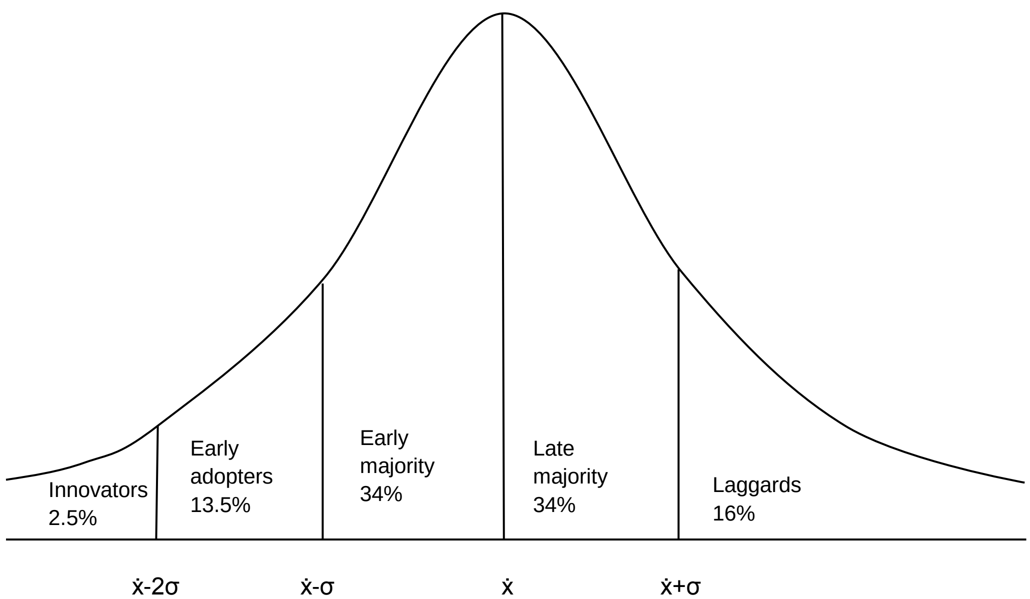


Figure 4.1: Adopter categorization on the basis of innovativeness (Rogers, 2003)

Innovators exhibit obsession for new ideas and this venturesomeness takes them out of their local peer networks to a more cosmopolite social network. Though the innovator may not be respected by members of his/her local system, it is the innovator who launches new ideas in the system by importing the innovation from outside and thus plays a very important role in the diffusion process. Early adopters are a more integral part of the local social system than the innovators and are thus widely followed by others in the system. Innovators are cosmopolites whereas early adopters are localites. Early adopters have the highest degree of opinion leadership in their local systems and members of this adopter category are generally sought by change agents as local missionaries for accelerating the diffusion process. By adopting an innovation early and providing subjecting evaluation of the innovation to the members of the local system, the early adopter decreases uncertainty about a new idea.  Because of their high degree of opinion leadership, early adopters help trigger the critical mass (the point after which further diffusion becomes self-sustaining) when they adopt an innovation. Individuals of the early majority category adopt innovations just ahead of the average member of a system. The early majority exhibit lesser innovativeness compared to innovators and early adopters and may deliberate for some time before adopting a new idea. Though the early majority interacts frequently with their peers, they lack opinion leadership in a system. Individuals of the the late majority group adopt new ideas just after the average member of a system. Both economic necessity and peer pressure triggers adoption of innovation by late majority. Their relatively scarce resources mean that the uncertainty about an innovation should be minimized before the late majority feels safe to adopt. Laggards are the most localite of all adopter categories in their outlook and are the last in a social system to adopt an innovation. Their uncertain economic position compels them to be extremely cautious in adopting new ideas.

Time dimension is also involved in the diffusion of innovations with respect to the rate of adoption of innovation. Rate of adoption is defined as the relative speed with which an innovation is adopted by members of a social system. An S-shaped curve (Figure 4.2) is observed when the cumulative number of individuals adopting an innovation is plotted against time. At the beginning, only few individuals adopt the innovation and these are the innovators. Subsequently, the diffusion curve exhibits sharp rise as more and more adoptions happen in each succeeding time period. Eventually, the trajectory of the curve levels off as fewer and fewer individuals remain who have not yet adopted the innovation. Finally, the S-shaped curve reaches its asymptote resulting in conclusion of the diffusion process.

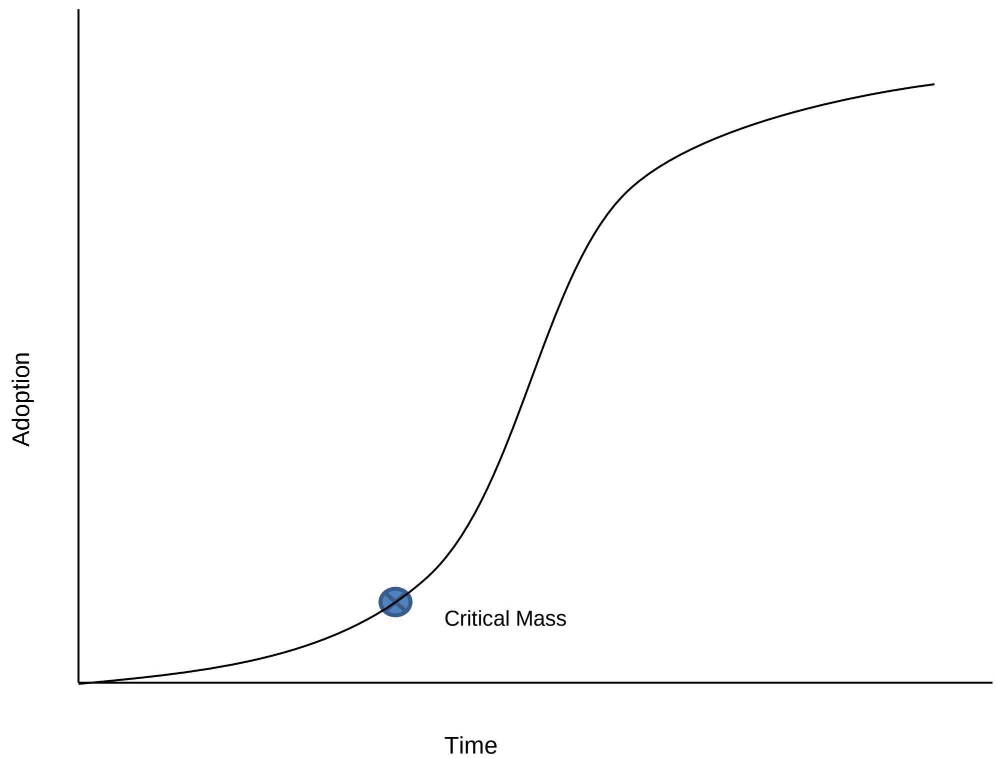


Figure 4.2: S-curve (Rogers, 2003)

A crucial concept in understanding the social nature of the diffusion process is the ‘critical mass’, the point after which further diffusion becomes self-sustaining. The critical mass occurs at the point (depicted in the S-curve) at which enough individuals in a system have adopted an innovation so that the innovation’s further rate of adoption becomes self-sustaining. Earlier adopters of non-interactive innovations have a sequential interdependence effect on later adopters. As more and more individuals in a system adopt, the non-interactive innovation is perceived as increasingly beneficial to future adopters (and this encourages them to adopt). But in the case of interactive innovations, not only do earlier adopters influence later adopters, but later adopters also influence earlier adopters in a process of reciprocal interdependence. The benefits from each additional adoption of an interactive innovation increase not only for all future adopters, but also for each previous adopter. For example, with each additional adopter of the internet, e-mail became slightly more valuable to everyone, as a larger number of other people could be reached by e-mail. So the benefits of an interactive innovation flow backward in time to previous adopters, as well as forward in time to future adopters. The strategies used to reach critical mass for an interactive innovation in a system are: a) targeting highly-respected individuals in a system's hierarchy for initial adoption of the innovation; b) shaping individual's perception of the innovation in desired manner through various mass media mechanisms; c) introducing innovation to an intact group in the system whose members are likely to be relatively more innovative; d) incentivizing early adoptions at least until a critical mass is reached.

#### *4.1.4. Social System*

Diffusion occurs within a social system. A social system is a combination of interrelated units that are pursuing a common goal. Social system may consist of individuals, informal groups, organizations, and/or subsystems. Though the units in a social system are not all identical in their behavior, a structure exists in a system with a patterned arrangement of the units of the system. This structure gives regularity and stability to human behavior in a system; it allows one to predict behavior with some degree of accuracy. Structure of the social system can facilitate or hinder diffusion of innovation. A system's social structure can have overriding effect on the individual characteristics of the members of the system due to peer pressure. For example, individual innovativeness is affected by an individual's characteristics as well as by the nature of the relevant social system. Societal norms, role of opinion leaders and change agents lead to development of social structure.

Social system has direct or indirect impact on the diffusion of innovations. Innovations are adopted or rejected by an individual member of a system or by the entire social system, which decides to adopt an innovation by a collective or an authoritative decision. Based on the adoption of an innovation by an individual or society, the following are the different types of innovation-decisions:

i. Optional innovation-decisions – adoption/rejection decisions made by an individual independent of the decisions of the other members of the system. In this case, the norms of the system and communication through interpersonal networks (social system) indirectly affect the choices made by the individual.

ii. Collective innovation-decisions – adoption/rejection decisions made by consensus among the members of a system. Usually, all units of the system must adhere to the system's decision.

iii. Authority innovation-decisions – adoption/rejection decisions taken by a statutory body or a small group of influential individuals in a system possessing power, status, or technical expertise. An individual member of the system is left with no option but to accept the decision of the authority.

Concepts and results of diffusion research have been utilized extensively in the areas of social psychology, communication, public relations, advertising, marketing, consumer behavior, public health, rural sociology, etc (Rogers, 2003). In this chapter, an attempt has been made to use the concept of diffusion of innovation to study the diffusion of DRESs in Uttarakhand.

### 4.2. Time-trend of Diffusion of DRESs in Uttarakhand

Subsequent to the formation of the state of Uttarakhand in 2000, Uttarakhand Renewable Energy Development Agency (UREDA) was established in July 2001 for the promotion of renewable energy in the state (UREDA, 2015). Through its annual reports (UREDA, n.d., 2005, 2007, 2011a, 2012a), UREDA has been reporting annual diffusion of various DRESs in Uttarakhand since 2003-04. Several DRESs such as solar water heaters, FSBPs, solar lanterns and solar home systems had achieved substantial cumulative dissemination in areas of Uttar

Pradesh that later became part of Uttarakhand. However, as those disseminations can't be corrrelated to the renewable energy promotion programmes of the government of Uttarakhand, they have been ignored. Data for annual capital subsidy disbursed for DRESs is available from the year 2007-08. With the available data, an attempt has been made to depict the time-trend of diffusion of DRESs in Uttarakhand after the formation of the state (Tables 4.2-4.6). The time-trend reflects the following salient features of the diffusion of DRESs in Uttarakhand:

i. Annual subsidy released by UREDA for the promotion of various DRESs (except solar water heater[2]) has been inconsistent over the years. Only solar water heater (SWH) has received consistent subsidy support since 2003-04 reflected by sustained growth in annual subsidy allocated for its promotion.
ii. Assessment of the time-trend of diffusion of DRESs in Uttarakhand has indicated that the dissemination of various DRESs (except SWH) has been highly inconsistent over the years. In the case of SWHs, barring few years, there has been substantial growth in their annual dissemination. In addition, rebate on electricity bill for SWH users has helped the diffusion of SWHs since 2005 (MNRE, 2010). Reasonably strong positive correlation (above 0.65) between diffusion and subsidy of DRESs reflect subsidy driven programme and dependence of diffusion on subsidy (DoS, n.d.). Among all DRESs, the correlation coefficient is highest for solar lanterns (1.00) and solar water heaters (0.91) reflecting strong dependence of their diffusion on subsidy.

[2] In case of solar water heaters, data for dissemination of DSWHs in Uttarakhand and subsidies associated with their promotion is not reported individually but cumulatively for all solar water heaters (domestic, institutional, commercial, and industrial) (UREDA, 2015). Past trend reflect that more than 3/4[th] of the cumulative dissemination (in litres per day) of solar water heaters in Uttarakhand has been in residential and institutional category that have been entitled for similar subsidy benefits (MNRE, 2011). Thus, through the assessment of dissemination of solar water heaters in Uttarakhand, this study makes an attempt to evaluate the trend of dissemination of domestic solar water heaters in the state. Also, this study assesses cumulative diffusion of solar water heaters in litres per day (LPD), as collector area (in $m^2$) for the same LPD solar water heater differs for FPC and ETC type collectors.

iii. Private equity leveraged by government expenditure on capital subsidy is significantly low (as the ratio of private equity leveraged to capital subsidy for all DRESs has been $\leq 1$) reflecting ineffective use of public finance.

Table 4.2: Diffusion pattern of solar water heaters and associated subsidy expenditure (UREDA, n.d., 2005, 2007, 2011a, 2012a; Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014)

| *Year* | *Annual installations* | | *Cumulative installations (LPD)* | *Annual subsidy released (₹)* | *Equity leveraged (₹)* | *Ratio of private equity leveraged to public finance through subsidy* |
|---|---|---|---|---|---|---|
| | *LPD* | *Area $m^2$* | | | | |
| 2003-04 | 13700 | 274 | 301400 | | | |
| 2004-05 | 12500 | 250 | 313900 | | | |
| 2005-06 | 42000 | 780 | 355900 | | | |
| 2006-07 | 68100 | 1222 | 424000 | | | |
| 2007-08 | 41400 | 771 | 465400 | 359650 | 239743 | 0.67 |
| 2008-09 | 151200 | 3024 | 616600 | 868900 | 579209 | 0.67 |
| 2009-10 | 193600 | 3372 | 810200 | 1286100 | 857314 | 0.67 |
| 2010-11 | 167425 | 2999 | 977625 | 7740200 | 5159617 | 0.67 |
| 2011-12 | 316575 | 5224 | 1294200 | 25000000 | 16665000 | 0.67 |
| 2012-13 | 520300 | 8152 | 1814500 | 29334679 | 19554497 | 0.67 |

* Correlation (installations in LPD and subsidy) – 0.91

** Correlation (installations in $m^2$ and subsidy) – 0.90

*** Correlation (subsidy and equity leverage) – 1.00

Table 4.3: Diffusion pattern of FSBPs and associated subsidy expenditure (UREDA, n.d., 2005, 2007, 2011a, 2012a; Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014)

| *Year* | *Annual installations (no.)* | *Cumulative installations (no.)* | *Annual subsidy released (₹)* | *Equity leveraged (₹)* | *Ratio of private equity leveraged to public finance through subsidy* |
|---|---|---|---|---|---|
| 2003-04 | 500 | 4407 | | | |
| 2004-05 | 1198 | 5605 | | | |
| 2005-06 | 998 | 6603 | | | |
| 2006-07 | 751 | 7354 | | | |
| 2007-08 | 825 | 8179 | | | |
| 2008-09 | 1104 | 9283 | | | |
| 2009-10 | 1225 | 10508 | 2680000 | 2680000 | 1 |
| 2010-11 | 2082 | 12590 | 8388200 | 8388200 | 1 |
| 2011-12 | 2114 | 14704 | 8903150 | 8903150 | 1 |
| 2012-13 | 1831 | 16535 | 2500000 | 2500000 | 1 |

* Correlation (installations and subsidy) – 0.79

** Correlation (subsidy and equity leverage) – 1.00

Table 4.4: Diffusion pattern of solar cookers and associated subsidy expenditure (UREDA, n.d., 2005, 2007, 2011a, 2012a; Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014)

| *Year* | *Annual installations (no.)* | *Cumulative installations (no.)* | *Annual subsidy released (₹)* | *Equity leveraged (₹)* | *Ratio of private equity leveraged to public finance through subsidy* |
|---|---|---|---|---|---|
| 2003-04 | 0 | 0 | | | |
| 2004-05 | 50 | 50 | | | |
| 2005-06 | 218 | 268 | | | |
| 2006-07 | 349 | 617 | | | |
| 2007-08 | 215 | 832 | 333000 | 221978 | 0.67 |
| 2008-09 | 885 | 1717 | 1479750 | 986401 | 0.67 |
| 2009-10 | 341 | 2058 | 1149400 | 766190 | 0.67 |
| 2010-11 | 699 | 2757 | 1253210 | 835390 | 0.67 |
| 2011-12 | 44 | 2801 | 620790 | 413819 | 0.67 |
| 2012-13 | 317 | 3118 | 1490152 | 993335 | 0.67 |

* Correlation (installation and subsidy) – 0.69

** Correlation (subsidy and equity leveraged) – 1.00

Table 4.5: Diffusion pattern of solar lanterns and associated subsidy expenditure (UREDA, n.d., 2005, 2007, 2011a, 2012a; Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014)

| *Year* | *Annual dissemination (no.)* | *Cumulative dissemination (no.)* | *Annual subsidy released (₹)* | *Equity leveraged (₹)* | *Ratio of private equity leveraged to public finance through subsidy* |
|---|---|---|---|---|---|
| 2003-04 | 672 | 40535 | | | |
| 2004-05 | 780 | 41315 | | | |
| 2005-06 | 0 | 41315 | | | |
| 2006-07 | 9500 | 50815 | | | |
| 2007-08 | 7500 | 58315 | 33109500 | 3678797 | 0.11 |
| 2008-09 | 1967 | 60282 | 13022575 | 1446938 | 0.11 |
| 2009-10 | 4009 | 64291 | 9961975 | 1106875 | 0.11 |
| 2010-11 | 2673 | 66964 | 57100000 | 6344381 | 0.11 |
| 2011-12 | 0 | 66964 | 0 | 0 | NA |
| 2012-13 | 0 | 66964 | 0 | 0 | NA |

* Correlation (installations and subsidy) – 1.00

** Correlation (subsidy and equity leverage) – 1.00

Table 4.6: Diffusion pattern of solar home systems and associated subsidy expenditure (UREDA, n.d., 2005, 2007, 2011a, 2012a; Project Officer of Uttarakhand Renewable Energy Development Agency, Personal Communication, May 11, 2014)

| *Year* | *Annual installations (no.)* | *Cumulative dissemination (no.)* | *Annual subsidy released (₹)* | *Equity leveraged (₹)* | *Ratio of private equity leveraged to public finance through subsidy* |
|---|---|---|---|---|---|
| 2003-04 | 4776 | 36082 | | | |
| 2004-05 | 0 | 36082 | | | |
| 2005-06 | 0 | 36082 | | | |
| 2006-07 | 9108 | 45190 | | | |
| 2007-08 | 7000 | 52190 | 36888350 | 4098296 | 0.11 |
| 2008-09 | 1791 | 53981 | 45734000 | 5081047 | 0.11 |
| 2009-10 | 3152 | 57133 | 32272250 | 3585447 | 0.11 |
| 2010-11 | 1697 | 58830 | 290000 | 32219 | 0.11 |
| 2011-12 | 0 | 58830 | 0 | 0 | NA |
| 2012-13 | 0 | 58830 | 0 | 0 | NA |

* Correlation (installations and subsidy) – 0.65

** Correlation (subsidy and equity leverage) – 1.00

## 4.3. Technology Diffusion Models

Generally, diffusion of a technology is assessed in terms of cumulative number of adoptions over a period of time. As discussed in earlier section, diffusion follows an exponential growth pattern reflected by an S-shaped curve. These S-shaped curves are characterized by a sluggish early growth, followed by accelerated growth phase and then again a slow growth phase headed for a finite upper limit. Bass model, Gompertz model, Logistic model and Pearl model are the commonly used technology diffusion models (Purohit and Kandpal, 2005; Rao and Kishore, 2010).

*a) Bass model*

Bass developed an empirical diffusion model with an intrinsic assumption that that early adopters influence later adoptions. As per the model (Bass, 1969), cumulative number of adoptions, N(t), of a technology up to a given point of time ($t^{th}$ year) can be estimated as per the following expression:

$$N(t) = M\left[\frac{1-e^{-(a+b)t}}{1+\left(\frac{b}{a}\right)e^{-(a+b)t}}\right] \qquad \text{(Eqn. 4.1)}$$

where $M$ represents estimated potential of the technology in the country, $a$ the coefficient of innovation and $b$ the coefficient of imitation. By utilizing the past data on diffusion of the technology, the values of these coefficients can be estimated.

*b) Gompertz model*

As per Gompertz model (Islam and Haque, 1994), cumulative diffusion, N(t), of the technology disseminated up to the $t^{th}$ year is expressed as:

$$N(t) = Me^{-ae^{-bt}} \qquad \text{(Eqn. 4.2)}$$

Here also, coefficients of $a$ and $b$ can be estimated from regression of past data on the dissemination of technology.

c) *Logistic model*

Logistic model (Islam and Haque, 1994) expresses cumulative diffusion, N(t), of the technology disseminated up to $t^{th}$ year as:

$$N(t) = M\left[\frac{e^{(a+bt)}}{1+e^{(a+bt)}}\right] \qquad \text{(Eqn. 4.3)}$$

and the regression coefficients (a and b) are estimated by a linear regression of the log-log form of equation (4.3) as expressed by equation (4.4).

$$ln\left[\frac{\frac{N(t)}{M}}{1-\frac{N(t)}{M}}\right] = a + bt \qquad \text{(Eqn. 4.4)}$$

d) *Pearl model*

As per Pearl model (Islam and Haque, 1994), the cumulative diffusion, N(t), till $t^{th}$ year can be expressed as:

$$N(t) = \frac{M}{1+ae^{-bt}} \qquad \text{(Eqn. 4.5)}$$

with a and b as the coefficients that can be estimated using regression of past diffusion data.

## 4.4. Estimation of Time Required for the Cumulative Diffusion of DRESs to Reach their Estimated Utilization Potential

Among the diffusion models discussed in the earlier section, logistic model has been frequently used to study the diffusion of renewable energy technologies (Purohit and Michaelowa, 2008). In this study, logistic model (equation 4.4) has been used to estimate the time required for the cumulative diffusion of DRESs to reach their utilization potential in Uttarakhand as estimated in Chapter 3.

Yearly diffusion data of DRESs in Uttarakhand (presented in Tables 4.2-4.6) and the estimated potential of these systems (output of Chapter 3) has been used to fit a curve to equation 4.4. Results of the curve fitting presented in Figures 4.3-4.7 indicate good fit with high $R^2$ values. From the results, coefficients a and b has been obtained for each DRESs. With the values of the coefficients and the estimated potential known, the time required for the cumulative diffusion of the DRESs to reach its estimated potential in Uttarakhand has been estimated by considering cumulative diffusion, N(t), as almost equal to M (i.e. N(t) = 0.999999999999999 M).

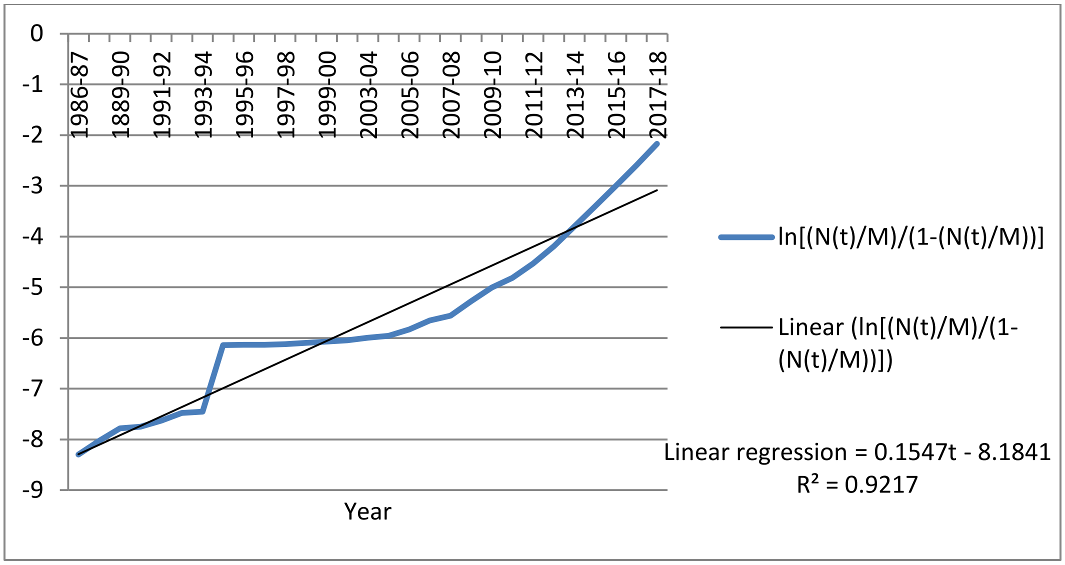


Figure 4.3: Curve fitting for DSWHs[3]

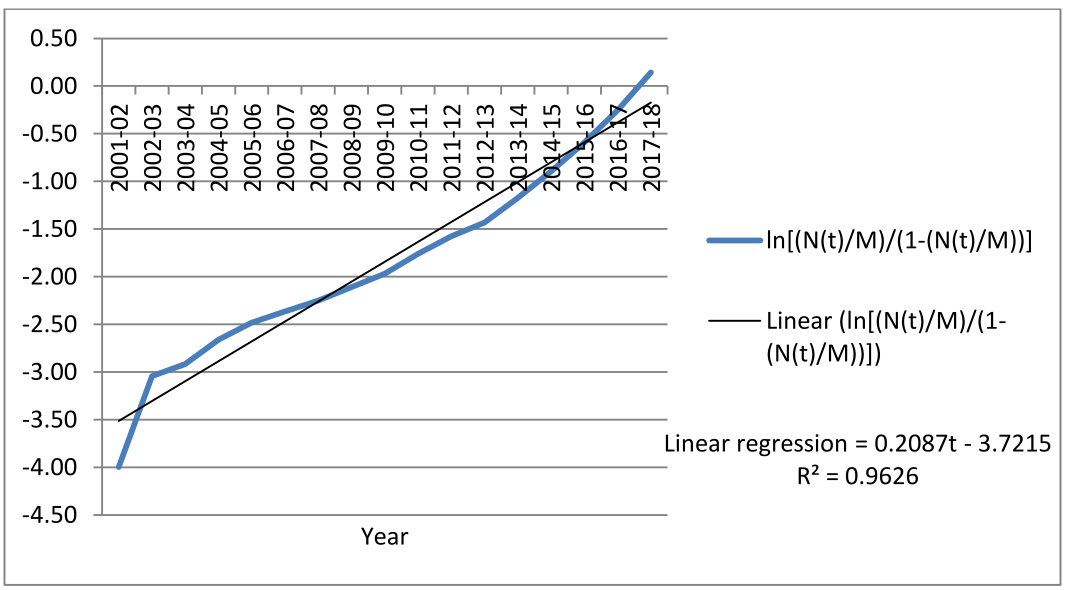


Figure 4.4: Curve fitting for FSBPs

[3] Data for annual dissemination of DSWHs in Uttarakhand has not been reported separately and is reported cumulatively for all solar water heaters since 1986-87 (UREDA, n.d.). Past trend and subsequent future projections indicate 24% share of DSWHs in cumulative dissemination (in $m^2$) of solar water heaters in Uttarakhand (MNRE, 2011) and the same share is assumed for annual dissemination (in LPD) of DSWHs in the state. Also, since data for annual dissemination of solar water heaters (and subsequently DSWHs) in Uttarakhand are available since 1986-87, the same has been used for curve fitting.

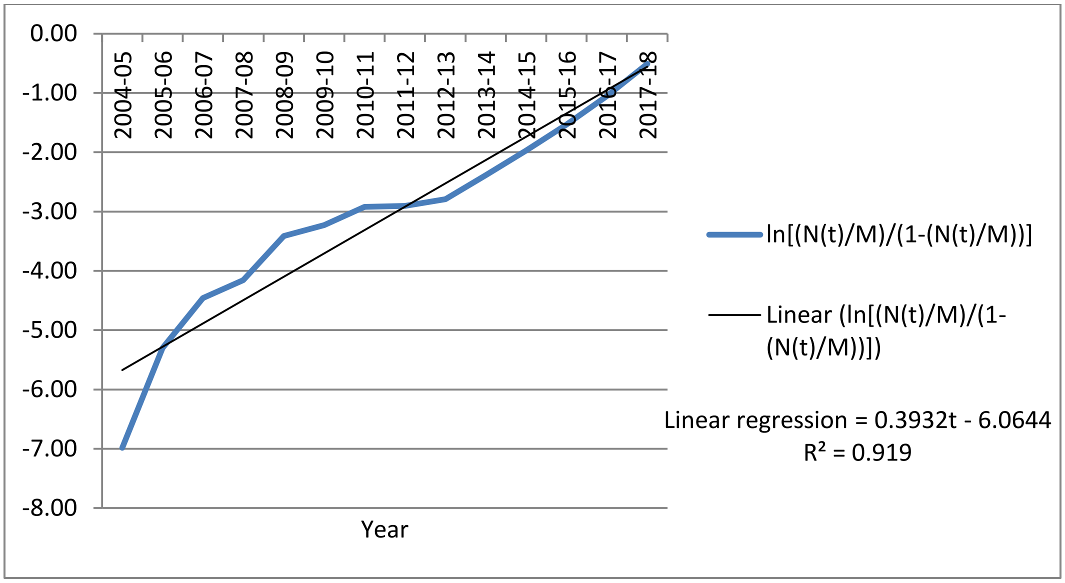


Figure 4.5: Curve fitting for solar cookers

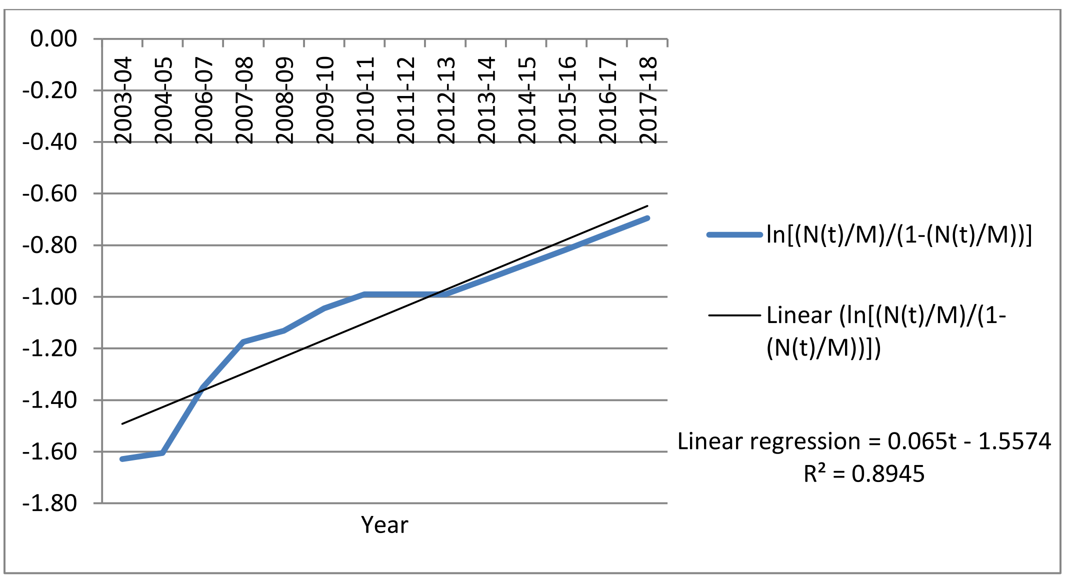


Figure 4.6: Curve fitting for solar lanterns

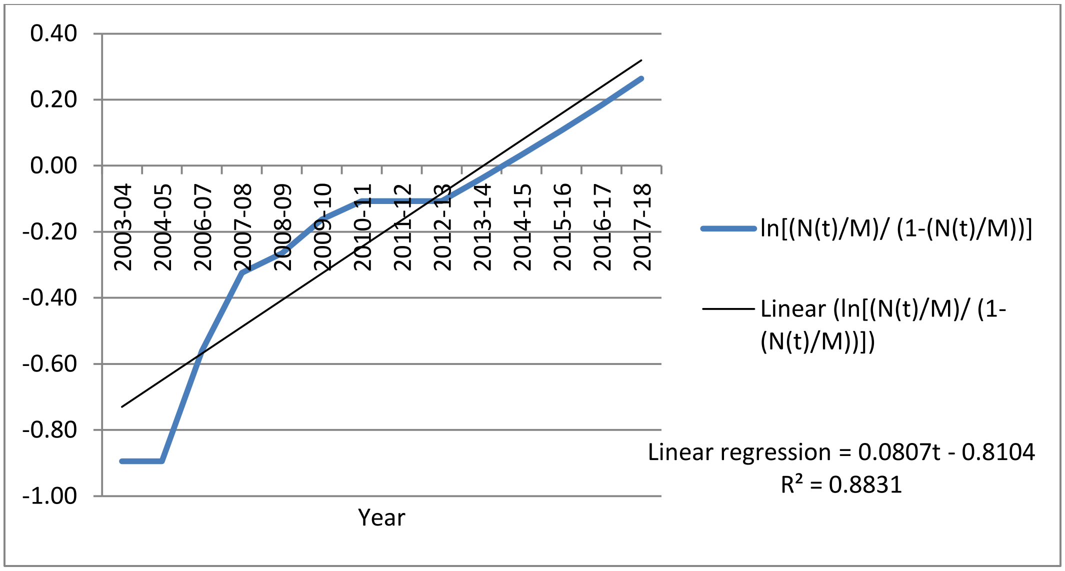


Figure 4.7: Curve fitting for solar home systems

The time durations required for the cumulative diffusion of the DRESs to reach their estimated potential in Uttarakhand have been presented in Table 4.7. Estimated time durations reflect that it may take more than two hundred years for the cumulative diffusion of the DRESs to reach their estimated potential indicating sluggishness and inconsistencies associated with the current trend.

Table 4.7: Estimated time duration by which cumulative diffusion of DRESs will reach their potential

| *DRES* | *Year by which cumulative diffusion will reach its potential* |
|---|---|
| DSWH | 2261-62 |
| FSBP | 2201-02 |
| Solar cooker | 2091-92 |
| Solar lantern | 2415-16 |
| Solar home system | 2326-27 |

### 4.5. Concluding Remarks

From an analysis of time-trend of diffusion of DRESs in Uttarakhand, it is observed that the promotion of various DRESs (except SWH) has been inconsistent over the years. Only SWH has received consistent subsidy support since 2003-04 reflected by sustained growth in annual subsidy allocated for its promotion. A similar trend is reflected in the cumulative annual dissemination of SWHs in Uttarakhand. Reasonably strong positive correlation (above 0.65) between diffusion and subsidy of DRESs indicate the dependence of diffusion on subsidy. Among all DRESs, the correlation coefficient is highest for solar lanterns (1.00) and solar water heaters (0.91), thereby reflecting strong dependence of their diffusion on subsidy. Private equity leveraged by the government expenditure on capital subsidy is significantly low as the ratio of private equity leveraged to capital subsidy for all DRESs has been $\leq 1$. This reflects ineffective use of public finance for the promotion of DRESs.

Based on past dissemination trends of DRESs in Uttarakhand and their estimated potential, time duration has been estimated by which their cumulative diffusion will reach their potential. Estimated time durations reflect sluggishness and inconsistencies associated with current trend emphasizing the need for sustained efforts to accelerate the dissemination of DRESs in Uttarakhand.

# CHAPTER 5

# ASSESSMENT OF BARRIERS FACED BY DECENTRALIZED RENEWABLE ENERGY SYSTEMS ADOPTERS AND NON-ADOPTERS IN UTTARAKHAND

## 5.1. Introduction

Estimated potential of DRESs in Chapter 3 indicate significant potential of DRESs in Uttarakhand. However, study of time-trend of diffusion of DRESs in Chapter 4 has indicated sluggishness in its diffusion in the state. The sluggishness in the diffusion of DRESs may be attributed to barriers as Chapter 2 has concluded that the diffusion of DRESs often faces barriers. The barriers may be similar or different for adopters (those who have adopted one or more DRES(s)) or non-adopters (those who are yet to adopt a DRES). In this chapter, an attempt has been made to assess the barriers faced by DRES adopters and non-adopters in Uttarakhand.

## 5.2. Sample Design for Survey

Assessment of the barriers faced by DRES adopters and non-adopters in Uttarakhand involve getting firsthand information from the adopters and non-adopters that necessitates conduct of survey. For a total number of 19,97,068 households in Uttarakhand, the sample size of the survey has been estimated as 204 households (determined using Yamane’s formula for 95% confidence level, ±7% level of precision and 50% degree of variability)(Yamane, 1967; Israel, 2013). Estimated sample size is in accordance with the sample size recommended by Churchill and Iacobucci (2002). As the geographical area of interest is large and the sampling units are heterogeneous, multi-stage sampling has been used in the study. The various stages of multi-stage sampling is as follows:

First-stage: Among all 13 districts of Uttarakhand, Nainital, Chamoli and Dehradun districts have been considered for sampling as these districts have experienced the maximum dissemination/usage of biogas plants, solar lighting systems and solar water heaters respectively.

Second-stage: Equal number of samples to be selected from each area for total sample size.

Third stage: From the total sample for the three districts, 50% of adopters and 50% non-adopters have been interviewed. For both adopter and non-adopter categories, households have been selected using quota sampling.

A questionnaire has been developed to record the information generated during the survey (Appendix II). The questionnaire attempts to capture information regarding the demography, source of awareness, current energy consumption pattern, usage of DRES (if any), and the opinion about DRES from adopters and non-adopters. For opinion, the responders of the survey have been asked to rate the impact of 11 barriers on the adoption of DRES on a 4-point scale (can't say, not at all, to some extent, to large extent). The barriers listed in the questionnaire have been selected on the basis of literature review (Chapter 2) and pilot study. The listed barriers are: high capital cost, lack of access to capital / loan, availability of cheaper fuel, unavailability of trained manpower for installation and maintenance, lack of user training for maintenance, unavailability of retail shops, unavailability of spares, inappropriateness of technology, poor resource availability, lack of adequate awareness, and lack of socio-cultural acceptability.

### 5.3. Results of Survey

The survey has been conducted during October-December 2014. Data collected during the survey has been analyzed using SPSS. Factor analysis has been conducted to assess the factors critical to the dissemination of DRESs in Uttarakhand. For the analysis, the data has been coded (can't say – 0; not at all – 1; to some extent – 2; to large extent – 3) (Wade, 2006) and results have been generated (Tables 5.1 – 5.5). Cronbach's Alpha value of 0.870 reflects reliability of the scale used in the study (Table 5.2) (George and Mallery, 2003). Results of KMO and Barlett's Test (MSA of 0.769) indicate that adequate number of samples has been taken for factor analysis (Table 5.3) (Kaiser, 1974; Hair et al., 2006). Scree plot (Figure 5.1) suggests that after the third factor, the slope of the curve doesn't change much, and three factors are adequate to explain about 80% variance (Table 5.4). Thus, all the 11 barriers used in the study have been classified under three broad factors. From the rotated component matrix (Table 5.5), it may be noted that the loading of the barriers on three factors are as follows:

i. Factor 1 – high capital cost, lack of access to capital / loan; availability of cheaper fuel, unavailability of trained manpower for installation and maintenance, lack of user training for maintenance, unavailability of retail shops and unavailability of spares
ii. Factor 2 – inappropriateness of technology, poor resource availability
iii. Factor 3 – lack of adequate awareness, lack of socio-cultural acceptability

The barriers listed under Factor 1 reflect economic, supply chain and after sales support aspects of DRES market and thus may be categorized as market barriers. The barriers loaded under Factor 2 deal with technical aspects of resource and technology and thus Factor 2 may be named as technical barrier. Similarly, as Factor 3 has barriers that reflect socio-cultural aspects of potential adopters, it may be termed as socio-cultural barrier. The survey questionnaire also includes questions on source of awareness regarding DRESs and responses have revealed that in rural areas of Uttarakhand, Panchayat Pradhan (elected representative of village in India) has been the main source of awareness to the villagers.

Table 5.1: Case processing summary

| | | N | % |
|---|---|---|---|
| Cases | Valid | 204 | 100.0 |
| | Excluded[a] | 0 | .0 |
| | Total | 204 | 100.0 |

a. Listwise deletion based on all variables in the procedure.

Table 5.2: Reliability statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| .870 | .874 | 11 |

Table 5.3: KMO and Bartlett's Test

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .769 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 2046.827 |
| | df | 55 |
| | Sig. | .000 |

Table 5.4: Total variance explained (Extraction method: Principal component analysis)

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 5.177 | 47.062 | 47.062 | 5.177 | 47.062 | 47.062 | 4.238 | 38.526 | 38.526 |
| 2 | 2.718 | 24.711 | 71.773 | 2.718 | 24.711 | 71.773 | 3.345 | 30.407 | 68.933 |
| 3 | .893 | 8.119 | 79.892 | .893 | 8.119 | 79.892 | 1.205 | 10.959 | 79.892 |
| 4 | .664 | 6.036 | 85.929 | | | | | | |
| 5 | .481 | 4.372 | 90.301 | | | | | | |
| 6 | .370 | 3.367 | 93.668 | | | | | | |
| 7 | .238 | 2.163 | 95.832 | | | | | | |
| 8 | .175 | 1.589 | 97.420 | | | | | | |
| 9 | .135 | 1.232 | 98.652 | | | | | | |
| 10 | .113 | 1.030 | 99.681 | | | | | | |
| 11 | .035 | .319 | 100.000 | | | | | | |

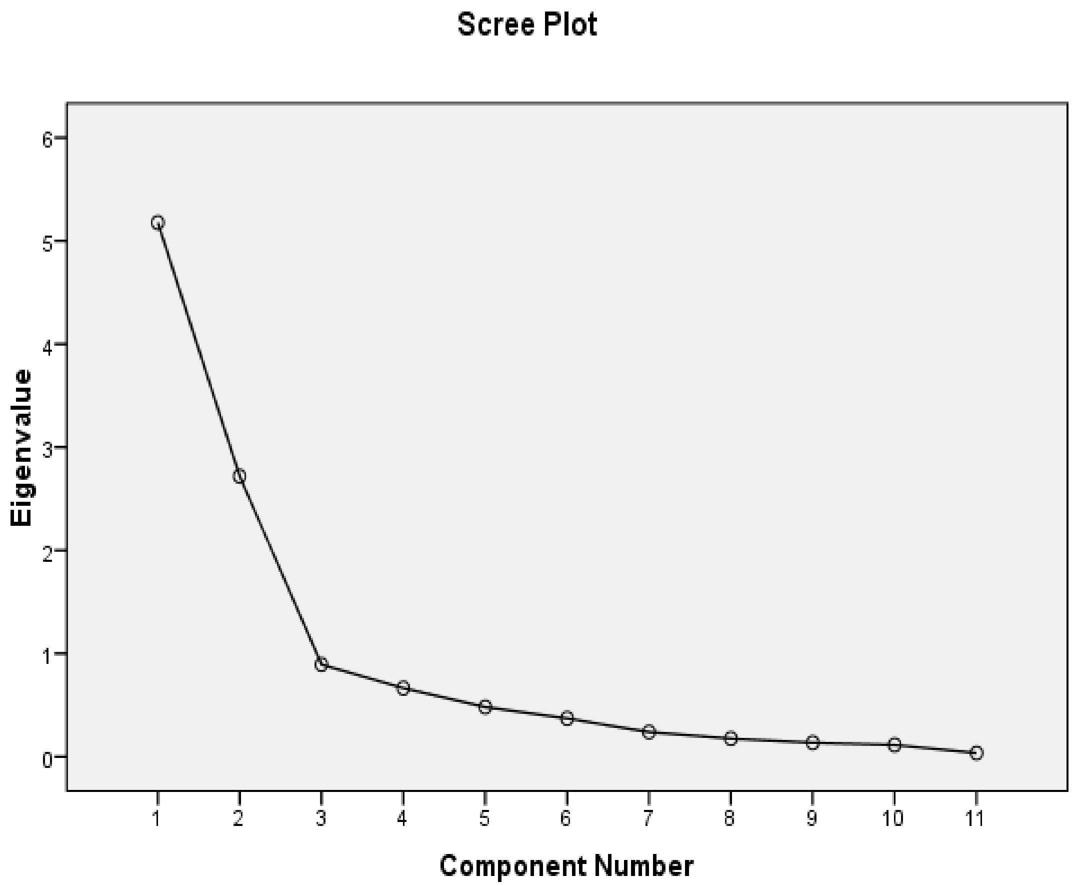


Figure 5.1: Scree plot

Table 5.5: Rotated Component Matrix[a]

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Lack of user training | .887 | | .320 |
| Unavailability of trained manpower for installation and maintenance | .885 | | |
| Lack of access to loan | .822 | | .429 |
| High capital cost | .893 | | |
| Unavailability of spare parts | .659 | .425 | |
| Unavailability of retail shop | .658 | .458 | |
| Lack of socio-cultural acceptability | | | .656 |
| Inappropriateness of technology | | .917 | |
| Poor resource availability | | .889 | |
| Availability of cheaper fuel | .836 | | .260 |
| Awareness issues | .332 | | .895 |

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Apart from rating the impact of barriers the adoption of DRES on a scale, the responders of the survey have also been asked to list three most critical barriers. The responses of both the adopters and non-adopters have been listed in Table 5.6. It may be noted from the table that high capital cost, lack of access to capital /

loan, lack of adequate awareness, unavailability of trained manpower for installation and maintenance, and unavailability of spare parts are the most critical barriers affecting the adoption of DRESs in Uttarakhand. As per the responses, lack of adequate awareness has been considered more critical by the non-adopters. It limits their understanding regarding the utility and functioning of the DRES and available government schemes (subsidy / loan), ultimately resulting in non-adoption. For the adopters of DRESs that need frequent maintenance services such as SHS and FSBP, unavailability of trained manpower for installation and maintenance and unavailability of spares are more critical barriers. High capital cost and lack of access to capital / loan are the barriers that are considered most critical by all categories of responders.

Table 5.6: Criticality of barriers to adoption in the opinion of adopters and non-adopters

| *DRES* | *Adopter / Non-adopter* | *Agree that barriers are hindering the adoption of DRES (% of responses)* | *Critical barrier no. 1 (% of responses)* | *Critical barrier no. 2 (% of responses)* | *Critical barrier no. 3 (% of responses)* |
|---|---|---|---|---|---|
| FSBP | Adopter | 91.18 | Unavailability of trained manpower for installation and maintenance (41.18); inappropriateness of technology (17.65); lack of access to capital / loan (11.76) | Unavailability of trained manpower for installation and maintenance (20.59); high capital cost (20.59); unavailability of spare parts (17.65) | Lack of adequate awareness (17.65); high capital cost (14.71); lack of access to capital / loan (14.71) |
| | Non-adopter | 88.24 | High capital cost (47.06); lack of adequate awareness (26.47); unavailability of land (8.82) | Lack of access to capital / loan (35.29); high capital cost (26.47); lack of adequate awareness (11.76) | Lack of access to capital / loan (17.65); lack of adequate awareness (17.65); unavailability of trained manpower for installation and maintenance (14.71) |
| DSWH | Adopter | 91.18 | Lack of adequate awareness (29.41); high capital cost (26.47); unavailability of retail shops (14.71) | High capital cost (20.59); lack of access to capital / loan (17.65); lack of adequate awareness (14.71) | Unavailability of trained manpower for installation and maintenance (26.47); lack of access to capital / loan (14.71); unavailability of space (11.76) |
| | Non-adopter | 94.12 | High capital cost (50.00); lack of adequate awareness (26.47); unavailability of retail shops (8.82) | High capital cost (32.35); lack of access to capital / loan (32.35); lack of adequate awareness (17.65) | Lack of adequate awareness (26.47); lack of access to capital / loan (20.59) high capital cost (11.76) |
| SHS | Adopter | 97.06 | High capital cost (61.76); unavailability of trained manpower for installation and maintenance (17.65); lack of user training for operation and maintenance (8.82) | Lack of access to capital / loan (26.47); unavailability of trained manpower for installation and maintenance (23.53); unavailability of spare parts (20.59) | Unavailability of spare parts (38.26); unavailability of trained manpower for installation and maintenance (26.47); lack of user training for operation and maintenance (11.76) |
| | Non-adopter | 88.24 | High capital cost (70.59); lack of adequate awareness (8.82) lack of user training for operation and maintenance (5.88) | Lack of access to capital / loan (61.76); high capital cost (11.76); unavailability of retail shops (11.76) | Unavailability of trained manpower for installation and maintenance (52.94); lack of adequate awareness (14.71); unavailability of spare parts (14.71) |

During the survey, responders have also been asked regarding the status of adopted DRESs. It may be noted from Table 5.7 that a substantial no. of SHS and FSBP adopters have discontinued DRES usage because of system failure and lack of repair facility. The problem is reportedly more severe in the case of SHS adopters. As expected, majority of SHS adopters and a

Table 5.7: Status of adopted DRESs and opinion and role of adopters

| *DRES adopted* | *Adopted DRES still in use (%)* | *Adopted DRES not in use (%)* | *Reasons for stopping usage* | *Opinion of adopters (%)* | | | *Experiences (%)* | | *DRES recommended by adopters (%)* | *Conversion of recommendations into adoption (%)* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Poor* | *Acceptable* | *Very good* | *Favorable (if any)* | *Unfavorable (if any)* | | |
| FSBP | 85.29 | 14.71 | System failure and lack of repair facility; dissatisfied with performance due to uncertainty in biogas production | 14.71 | 44.11 | 41.18 | Saves LPG (82.35) | Maintenance issues (8.82); uncertainty in gas production during winter (32.35); system failure and lack of repair facility (14.71) | 41.18 | 85.72 |
| DSWH | 100.00 | 0.00 | NA | 0.00 | 44.11 | 55.89 | Less electricity bill and subsidy on electricity bill (100.00) | Heating problem during cloudy weather (41.18) | 82.35 | 89.29 |
| SHS | 44.11 | 55.89 | System failure and lack of repair facility | 55.89 | 32.35 | 11.75 | Useful for lighting (44.11) | System failure and lack of repair facility (55.89); Maintenance issues (20.58); Unavailability of spares (CFLs) (5.88); Problem during cloudy weather (5.88) | 0.00 | NA |

significant number of FSBP adopters have poor opinion about them. However, all DSWH adopters are using the system and have positive opinion about them. Generally, a satisfied adopter of DRES is expected to promote the system among his neighbors and friends and relatives. The same is reflected from the data gathered during the survey (Table 8). A large number (82%) of DSWH adopters have recommended it to others and almost 90% of them have resulted in its adoption. Though only 40% of FSBP adopters have recommended it to others, conversion of recommendation into adoption is still high (85%). Due to system failure issues in majority of SHS adoptions, none of its adopters have recommended it to other.

### 5.4. Concluding Remarks

High capital cost, lack of access to capital / loan, lack of adequate awareness, unavailability of trained manpower for installation and maintenance, and unavailability of spare parts are the most critical barriers affecting the adoption of DRESs in Uttarakhand. Lack of awareness is a critical barrier to the non-adopters of DRESs whereas the adopters consider unavailability of trained manpower for installation and maintenance and unavailability of spares as more critical. High capital cost and lack of access to capital / loan are the barriers that are considered most critical by all categories of responders.

Recommendations and adoption trends point that a satisfied DRES adopter is more likely to recommend it to others. Also, such recommendations are more likely to result in adoptions. Thus, it may be inferred that DRES promoting institutions can accelerate the rate of adoption of DRES by ensuring effective maintenance services to the adopters. The maintenance services can be improved by countering the barriers namely unavailability of trained manpower for maintenance, unavailability of spare parts and lack of user training for operation and maintenance.

# CHAPTER 6

# ASSESSMENT OF FINANCIAL ATTRACTIVENESS OF DECENTRALIZED RENEWABLE ENERGY SYSTEMS IN UTTARAKHAND

## 6.1. Introduction

Literature review on the barriers to the dissemination of DRESs (Chapter 2) has evidently pointed out that financial or economic barrier is one of the most critical barriers impeding the dissemination of DRESs. Results of the survey presented in Chapter 5 also reaffirm the criticality of financial barrier to the diffusion of DRESs. Considering the importance of financial barrier, and the potential of solar and biomass based DRESs in Uttarakhand (presented in Chapter 3), this chapter is an attempt to assess the financial attractiveness of solar and biomass based DRESs in the state.

## 6.2. Methodology

The DRESs considered in the study are domestic solar water heater, solar home system, solar lantern, family size biogas plant, improved biomass cookstove, solar cooker, solar dryer and solar PV pump. For assessing the financial attractiveness of DRESs in Uttarakhand, input data regarding capital cost, useful life, usage hours or capacity utilization factor, operation and maintenance cost and other parameters are obtained from relevant sources such as Ministry of New and Renewable Energy (MNRE) India, government agencies, manufacturers, distributors and the published literature. In the analysis, the incentive schemes (capital subsidy and/or rebate on electricity bill) currently applicable in Uttarakhand have also been considered.

The measures of financial performance used in the analysis are discounted payback period, net present value, internal rate of return and unit cost of useful energy. Scenario analysis is also performed to assess the financial attractiveness of DRESs under various conditions. The expressions used for estimating the values of different measures of financial performance are presented in the following sections.

### *6.2.1. Expressions for Measures of Financial Performance*

#### *6.2.1.1. Discounted Payback Period*

Discounted payback period (DPP) of an investment in a DRES is the period by which the cumulative present value of net benefits is equal to the capital cost. In case of uniform net annual benefits, the DPP of an investment can be expressed as:

$$\mathrm{DPP} = \frac{\ln(B-C)-\ln[(B-C)-dC_0]}{\ln(1+d)} \qquad \text{(Eqn. 6.1)}$$

where B represents the annual benefit accrued to the DRES user as a result of fuel savings, C the annual cost of operation and maintenance, d the discount rate and $C_0$ the capital cost[4] of the DRES. For various DRESs, the mathematical expressions for estimating B may vary and the same have been presented for each of the DRESs considered in the next section. Annual operation and maintenance cost (C) can be estimated as:

$$C = fC_0 - R \qquad \text{(Eqn. 6.2)}$$

where f represents annual operation and maintenance cost as a fraction of the capital cost of the DRES and R is the annual rebate (if any) to the DRES user (e.g., solar water heater users in several states of India get rebate in their electricity bills for using the heaters).

[4] If any capital subsidy (CS) is available on the purchase of DRES, the effective value of capital cost ($C_0$) for the investment would be $C_0$-CS in expressions (1), (2), (3), (4), and (7) and all these expressions shall be accordingly modified.

*6.2.1.2. Net Present Value*

Net present value (NPV) of an investment in a product is the sum of present value of all cash flows associated with it during its useful life. In the case of uniform net annual benefits accrued as a result of DRES usage, NPV can be expressed as:

$$NPV = (B - C)\left[\frac{(1+d)^n - 1}{d(1+d)^n}\right] - C_0 \qquad \text{(Eqn. 6.3)}$$

where n is the useful life of the DRES.

*6.2.1.3. Internal Rate of Return*

Internal rate of return (IRR) is defined as the discount rate at which the NPV of an investment on DRES is zero. For a uniform series of cash flows (i.e. net annual benefits), IRR can be estimated by solving the following equation:

$$(B - C)\left[\frac{(1+IRR)^n - 1}{IRR(1+IRR)^n}\right] - C_0 = 0 \qquad \text{(Eqn. 6.4)}$$

*6.2.1.4. Levelized Cost of Useful Energy*

Levelized cost of useful energy (LCUE) associated with the usage of a DRES can be estimated as the ratio of total annual cost (AC) to the annual useful energy (AUE) delivered by the DRES.

$$LCUE = \frac{AC}{AUE} \qquad \text{(Eqn. 6.5)}$$

AC can be estimated as the sum of the annualized capital cost ($AC_c$) and annual cost of operation and maintenance (C):

$$AC = AC_C + C \qquad \text{(Eqn. 6.6)}$$

For a defined discount rate (d) and the useful life (n) of a DRES costing $C_0$, the annualized capital cost can be estimated as a product of the capital cost and the capital recovery factor:

$$AC_C = C_0 \frac{d(1+d)^n}{(1+d)^n - 1} \quad \text{(Eqn. 6.7)}$$

### *6.2.2. DRES Specific Expressions for Estimation of Monetary Value of Annual Benefits*

The DRESs considered in the study are expected to satisfy different household needs such as water heating, lighting, cooking, etc. The benefits accrued from usage of such DRESs are different as the amounts and types of fuel substituted could be different and are thus estimated independently for each DRES. In the following sub-sections the expressions for estimation of annual monetary benefits have been presented with $P_f$, $CV_f$, and $\eta_{fu}$ representing the unit price, calorific value and efficiency of fuel utilization of the fuel replaced by the DRES respectively.

#### *6.2.2.1. Domestic Solar Water Heater*

A DSWH is generally used to heat water up to 60 °C to satisfy hot water needs for bathing and washing. There are two types of DSWH: a) design using a flat plate collector (FPC); and b) design using evacuated tubular collector (ETC). Temperature data mined for sub-district regions of the 13 districts of Uttarakhand from NASA database (NASA, n.d.) reflect that majority of the locations in the state have monthly average minimum ambient temperature less than 20 °C for seven months or more in a year. Such low temperatures indicate potential for water heating (and subsequently DSWH) in Uttarakhand. Annual monetary benefits (B) expected to accrue to a household as a result of usage of DSWH to fulfill partial or total water heating needs of the household is estimated as:

$$B = \frac{365 \times CUF_{DSWH} \times M_{DSWH} \times c_{pw} \times (T_2 - T_1) \times P_f}{CV_f \times \eta_{fu}} \quad \text{(Eqn. 6.8)}$$

where $CUF_{DSWH}$ represents the annual capacity utilization factor of the DSWH, $M_{DSWH}$ the daily water heating capacity of the DSWH, $c_{pw}$ the specific heat of water, and $T_1$ and $T_2$ the inlet and outlet (delivery) temperatures of water. The annual useful energy (AUE) delivered by a DSWH can be expressed as:

$$\mathrm{AUE} = 365 \times \mathrm{CUF_{DSWH}} \times \mathrm{M_{DSWH}} \times \mathrm{c_{pw}} \times (\mathrm{T_2} - \mathrm{T_1}) \qquad \text{(Eqn. 6.9)}$$

*6.2.2.2. Family Size Biogas Plant*

A FSBP generates biogas from organic feed-stocks such as animal manure, chicken droppings, agricultural residues etc. through anaerobic digestion. Biogas is environmentally clean and renewable energy source and its chemical composition is – approximately 55-65% methane, 35-40% carbon dioxide and traces of other gases such as hydrogen sulphide and ammonia. Calorific value of biogas is about 20 MJ/$m^3$. Biogas produced by a FSBP may be used for cooking, lighting and other applications. However, in India, it is generally used for cooking. With 0.3-0.4 $m^3$ per person per day biogas requirement for cooking, a 2 $m^3$ capacity FSBP is sufficient to meet the cooking energy needs of a 5 member household (Nijaguna, 2002). In plain areas of Uttarakhand, significant biogas usage for cooking has been reported (ORGCC, n.d.). Annual monetary benefits accrued to the owner of a FSBP as a result of replacement of existing cooking fuel with biogas can be estimated as:

$$\mathrm{B} = \frac{365 \times \mathrm{f_{bp}} \times \mathrm{n_{ph}} \times \mathrm{UER_{pd}} \times \mathrm{P_f}}{\mathrm{CV_f} \times \eta_{\mathrm{fu}}} \qquad \text{(Eqn. 6.10)}$$

where $f_{bp}$ represents the fraction of annual useful energy required for domestic cooking met with biogas, $n_{ph}$ the number of persons per household, and $UER_{pd}$ the useful cooking energy requirement per person per day. Annual useful energy delivered by an FSBP can be expressed as:

$$\mathrm{AUE} = 365 \times \mathrm{f_{bp}} \times \mathrm{n_{ph}} \times \mathrm{UER_{pd}} \qquad \text{(Eqn. 6.11)}$$

*6.2.2.3. Improved Biomass Cookstove*

Improved biomass cookstoves have significantly higher efficiency than traditional cookstoves and their adoption by replacing the traditional cookstoves would result in in saving of biomass presently being used for cooking. With about 63% of the rural households practicing fire-wood based cooking in Uttarakhand (ORGCC, n.d.), the state has significant potential for improved biomass cookstoves. The annual monetary benefit likely to accrue to a user on replacing a traditional biomass cookstove with an improved cookstove can be estimated as:

$$B = \frac{365 \times f_{ic} \times n_{ph} \times UER_{pd} \times P_f}{CV_f} \times \left(\frac{1}{\eta_{tc}} - \frac{1}{\eta_{ic}}\right) \quad \text{(Eqn. 6.12)}$$

where $f_{ic}$ represents the fraction of annual useful energy required for domestic cooking met with improved biomass cookstove, $\eta_{tc}$ and $\eta_{ic}$ the efficiencies of tradition cookstoves and improved cookstoves respectively. Annual useful energy delivered by an improved biomass cookstove can be computed as:

$$AUE = 365 \times f_{ic} \times n_{ph} \times UER_{pd} \quad \text{(Eqn. 6.13)}$$

*6.2.2.4. Paraboloid (Dish) Type Solar Cooker*

A dish type solar cooker is essentially a paraboloid solar cooker that focusses the Direct Normal Irradiance (DNI) component of solar radiation to provide heat to the cooking vessel located at its focal point. With sufficient solar radiation availability in Uttarakhand, households in the state may opt for household type solar cookers. Also, there are about 17978 schools in the state that have mid-day meal schemes (MHRD, 2013) that involve providing cooked meals to the school going children. These mid-day meals can also be prepared with community type paraboloid solar cookers. Cooking of several food items commonly prepared by households and schools in Uttarakhand such as rice, dal (cereals) and vegetables involve boiling type cooking. Usage of dish type solar cooker by a household or community for one or multiple meals per day would lead to replacement of fuels such as LPG, kerosene, fuelwood, etc. Due to such replacements, the solar cooker user would save expenditure on fuel and the annual monetary benefit to such a solar cooker user can be expressed as:

$$B = \frac{n_{mcy} \times UER_{mp} \times n_{mc} \times P_f}{CV_f \times \eta_{fu}} \quad \text{(Eqn. 6.14)}$$

where $n_{mcy}$ represents the number of meals cooked by solar cooker per year, $UER_{mp}$ the useful energy required per meal per person and $n_{mc}$ the average number of persons for whom the meal is cooked. Annual useful energy delivered by a dish type solar cooker can be estimated as:

$$AUE = n_{mcy} \times UER_{mp} \times n_{mc} \quad \text{(Eqn. 6.15)}$$

*6.2.2.5. Solar Lantern*

A solar lantern is a portable lighting device that utilizes GHI component of solar radiation and converts it into electricity to charge a battery that can power a CFL or LED whenever required. There are about 17% unelectrified households in rural areas of the state of Uttarakhand (ORGCC, n.d.) that may be accounted as potential users of solar lantern. A solar lantern generally replaces lighting devices such as kerosene lamp or LPG lamp. The fuel savings as a result of replacement of an LPG/kerosene lamp with a solar lantern would result in annual monetary benefit to the lantern user that can be estimated as:

$$B = 365 \times f_{sl} \times n_{hrld} \times SFC \times P_f \quad \text{(Eqn. 6.16)}$$

where $f_{sl}$ represents the fraction of annual lighting energy demand met with solar lantern, $n_{hrld}$ the number of hours of lighting per day, and SFC the specific fuel consumption of the lighting appliance replaced by solar lighting device.

*6.2.2.6. Solar Home System*

A solar home system has a PV module, charge controller and battery to convert GHI component of solar radiation into electricity that can power multiple electric appliances such as CFLs, LEDs, fans, television, mobile charger, etc. With sufficient solar radiation availability throughout the year and about 17% unelectrified households in rural areas (ORGCC, n.d.), the state of Uttarakhand may have potential for solar lantern and/or solar home system. As solar home systems are significantly costlier compared to solar lanterns, solar home systems would be preferred only by those households that have adequate purchasing power. The SHS generally promoted in Uttarakhand has two lamps (CFLs). As a result of adoption of an SHS and consequent fuel savings, the annual monetary benefit to the SHS user can be estimated as:

$$B = n_l \times 365 \times f_{shs} \times n_{hrld} \times SFC \times P_f \qquad \text{(Eqn. 6.17)}$$

where $n_l$ represents the number of lamps replaced by SHS, and $f_{shs}$ the fraction of annual lighting energy demand met by SHS.

*6.2.2.7. Solar PV Pump*

A solar PV pump consists of a PV module, charge controller, pump and balance of system. It converts GHI component of solar radiation into electricity that is used to energize the pump. In areas that have adequate solar radiation availability throughout the year (e.g. Uttarakhand) along with good rainfall and perennial water streams, it may be used for water pumping. As solar PV pump is a costly device, it may not be widely adopted by individual households due to poor purchasing power in water scarce areas but it may be installed as community pumps. A solar PV pump may replace electric or diesel pump and such replacement would lead to monetary savings as a result of fuel savings. The expected annual monetary benefit due to utilization of a solar PV pump to fulfill the domestic water needs of a village can be estimated as:

$$B = \frac{365 \times f_{sp} \times \rho_w \times g \times V_{wpd} \times n_{pv} \times h \times P_f}{CV_f \times \eta_{fu}} \qquad \text{(Eqn. 6.18)}$$

where $f_{sp}$ represents the fraction of annual water pumping energy requirement met by solar PV pump, $\rho_w$ the density of water (1000 kg/m$^3$), g the acceleration due to gravity (9.8 m/s$^2$), $V_{wpd}$ the volume of water required per person per day for various domestic activities, $n_{pv}$ the number of persons in the village, and h the head for water pumping. The annual useful energy delivered by a solar PV pump is estimated as:

$$AUE = 365 \times f_{sp} \times \rho_w \times g \times V_{wpd} \times n_{pv} \times h \qquad \text{(Eqn. 6.19)}$$

*6.2.2.8. Solar Dryer*

A solar dryer is a heat transfer device that utilizes solar energy to dry organic materials such as fruits, vegetables, herbs, etc. that enhances their shelf lives. As the state of Uttarakhand produces varieties of agricultural products and it also has adequate solar radiation availability throughout the year, solar dryers may be used in the state to increase the shelf life of agricultural products. For effective drying, it may be necessary to either adopt a fossil fuel / biomass based dryer or adopt solar drying. In this study, it is assumed that use of a solar dryer would save fuel consumption in the proposed fossil fuel / biomass based drying that need to be adopted otherwise. Hence, adoption of solar dryer would result in fuel savings. As per Kumar and Kandpal (2005), the annual monetary benefit to the solar dryer user can be expressed as:

$$B = \left[s(T_d - T_a) + \left(\frac{M_i - M_f}{1 - M_f}\right) h_{fg}\right] \frac{M_{sd} \times n_{ly} \times P_f}{CV_f \times \eta_{fu}} \qquad \text{(Eqn. 6.20)}$$

where s represents the specific heat of wet crop, $T_d$ the drying temperature, $T_a$ the ambient temperature, $M_i$ and $M_f$ the initial and final moisture contents (in fraction) of the crop on wet basis respectively, $h_{fg}$ the enthalpy of evaporation of water at the drying temperature, $M_{sd}$ the capacity of solar dryer (mass of crop dried on wet basis), and $n_{ly}$ the number of loadings per year. Annual useful energy delivered by a solar dryer can be estimated as:

$$\mathrm{AUE} = \left[s(T_d - T_a) + \left(\frac{M_i - M_f}{1 - M_f}\right) h_{fg}\right] \times M_{sd} \times n_{ly} \qquad \text{(Eqn. 6.21)}$$

## 6.3. Results and Discussion

For financial analysis of the DRESs considered in the study, values of relevant input parameters such as subsidized/unsubsidized price of fuel(s), calorific value of fuel(s), efficiency of fuel utilization, etc. are presented in Table 6.1. In case of availability of multiple values for a parameter, the study has considered values that lead to conservative estimates of NPV and IRR. DRES specific input data such as capital cost, subsidy, useful life, operation and maintenance cost, etc. and subsequent results of financial analysis are presented in the following subsections.

Table 6.1: General input parameters for financial analysis of DRESs in Uttarakhand

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Price of subsidized domestic LPG | ₹ per 14.2 kg LPG cylinder | 433.50 | Indane, n.d. |
| Price of unsubsidized domestic LPG | ₹ per 14.2 kg LPG cylinder | 755.00 | Indane, n.d. |
| Price of subsidized electricity (domestic category) | ₹ per kWh | 2.30 | UPCL, 2013 |
| Price of subsidized electricity (pumps – domestic, agriculture) | ₹ per kWh | 1.10 | UPCL, 2013 |
| Price of unsubsidized electricity | ₹ per kWh | 4.55 | Planning Commission, 2011 |
| Price of subsidized kerosene | ₹ per liter | 14.15 | DFCS, 2015 |
| Price of unsubsidized kerosene | ₹ per liter | 50.00 | Kerosene Vendor, Personal Communication, May 12, 2014 |
| Price of subsidized fuelwood | ₹ per kg | 1.60 | UFDC, n.d. |
| Price of unsubsidized fuelwood | ₹ per kg | 10.00 | Fuelwood Vendor, Personal Communication, May 27, 2014 |
| Calorific value of fuelwood | kJ per kg | 16000 | Chandrasekar and Kandpal, 2004 |
| Efficiency of fuelwood | % | 10 | Chandrasekar and Kandpal, 2004 |

Table 6.1: General input parameters for financial analysis of DRESs in Uttarakhand (continued…)

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| utilization in traditional cookstove | | | |
| Density of kerosene | kg per liter | 0.81 | Pathak et al., 2009 |
| Calorific value of kerosene | kJ per kg | 44500 | Chandrasekar and Kandpal, 2004 |
| Efficiency of kerosene utilization in kerosene stove | % | 40 | Chandrasekar and Kandpal, 2004; Ravindranath and Ramakrishna, 1997 |
| Calorific value of LPG | kJ per kg | 45000 | Chandrasekar and Kandpal, 2004 |
| Efficiency of LPG stove | % | 60 | Chandrasekar and Kandpal, 2004; Ravindranath and Ramakrishna, 1997 |
| Efficiency of electric geyser | % | 90 | Chandrasekar and Kandpal, 2004 |
| Density of diesel | kg per liter | 0.845 | SIAM, n.d.; BEE, 2011 |
| Calorific value of diesel | kJ per kg | 42700 | Kandpal and Garg, 2003 |
| Price of subsidized diesel | ₹ per liter | 62.21 | IOCL, n.d. |
| Price of unsubsidized diesel | ₹ per liter | 65.61 | PPAC, 2014 |
| Discount rate | % | 10.95 | CERC, 2013 |
| Energy required for cooking in rural areas per person per day | kJ per person per day | 2130 | Kandpal and Garg, 2003 |
| Number of persons per household in Uttarakhand | number | 5 | ORGCC, n.d. |
| Number of hours of lighting requirement per day | hr | 4 | Kandpal and Garg, 2003; Mahapatra et al., 2009 |
| Rate of consumption of LPG in an LPG lamp | kg per hr | 0.03 | Kandpal and Garg, 2003; Mahapatra et al., 2009 |
| Rate of consumption of kerosene in a kerosene (hurricane) lantern | liter per hr | 0.04 | Kandpal and Garg, 2003; Mahapatra et al., 2009 |
| Efficiency of pump used with solar PV system | % | 40 | Purohit and Kandpal, 2005 |
| Efficiency of diesel pump | % | 40 | Kandpal and Garg, 2003 |
| Efficiency of electric-motor-pumpset | % | 52 | Purohit and Kandpal, 2005 |

### *6.3.1. Domestic Solar Water Heater*

To assess the financial attractiveness of a DSWH in Uttarakhand, input data is presented in Table 6.2. For various combinations of capacity utilization factor (CUF), capital subsidy and subsidy on fuel, financial attractiveness of a DSWH has been assessed and the results are presented in Tables 6.3 – 6.4. Breakeven values of CUF and price of fuel substituted have also been estimated and the results of the same are presented in Tables 6.5 – 6.6.

Table 6.2: Input values for financial analysis of 100 liters per day (LPD) DSWH

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost<br>FPC<br>ETC | <br>₹<br>₹ | <br>24000<br>18000 | <br>RAF, n.d.<br>SES, n.d.; SS, n.d. |
| Capital subsidy<br>FPC<br>ETC | <br>₹<br>₹ | <br>13200<br>7650 | <br>MNRE, 14c; UREDA, n.d.a<br>MNRE, 14c; UREDA, n.d.a |
| Useful life<br>FPC<br>ETC | <br>Years<br>Years | <br>20<br>15 | <br>AS, n.d.<br>AS, n.d. |
| Annual operation and maintenance cost as a fraction of its capital cost<br>FPC<br>ETC | <br>Fraction<br>Fraction | <br>0.02<br>0.02 | <br>Chandrasekar and Kandpal, 2004<br>Chandrasekar and Kandpal, 2004 |
| Inlet temperature of water | °C | 15 | Assumption based on MNRE's specification |
| Outlet temperature of water | °C | 60 | MNRE, n.d.a |
| Specific heat of water | kJ per Kg °C | 4.20 | Nag, 2005 |
| Rebate in electricity bill to consumers using 100 LPD DSWH | ₹ per month | 100 | UPCL, 2013 |

Results of financial analysis of DSWH show that its usage is a financially viable option in all conditions (with/without capital subsidy on DSWH and subsidy of fuel price) with the prevailing rebate provision. As expected, its usage becomes financially more attractive for users not availing any kind of subsidy in the price of electricity or any other fuel used for water heating at household level. Also, both ETC and FPC are competitive and ETC type DSWH has marginal edge over FPC type. Estimated breakeven values of CUF and fuel prices also suggest financial viability of DSWH in Uttarakhand. However, in the absence of electricity bill rebate and capital subsidy on DSWH, higher CUF (around 0.70) is critical for its financial viability.

Table 6.3: Measures of financial performance of DSWH with subsidized fuel and rebate in electricity bill

| *Type of DSWH* | *CUF (in fraction)* | *LCUE (Rs/MJ)* | *Discounted Payback Period (years)* | | | | *NPV (₹)* | | | | *IRR (%)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* |
| Without capital subsidy | | | | | | | | | | | | | | |
| ETC | 0.40 | 0.60 | 11.72 | 6.63 | 7.80 | 7.63 | 2181.72 | 10554.46 | 7584.56 | 7954.41 | 13 | 21 | 18 | 18 |
| | 0.50 | 0.48 | 8.80 | 5.17 | 6.05 | 5.92 | 5712.89 | 16178.82 | 12466.45 | 12928.76 | 16 | 25 | 22 | 23 |
| | 0.60 | 0.40 | 7.10 | 4.25 | 4.95 | 4.85 | 9244.06 | 21803.17 | 17348.33 | 17903.10 | 20 | 30 | 26 | 27 |
| | 0.70 | 0.34 | 5.96 | 3.61 | 4.19 | 4.11 | 12775.23 | 27427.53 | 22230.21 | 22877.45 | 23 | 35 | 30 | 31 |
| | 0.80 | 0.30 | 5.15 | 3.14 | 3.64 | 3.57 | 16306.40 | 33051.89 | 27112.09 | 27851.79 | 26 | 39 | 34 | 35 |
| FPC | 0.40 | 0.83 | 38.15 | 11.10 | 14.00 | 13.55 | -2597.63 | 6679.27 | 3388.66 | 3798.45 | 09 | 15 | 13 | 13 |
| | 0.50 | 0.66 | 17.02 | 8.10 | 9.84 | 9.58 | 1314.86 | 12910.99 | 8797.72 | 9309.96 | 12 | 19 | 16 | 17 |
| | 0.60 | 0.55 | 12.20 | 6.42 | 7.67 | 7.49 | 5227.36 | 19142.71 | 14206.79 | 14821.47 | 14 | 22 | 19 | 20 |
| | 0.70 | 0.47 | 9.66 | 5.33 | 6.32 | 6.18 | 9139.85 | 25374.43 | 19615.86 | 20332.99 | 16 | 25 | 22 | 23 |
| | 0.80 | 0.41 | 8.05 | 4.56 | 5.38 | 5.26 | 13052.35 | 31606.14 | 25024.92 | 25844.50 | 19 | 29 | 25 | 26 |
| With capital subsidy | | | | | | | | | | | | | | |
| ETC | 0.40 | 0.22 | 5.00 | 3.24 | 3.70 | 3.64 | 9831.72 | 18204.46 | 15234.56 | 15604.41 | 26 | 38 | 34 | 34 |
| | 0.50 | 0.17 | 4.07 | 2.63 | 3.01 | 2.95 | 13362.89 | 23828.82 | 20116.45 | 20578.76 | 31 | 46 | 41 | 41 |
| | 0.60 | 0.14 | 3.43 | 2.21 | 2.53 | 2.49 | 16894.06 | 29453.17 | 24998.33 | 25553.10 | 36 | 53 | 47 | 48 |
| | 0.70 | 0.12 | 2.97 | 1.91 | 2.19 | 2.15 | 20425.23 | 35077.53 | 29880.21 | 30527.45 | 41 | 61 | 54 | 55 |
| | 0.80 | 0.11 | 2.62 | 1.68 | 1.92 | 1.89 | 23956.40 | 40701.89 | 34762.09 | 35501.79 | 46 | 68 | 60 | 61 |
| FPC | 0.40 | 0.23 | 5.61 | 3.54 | 4.07 | 4.00 | 10602.37 | 19879.27 | 16588.66 | 16998.45 | 24 | 35 | 32 | 32 |
| | 0.50 | 0.18 | 4.50 | 2.85 | 3.27 | 3.21 | 14514.86 | 26110.99 | 21997.72 | 22509.96 | 29 | 43 | 38 | 39 |
| | 0.60 | 0.15 | 3.76 | 2.38 | 2.73 | 2.68 | 18427.36 | 32342.71 | 27406.79 | 28021.47 | 34 | 50 | 44 | 45 |
| | 0.70 | 0.13 | 3.23 | 2.04 | 2.35 | 2.31 | 22339.85 | 38574.43 | 32815.86 | 33532.99 | 38 | 57 | 51 | 51 |
| | 0.80 | 0.11 | 2.83 | 1.79 | 2.06 | 2.02 | 26252.35 | 44806.14 | 38224.92 | 39044.50 | 43 | 64 | 57 | 58 |

Table 6.4: Measures of financial performance of DSWH with unsubsidized fuel and rebate in electricity bill

| *Type of DSWH* | *CUF (in fraction)* | *LCUE (Rs/MJ)* | *Discounted Payback Period (years)* | | | | *NPV (₹)* | | | | *IRR (%)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* |
| Without capital subsidy | | | | | | | | | | | | | | |
| ETC | 0.40 | 0.60 | 5.21 | 3.63 | 2.02 | 1.11 | 15999.34 | 27239.40 | 57058.89 | 112415.63 | 25 | 34 | 58 | 100 |
| | 0.50 | 0.48 | 4.10 | 2.87 | 1.61 | 0.89 | 22984.92 | 37034.99 | 74309.36 | 143505.28 | 31 | 42 | 71 | 124 |
| | 0.60 | 0.40 | 3.38 | 2.38 | 1.34 | 0.74 | 29970.49 | 46830.58 | 91559.82 | 174594.93 | 37 | 50 | 84 | 148 |
| | 0.70 | 0.34 | 2.88 | 2.03 | 1.14 | 0.63 | 36956.07 | 56626.17 | 108810.28 | 205684.57 | 42 | 57 | 98 | 172 |
| | 0.80 | 0.30 | 2.51 | 1.77 | 1.00 | 0.55 | 43941.64 | 66421.76 | 126060.75 | 236774.22 | 48 | 65 | 111 | 196 |
| FPC | 0.40 | 0.83 | 8.17 | 5.36 | 2.84 | 1.52 | 12712.13 | 25165.98 | 58205.62 | 119540.23 | 19 | 25 | 43 | 75 |
| | 0.50 | 0.66 | 6.15 | 4.14 | 2.23 | 1.21 | 20452.06 | 36019.38 | 77318.93 | 153987.18 | 23 | 31 | 53 | 93 |
| | 0.60 | 0.55 | 4.95 | 3.38 | 1.84 | 1.00 | 28192.00 | 46872.78 | 96432.24 | 188434.14 | 27 | 37 | 63 | 111 |
| | 0.70 | 0.47 | 4.15 | 2.86 | 1.57 | 0.86 | 35931.93 | 57726.18 | 115545.54 | 222881.10 | 31 | 43 | 73 | 129 |
| | 0.80 | 0.41 | 3.57 | 2.48 | 1.37 | 0.75 | 43671.86 | 68579.57 | 134658.85 | 257328.06 | 35 | 48 | 83 | 147 |
| With capital subsidy | | | | | | | | | | | | | | |
| ETC | 0.40 | 0.22 | 2.65 | 1.92 | 1.11 | 0.62 | 23649.34 | 34889.40 | 64708.89 | 120065.63 | 45 | 61 | 101 | 175 |
| | 0.50 | 0.17 | 2.14 | 1.55 | 0.89 | 0.50 | 30634.92 | 44684.99 | 81959.36 | 151155.28 | 55 | 74 | 124 | 216 |
| | 0.60 | 0.14 | 1.80 | 1.30 | 0.75 | 0.42 | 37620.49 | 54480.58 | 99209.82 | 182244.93 | 64 | 87 | 147 | 258 |
| | 0.70 | 0.12 | 1.55 | 1.12 | 0.64 | 0.36 | 44606.07 | 64276.17 | 116460.28 | 213334.57 | 74 | 100 | 170 | 300 |
| | 0.80 | 0.11 | 1.36 | 0.98 | 0.56 | 0.31 | 51591.64 | 74071.76 | 133710.75 | 244424.22 | 83 | 113 | 193 | 341 |
| FPC | 0.40 | 0.23 | 2.86 | 2.05 | 1.18 | 0.66 | 25912.13 | 38365.98 | 71405.62 | 132740.23 | 43 | 57 | 95 | 166 |
| | 0.50 | 0.18 | 2.30 | 1.65 | 0.94 | 0.52 | 33652.06 | 49219.38 | 90518.93 | 167187.18 | 52 | 70 | 117 | 206 |
| | 0.60 | 0.15 | 1.92 | 1.38 | 0.79 | 0.44 | 41392.00 | 60072.78 | 109632.24 | 201634.14 | 60 | 82 | 140 | 246 |
| | 0.70 | 0.13 | 1.65 | 1.18 | 0.67 | 0.38 | 49131.93 | 70926.18 | 128745.54 | 236081.10 | 69 | 95 | 162 | 286 |
| | 0.80 | 0.11 | 1.45 | 1.04 | 0.59 | 0.33 | 56871.86 | 81779.57 | 147858.85 | 270528.06 | 78 | 107 | 184 | 326 |

Table 6.5: Breakeven values of CUF (in fraction) for DSWH with/without rebate

| | | *With rebate* | | | | | | | | *Without rebate* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Subsidized fuel* | | | | *Unsubsidized fuel* | | | | *Subsidized fuel* | | | | *Unsubsidized fuel* | | | |
| | | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* | *Electricity* | *LPG* | *Kerosene* | *Biomass* |
| Without capital subsidy | ETC | 0.34 | 0.21 | 0.24 | 0.24 | 0.17 | 0.19 | 0.07 | 0.04 | 0.58 | 0.37 | 0.42 | 0.41 | 0.29 | 0.21 | 0.12 | 0.07 |
| | FPC | 0.47 | 0.29 | 0.34 | 0.33 | 0.24 | 0.23 | 0.10 | 0.05 | 0.71 | 0.45 | 0.51 | 0.51 | 0.36 | 0.26 | 0.15 | 0.08 |
| With capital subsidy | ETC | 0.12 | 0.08 | 0.09 | 0.09 | 0.06 | 0.12 | 0.02 | 0.01 | 0.37 | 0.23 | 0.27 | 0.26 | 0.19 | 0.13 | 0.08 | 0.04 |
| | FPC | 0.13 | 0.08 | 0.09 | 0.09 | 0.07 | 0.12 | 0.03 | 0.01 | 0.37 | 0.23 | 0.27 | 0.27 | 0.19 | 0.13 | 0.08 | 0.04 |

Table 6.6: Breakeven values of fuel price for DSWH with/without rebate

| | *CUF (in fraction)* | *with rebate* | | | | | | | | *without rebate* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Without capital subsidy* | | | | *With capital subsidy* | | | | *Without capital subsidy* | | | | *With capital subsidy* | | | |
| | | *Electricity (₹/kWh)* | *LPG (₹/kg)* | *Kerosene (₹/l)* | *Biomass (₹/kg)* | *Electricity (₹/kWh)* | *LPG (₹/kg)* | *Kerosene (₹/l)* | *Biomass (₹/kg)* | *Electricity (₹/kWh)* | *LPG (₹/kg)* | *Kerosene (₹/l)* | *Biomass (₹/kg)* | *Electricity (₹/kWh)* | *LPG (₹/kg)* | *Kerosene (₹/l)* | *Biomass (₹/kg)* |
| ETC | 0.40 | 1.94 | 16.21 | 8.65 | 0.96 | 0.70 | 5.83 | 3.11 | 0.35 | 3.35 | 27.95 | 14.92 | 1.66 | 2.11 | 17.57 | 9.38 | 1.04 |
| | 0.50 | 0.48 | 12.96 | 6.92 | 0.77 | 0.17 | 4.66 | 2.49 | 0.28 | 2.68 | 22.36 | 11.94 | 1.32 | 1.69 | 14.05 | 7.50 | 0.83 |
| | 0.60 | 1.30 | 10.80 | 5.77 | 0.64 | 0.47 | 3.88 | 2.07 | 0.23 | 2.24 | 18.63 | 9.95 | 1.10 | 1.41 | 11.71 | 6.25 | 0.69 |
| | 0.70 | 1.11 | 9.26 | 4.95 | 0.55 | 0.40 | 3.33 | 1.78 | 0.20 | 1.92 | 15.97 | 8.53 | 0.95 | 1.20 | 10.04 | 5.36 | 0.59 |
| | 0.80 | 0.97 | 8.10 | 4.33 | 0.48 | 0.35 | 2.91 | 1.56 | 0.17 | 1.68 | 13.97 | 7.46 | 0.83 | 1.05 | 8.78 | 4.69 | 0.52 |
| FPC | 0.40 | 2.68 | 22.35 | 11.93 | 1.32 | 0.74 | 6.18 | 3.30 | 0.37 | 4.09 | 34.09 | 18.20 | 2.02 | 2.15 | 17.92 | 9.57 | 1.06 |
| | 0.50 | 0.66 | 17.88 | 9.55 | 1.06 | 0.18 | 4.95 | 2.64 | 0.29 | 3.27 | 27.27 | 14.56 | 1.62 | 1.72 | 14.34 | 7.66 | 0.85 |
| | 0.60 | 1.79 | 14.90 | 7.96 | 0.88 | 0.49 | 4.12 | 2.20 | 0.24 | 2.73 | 22.73 | 12.14 | 1.35 | 1.43 | 11.95 | 6.38 | 0.71 |
| | 0.70 | 1.53 | 12.77 | 6.82 | 0.76 | 0.42 | 3.53 | 1.89 | 0.21 | 2.34 | 19.48 | 10.40 | 1.15 | 1.23 | 10.24 | 5.47 | 0.61 |
| | 0.80 | 1.34 | 11.17 | 5.97 | 0.66 | 0.37 | 3.09 | 1.65 | 0.18 | 2.05 | 17.04 | 9.10 | 1.01 | 1.08 | 8.96 | 4.79 | 0.53 |

### *6.3.2. Family Size Biogas Plant*

Input data used for assessment of financial attractiveness of FSBP is presented in Table 6.7. Results of the assessment are presented in Table 6.8. The results indicate that Deenbandhu model of FSBP is financially more rewarding for the user. Also, for a user having access to cooking fuel(s) such as kerosene and LPG at subsidized rates, owning a Khadi and Village Industries Commission (KVIC) model biogas plant would not be financially viable and the household would incur loss as its NPV is negative even with the provision of capital subsidy on it. However, for the case of users purchasing cooking fuels at prevailing market prices, both KVIC and Deenbandhu model biogas plants are expected to be financially profitable. Breakeven values also favor investments in Deenbandhu model as the values are significantly lower for it compared to the KVIC model due to substantially higher capital cost of KVIC model biogas plant (Table 6.9).

Table 6.7: Input values for financial analysis of 2 $m^3$ FSBP

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | | | |
| KVIC model | ₹ | 32000 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Deenbandhu model | ₹ | 26000 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Capital subsidy | ₹ | 10000 | Project Officer of UREDA, Personal Communication, May 11, 2014; UREDA, n.d.b |
| Useful life | Years | 25 | Singh and Sooch, 2004 |
| Annual operation and maintenance cost as a fraction of its capital cost | | | |
| KVIC model | Fraction | 0.07 | Kandpal and Garg, 2003 |
| Deenbandhu model | Fraction | 0.045 | Kandpal and Garg, 2003 |
| Fraction of annual useful energy required for domestic cooking met with biogas ($f_{bp}$) (considering 300 days of domestic cooking energy demand met with biogas per year) | Fraction | 0.82 | Assumption based on inputs from existing users |

Table 6.8: Measures of financial performance of FSBP (2 $m^3$)

| *Scheme* | *Type of FSBP* | *LCUE (₹/MJ)* | *Discounted Payback Period (years)* | | | *NPV (₹)* | | | *IRR (%)* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* |
| With subsidized fuel | | | | | | | | | | | |
| Without capital subsidy | KVIC | 1.89 | - | - | - | -23927.78 | -20398.83 | -24429.77 | -2 | 1 | -3 |
| | Deenbandhu | 1.33 | - | - | - | -8883.51 | -5354.56 | -9385.50 | 6 | 8 | 6 |
| With capital subsidy | KVIC | 1.52 | - | - | - | -13927.78 | -10398.83 | -14429.77 | 1 | 4 | 0 |
| | Deenbandhu | 0.96 | 19.28 | 12.16 | 21.36 | 1116.49 | 4645.44 | 614.50 | 12 | 15 | 11 |
| With unsubsidized fuel | | | | | | | | | | | |
| Without capital subsidy | KVIC | 1.89 | 2.12 | 19.26 | 4.86 | 117853.78 | 2247.06 | 42720.01 | 55 | 12 | 28 |
| | Deenbandhu | 1.33 | 1.58 | 7.81 | 3.26 | 132898.04 | 17291.33 | 57764.28 | 72 | 19 | 38 |
| With capital subsidy | KVIC | 1.52 | 1.41 | 8.69 | 3.06 | 127853.78 | 12247.06 | 52720.01 | 81 | 18 | 40 |
| | Deenbandhu | 0.96 | 0.94 | 4.03 | 1.87 | 142898.04 | 27291.33 | 67764.28 | 117 | 32 | 62 |

- Undefined numbers

Table 6.9: Breakeven values of number of days in a year during which FSBP satisfies full cooking need of the household ($n_{dbpy}$) and fuel price for replaced fuel

| *Scheme* | *Type of FSBP* | *Breakeven value of number of days in a year* | | | | | | *Breakeven value of fuel price* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *For subsidized fuel* | | | *For unsubsidized fuel* | | | *Biomass (₹/kg)* | *LPG (₹/kg)* | *Kerosene (₹/l)* |
| | | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* | | | |
| Without capital subsidy | KVIC | 566** | 500* | 577** | 91 | 287 | 163 | 3.02 | 50.92 | 27.19 |
| | Deenbandhu | 399** | 353 | 406** | 64 | 202 | 115 | 2.13 | 35.88 | 19.16 |
| With capital subsidy | KVIC | 455** | 402** | 463** | 73 | 231 | 131 | 2.43 | 40.92 | 21.85 |
| | Deenbandhu | 288 | 254 | 293 | 46 | 146 | 83 | 1.53 | 25.88 | 13.82 |

* Illogical values as these indicate more than 365 days cooking per year.

### *6.3.3. Improved Biomass Cookstove*

Input data used for assessment of financial viability of improved biomass cookstove is presented in Table 6.10. The results of financial assessment of improved biomass cookstove (Table 6.11) indicate that improved cookstoves are financially rewarding for the user as the NPV and IRR values obtained for all scenarios (with/without capital subsidy or fuel subsidy) are very attractive. Even the breakeven values of fuelwood price and number of days of operation per year (Table 6.12) are much lower indicating its financial attractiveness. For example, even for subsidized fuel and without capital subsidy scenario, the estimated breakeven value of number of days of its utilization is less than three months per year. Such low breakeven value can accommodate uncertainties in improved biomass cookstove usage due to unavailability of usable firewood because of rain, forest fire, etc. From the results of breakeven analysis for the fuelwood price, it is noted that even for a negligibly small value of Rs 0.34/kg, the cumulative present value of net benefits accrued to the user breaks even with the cost. This implies that if an improved biomass cookstove satisfies the perceived need of the user with the declared efficiency of utilization, then the low price of the biomass would not matter in its adoption.

Table 6.10: Input values for financial analysis of improved biomass cookstove (natural draft type)

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | ₹ | 1794 | Quote received from isquareD for Chulika Biomass Stove, Personal Communication, May 20, 2014 |
| Capital subsidy | ₹ | 300 | MNRE, n.d.b |
| Useful life | Years | 5 | MNRE, n.d.b |
| Annual operation and maintenance cost (excluding fuel cost) as a fraction of its capital cost | Fraction | 0.00 | Kandpal and Garg, 2003 |
| Thermal efficiency | | | |
| Traditional biomass cookstove | % | 10.00 | Chandrasekar and Kandpal, 2004; Kandpal and Garg, 2003 |
| Improved biomass cookstove | % | 24.10 | MNRE, n.d.b |
| Fraction of annual useful energy required for domestic cooking met with biogas ($f_{ic}$) (considering 365 days of domestic cooking energy demand met with improved biomass cookstove per year) | Fraction | 1.00 | Assumption based on inputs from existing users |

Table 6.11: Measures of financial performance of improved biomass cookstoves

| *Scheme* | | *LCUE (₹/MJ)* | *Discounted payback period (Years)* | *NPV (₹)* | *IRR (%)* |
|---|---|---|---|---|---|
| Subsidized fuel | Without capital subsidy | 0.54 | 0.87 | 6622.10 | 125 |
| | With capital subsidy | 0.46 | 0.72 | 6922.10 | 151 |
| Unsubsidized fuel | Without capital subsidy | 2.72 | 0.13 | 50806.62 | 792 |
| | With capital subsidy | 2.64 | 0.11 | 51106.62 | 951 |

Table 6.12: Breakeven values for fuelwood price and number of days of improved biomass cookstove operation per year

| *Scheme* | *Fuelwood price (₹/kg)* | *No. of days of operation per year* | |
|---|---|---|---|
| | | *Subsidized fuelwood* | *Unsubsidized fuelwood* |
| Without capital subsidy | 0.34 | 78 | 12 |
| With capital subsidy | 0.28 | 65 | 10 |

### *6.3.4. Dish Type (Parabolic) Solar Cooker*

Relevant input data for the assessment of financial attractiveness of dish type solar cooker has been obtained from various sources and are presented in Table 6.13. Results of financial assessment (Table 6.14) indicate that community type solar cooker is more appealing compared to the household type solar cooker under all scenarios considered. Under subsidized fuel scenario, community solar cooker is found to be viable even without capital subsidy whereas household type needs capital subsidy to be viable. As expected, for unsubsidized fuel scenario, both household and community type solar cookers become financially attractive option. In Table 6.15, breakeven values also reflect the same pattern.

Table 6.13: Input values for financial analysis of household and community type solar cooker

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | | | |
| Household type (1.5 $m^2$) | ₹ | 8800 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Community type (4.0 $m^2$) | ₹ | 30000 | Project Officer of UREDA, Personal Communication, May 11, 2014; MNRE, n.d.c |
| Capital subsidy | | | |
| Household type (1.5 $m^2$) | ₹ | 5280 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Community type (4.0 $m^2$) | ₹ | 16800 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Useful life of household and community type solar cooker | Years | 15 | MNRE, n.d.d |
| Annual operation and maintenance cost as a fraction of its capital cost for both household and community type solar cooker | Fraction | 0.03 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Number of meals cooked by solar cooker per year | Number | 250 | Assumption based on inputs from existing users |
| Energy requirement in cooking per meal per person | kJ | 983 | Ravindranath and Ramakrishna, 1997 |
| Average number of persons for whom meal is cooked | | | |
| Household type | Number | 5 | Assumption based on inputs from existing users |
| Community type | Number | 40 | Assumption based on inputs from existing users |

Table 6.14: Measures of financial performance of solar cooker

| *Scheme* | *Type of solar cooker* | *LCUE (₹/MJ)* | *Discounted Payback Period (years)* | | | *NPV (₹)* | | | *IRR (%)* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* |
| With subsidized fuel | | | | | | | | | | | |
| Without capital subsidy | Household | 1.21 | 64.79 | 18.67 | - | -1843.42 | -685.63 | -2008.11 | 7 | 10 | 7 |
| | Community | 0.51 | 4.41 | 3.73 | 4.53 | 34392.10 | 43654.43 | 33074.56 | 29 | 34 | 28 |
| With capital subsidy | Household | 0.53 | 4.91 | 4.04 | 5.06 | 3436.58 | 4594.37 | 3271.89 | 27 | 31 | 26 |
| | Community | 0.24 | 1.70 | 1.47 | 1.74 | 51192.10 | 60454.43 | 49874.56 | 68 | 77 | 66 |
| With unsubsidized fuel | | | | | | | | | | | |
| Without capital subsidy | Household | 1.21 | 1.34 | 5.70 | 2.65 | 44672.75 | 6744.11 | 20022.61 | 84 | 23 | 45 |
| | Community | 0.51 | 0.54 | 1.89 | 1.00 | 406521.46 | 103092.33 | 209320.36 | 202 | 61 | 111 |
| With capital subsidy | Household | 0.53 | 0.51 | 1.90 | 0.98 | 49952.75 | 12024.11 | 25302.61 | 211 | 61 | 114 |
| | Community | 0.24 | 0.23 | 0.78 | 0.43 | 423321.46 | 119892.33 | 226120.36 | 459 | 140 | 251 |

- Undefined number

Table 6.15: Breakeven values of number of meals cooked by solar cooker in a year ($n_{mcy}$) and breakeven values of fuel price for replaced fuel

| *Scheme* | *Type of solar cooker* | *Breakeven value of number of meals cooked per year* | | | | | | *Breakeven value of fuel price* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *For subsidized fuel* | | | *For unsubsidized fuel* | | | *Biomass (₹/kg)* | *LPG (₹/kg)* | *Kerosene (₹/l)* |
| | | *Biomass* | *LPG* | *Kerosene* | *Biomass* | *LPG* | *Kerosene* | | | |
| Without capital subsidy | Household | 302 | 267 | 308 | 48 | 153 | 87 | 2 | 33 | 17 |
| | Community | 129 | 114 | 131 | 21 | 65 | 37 | 1 | 14 | 7 |
| With capital subsidy | Household | 153 | 135 | 156 | 24 | 78 | 44 | 1 | 17 | 9 |
| | Community | 69 | 61 | 71 | 11 | 35 | 20 | 0 | 8 | 4 |

### *6.3.5. Solar Lantern*

Input data used for assessment of financial viability of solar lantern for potential users in Uttarakhand has been obtained from relevant sources and the same are presented in Table 6.16. Results of financial assessment (Table 6.17) indicate that solar lanterns (both CFL and LED based) are viable under all scenarios (with/without capital subsidy and with subsidized/unsubsidized fuel being replaced). However, LED based solar lanterns are found to be financially more rewarding. The same trend is reflected by the breakeven values in Table 6.18.

Table 6.16: Input values for financial analysis of solar lantern

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | | | |
| 7 W CFL based | ₹ | 2700 | MNRE, 2013a; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| 5 W LED based | ₹ | 2250 | MNRE, 2013a; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Capital subsidy | | | |
| 7 W CFL based | ₹ | 810 | MNRE, 2014b; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| 5 W LED based | ₹ | 675 | MNRE, 2014b; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Useful life (both CFL and LED based solar lantern) | Years | 20 | Kandpal and Garg, 2003 |
| Annual operation and maintenance cost as a fraction of its capital cost (both CFL and LED based solar lantern) | Fraction | 0.075 | Kandpal and Garg, 2003 |
| Fraction of annual lighting energy demand met with solar lantern ($f_{sl}$) (considering 300 days annual lighting energy demand met with solar lantern per year) | Fraction | 0.82 | Assumption based on inputs from existing users |

Table 6.17: Measures of financial performance of solar lantern

| *Scheme* | *Type of solar lantern* | *Discounted Payback Period (years)* | | *NPV (₹)* | | *IRR (%)* | |
|---|---|---|---|---|---|---|---|
| | | *Kerosene* | *LPG* | *Kerosene* | *LPG* | *Kerosene* | *LPG* |
| With subsidized fuel | | | | | | | |
| Without capital subsidy | CFL | 9.32 | 3.85 | 1108.56 | 4462.64 | 17 | 33 |
| | LED | 6.34 | 2.96 | 1828.21 | 5182.29 | 22 | 41 |
| With capital subsidy | CFL | 5.48 | 2.53 | 1918.56 | 5272.64 | 25 | 47 |
| | LED | 3.97 | 1.97 | 2503.21 | 5857.29 | 32 | 59 |
| With unsubsidized fuel | | | | | | | |
| Without capital subsidy | CFL | 1.39 | 1.82 | 14856.79 | 10974.60 | 81 | 63 |
| | LED | 1.13 | 1.46 | 15576.43 | 11694.24 | 99 | 78 |
| With capital subsidy | CFL | 0.95 | 1.24 | 15666.79 | 11784.60 | 116 | 91 |
| | LED | 0.77 | 1.00 | 16251.43 | 12369.24 | 142 | 111 |

Table 6.18: Breakeven values of number of days of solar lantern usage per year ($n_{dsly}$) and breakeven values of fuel price for replaced fuel

| *Scheme* | *Type of solar lantern* | *Breakeven values of number of days of solar lantern usage per year* | | | | *Breakeven values of fuel price* | |
|---|---|---|---|---|---|---|---|
| | | *For subsidized fuel* | | *For unsubsidized fuel* | | *Kerosene (₹/l)* | *LPG (₹/kg)* |
| | | *Kerosene* | *LPG* | *Kerosene* | *LPG* | | |
| Without capital subsidy | CFL | 239 | 148 | 68 | 85 | 11.26 | 15.01 |
| | LED | 199 | 123 | 56 | 71 | 9.38 | 12.51 |
| With capital subsidy | CFL | 194 | 120 | 55 | 69 | 9.15 | 12.20 |
| | LED | 162 | 100 | 46 | 57 | 7.62 | 10.16 |

### *6.3.6. Solar Home System*

Assessment of financial viability of solar home system has been undertaken by using relevant input data (Table 6.19). In Uttarakhand, MNRE Model II solar home system of 37 $W_p$ has been distributed that powers 2 CFLs. Results of financial analysis of solar home system for potential users in Uttarakhand are presented in Table 6.20. Results reflect that SHS is financially viable under all scenarios except when it is adopted without capital subsidy to replace subsidized kerosene usage for lighting. As expected, an investment in an SHS would be financially more attractive if it replaces LPG lamps. Estimated breakeven values (Table 6.21) also indicate that apart from the scenario where an SHS with no capital subsidy replaces lamps energized by subsidized kerosene, an SHS is financially attractive in all other scenarios.

Table 6.19: Input values for financial analysis of solar home system (Model II, 37 $W_p$)

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | ₹ | 12650 | Quote from Tata BP Solar, Personal Communication, July 12, 2014 |
| Capital subsidy | ₹ | 2997 | MNRE, 2014b; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Useful life | Years | 20 | Mahapatra et al., 2009 |
| Annual operation and maintenance cost as a fraction of its capital cost | Fraction | 0.02 | Kandpal and Garg, 2003 |
| Fraction of annual lighting energy demand met with solar home system ($f_{shs}$) (considering 365 days annual lighting energy demand met with solar home system per year) | Fraction | 1.00 | Assumption based on inputs from existing users |
| Number of CFLs powered by solar home system | Number | 2 | MNRE, 2012 |

Table 6.20: Measures of financial performance of solar home system

| *Scheme* | | *Discounted Payback Period (years)* | | *NPV (₹)* | | *IRR (%)* | |
|---|---|---|---|---|---|---|---|
| | | *Kerosene* | *LPG* | *Kerosene* | *LPG* | *Kerosene* | *LPG* |
| Subsidized fuel | Without capital subsidy | 43.95 | 8.17 | -1467.03 | 6694.57 | 9 | 18 |
| | With capital subsidy | 13.54 | 5.52 | 1529.97 | 9691.57 | 13 | 25 |
| Unsubsidized fuel | Without capital subsidy | 2.74 | 3.63 | 31986.99 | 22540.32 | 44 | 35 |
| | With capital subsidy | 2.02 | 2.64 | 34983.99 | 25537.32 | 58 | 46 |

Table 6.21: Breakeven values of number of days of solar home system usage per year ($n_{dshsy}$)

| *Scheme* | *Breakeven values of number of days of solar home system usage per year* | | | | *Breakeven values of fuel price for replaced fuel* | |
|---|---|---|---|---|---|---|
| | *For subsidized fuel* | | *For unsubsidized fuel* | | *Kerosene (₹/l)* | *LPG (₹/kg)* |
| | *Kerosene* | *LPG* | *Kerosene* | *LPG* | | |
| Without capital subsidy | 406* | 251 | 115 | 144 | 15.72 | 20.96 |
| With capital subsidy | 323 | 199 | 91 | 115 | 12.51 | 16.68 |

* Illogical value as it indicates more than 365 days of solar home system usage per year

### *6.3.7. Solar PV Pump*

Input data used for financial analysis of community solar PV pump is presented in Table 6.22 and the results of the analysis are presented in Table 6.23. Also, breakeven values of number of days of operation of solar PV pump per year, number of persons per village and fuel price are presented in Table 6.24. Solar PV pump for community use is found to be viable under all scenarios. The results of

Table 6.22: Input values for financial analysis of 1800 $W_p$ submersible solar PV pump for community use

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | ₹ | 290700 | MNRE, 2013a; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Capital subsidy | ₹ | 87210 | MNRE, 2014b; Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Useful life | Years | 20 | Kandpal and Garg, 2003 |
| Annual operation and maintenance cost as a fraction of its capital cost | Fraction | 0.01 | Purohit and Michaelowa, 2008 |
| Volume of water required per person per day for domestic use | $m^3$ | 0.07 | Kandpal and Garg, 2003 |
| Numbers of persons in the village | Number | 750 | Assumption based on data from ORGCC (n.d.) |
| Number of persons per household in Uttarakhand | Number | 5 | ORGCC, n.d. |
| Total water requirement of village for domestic use | $m^3$ | 52.5 | Kandpal and Garg, 2003 |
| Water supply capacity of a 1800 $W_p$ solar pump with a head of 30 m | $m^3$ | 57.0 | MNRE, 2013 |
| Head of pump | m | 30 | MNRE, 2013 |
| Fraction of annual water pumping energy requirement met by solar pump ($f_{sp}$) (considering 250 days water pumping energy requirement met by solar pump) | Fraction | 0.68 | Assumption based on inputs from existing users |

financial analysis also indicate that usage of a solar pump would lead to more savings if it replaces a diesel pump. Breakeven values of number of persons per

Table 6.23: Measures of financial performance of solar PV pump

| *Scheme* | | *LCUE (₹/MJ)* | *Discounted Payback Period (years)* | | *NPV (₹)* | | *IRR (%)* | |
|---|---|---|---|---|---|---|---|---|
| | | | *Electricity* | *Diesel* | *Electricity* | *Diesel* | *Electricity* | *Diesel* |
| Subsidized fuel | Without capital subsidy | 38.30 | 0.52 | 0.07 | 4502858.09 | 35019023.45 | 206 | 1520 |
| | With capital subsidy | 27.66 | 0.36 | 0.05 | 4590068.09 | 35106233.45 | 295 | 2172 |
| Unsubsidized fuel | Without capital subsidy | 38.30 | 0.12 | 0.07 | 19610042.35 | 36950096.04 | 857 | 1603 |
| | With capital subsidy | 27.66 | 0.09 | 0.05 | 19697252.35 | 37037306.04 | 1224 | 2291 |

Table 6.24: Breakeven values of number of days of solar PV pump usage per year ($n_{dspy}$), number of persons in a village, and fuel price for replaced fuel

| *Scheme* | *Breakeven values of number of days of solar PV pump usage per year* | | | | *Breakeven values of number of persons in a village* | | | | *Breakeven values of fuel price for replaced fuel* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *For subsidized fuel* | | *For unsubsidized fuel* | | *For subsidized fuel* | | *For unsubsidized fuel* | | | |
| | *Electricity* | *Diesel* | *Electricity* | *Diesel* | *Electricity* | *Diesel* | *Electricity* | *Diesel* | *Electricity (₹/kWh)* | *Diesel (₹/l)* |
| Without capital subsidy | 16 | 2 | 4 | 2 | 13 | 2 | 3 | 2 | 0.07 | 0.55 |
| With capital subsidy | 12 | 2 | 3 | 2 | 9 | 1 | 2 | 1 | 0.05 | 0.40 |

village suggest that when a solar PV pump replaces a diesel pump, even usage of solar pump by one or two person (or a household) would be financially viable. From the results, it can be inferred that if a household can afford solar PV pump, it may adopt it as its usage would be financially rewarding for the household.

### *6.3.8. Solar Dryer*

Based on the input values for solar dryer presented in Table 6.25, financial assessment has been done and the results are presented in Tables 6.26 – 6.27. For investors having access to the fuel(s) used for drying at subsidized rates, the investment in the solar dryer (both household and community size) is financially

Table 6.25: Input values for financial analysis of solar dryer (household and community type)

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Capital cost | | | |
| Household type (capacity of solar dryer - 15 kg) | ₹ | 25340 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Community type (capacity of solar dryer - 50 kg) | ₹ | 60000 | Project Officer of UREDA, Personal Communication, May 11, 2014; SSSPL, 2014 |
| Capital subsidy | | | |
| Household type | ₹ | 15204 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Community type | ₹ | 34610 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Useful life (both household and community type solar dryer) | Years | 10 | Sanchavat et al., 2012 |
| Annual operation and maintenance cost as a fraction of its capital cost (both household and community type solar dryer) | Fraction | 0.02 | Sanchavat et al., 2012 |
| Number of loadings per year | | | |

Table 6.25: Input values for financial analysis of solar dryer (household and community type) (continued…)

| *Parameter* | *Unit* | *Value* | *Reference* |
|---|---|---|---|
| Household type | Number | 15 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Community type | Number | 50 | Project Officer of UREDA, Personal Communication, May 11, 2014 |
| Initial moisture content in raw chilli | Fraction | 0.80 | Kumar and Kandpal, 2005 |
| Final moisture content in dried chilli | Fraction | 0.08 | Kumar and Kandpal, 2005 |
| Specific heat of wet crop (with high initial moisture content, assumed same as that of water) | kJ per kg °C | 4.20 | Assumption |
| Drying temperature of chilli | °C | 60 | Kumar and Kandpal, 2005 |
| Ambient temperature | °C | 25 | Assumption |
| Enthalpy of evaporation of water at the drying temperature (assumed same as enthalpy of evaporation at 100 °C) | kJ per kg | 2257 | Nag, 2005 |

unattractive. However, if the investor needs to purchase fuel(s) at market (unsubsidized) price, investment in community size solar dryer has been found to be financially viable. Community solar dryers replacing conventional non-electric dryers working on unsubsidized biomass, LPG or kerosene are found to be financially more rewarding. Household solar dryers are found to be financially viable only when the same receive capital subsidy and replace usage of unsubsidized biomass for drying.

Table 6.26: Measures of financial performance of solar dryer

| *Scheme* | *Type of solar dryer* | *LCUE (₹/MJ)* | *Discounted Payback Period (years)* | | | | *NPV (×10³ ₹)* | | | | *IRR (%)* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Biomass* | *LPG* | *Kerosene* | *Electricity* | *Biomass* | *LPG* | *Kerosene* | *Electricity* | *Biomass* | *LPG* | *Kerosene* | *Electricity* |
| With subsidized fuel | | | | | | | | | | | | | | |
| Without capital subsidy | Household | 11.15 | - | - | - | - | -25.79 | -25.46 | -25.84 | -26.53 | - | - | - | - |
| | Community | 2.38 | - | - | - | - | -38.85 | -35.16 | -39.38 | -47.04 | -8 | -6 | -9 | -15 |
| With capital subsidy | Household | 3.75 | - | - | - | - | -10.59 | -10.25 | -10.63 | -11.32 | - | - | - | - |
| | Community | 0.83 | 14.39 | 10.40 | 15.28 | - | -4.24 | -0.55 | -4.77 | -12.43 | 7 | 10 | 6 | -3 |
| With unsubsidized fuel | | | | | | | | | | | | | | |
| Without capital subsidy | Household | 11.15 | - | - | - | - | -12.45 | -23.33 | -19.52 | -24.76 | -3 | -26 | -14 | -37 |
| | Community | 2.38 | 2.50 | 15.46 | 5.36 | - | 109.35 | -11.49 | 30.81 | -27.44 | 47 | 6 | 22 | -1 |
| With capital subsidy | Household | 3.75 | 6.83 | - | - | - | 2.75 | -8.12 | -4.32 | -9.56 | 17 | -16 | 0 | -29 |
| | Community | 0.83 | 0.98 | 3.97 | 1.92 | 6.75 | 143.96 | 23.12 | 65.43 | 7.17 | 113 | 30 | 60 | 17 |

- Undefined numbers

Table 6.27: Breakeven values of number of loadings per year (with drying time of 8 hours required per loading for chilli) and breakeven values of fuel price for replaced fuel

| *Scheme* | *Type of solar dryer* | *Breakeven values of number of loadings per year* | | | | | | | | *Breakeven values of fuel price for replaced fuel* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *For subsidized fuel* | | | | *For unsubsidized fuel* | | | | *Biomass (₹/kg)* | *LPG (₹/kg)* | *Kerosene (₹/l)* | *Electricity (₹/kWh)* |
| | | *Biomass* | *LPG* | *Kerosene* | *Electricity* | *Biomass* | *LPG* | *Kerosene* | *Electricity* | | | | |
| Without capital subsidy | Household | 167 | 148 | 170 | 236 | 27 | 85 | 48 | 119 | 17.84 | 301.08 | 160.78 | 36.13 |
| | Community | 119 | 105 | 121 | 167 | 19 | 60 | 34 | 85 | 3.80 | 64.16 | 34.26 | 7.70 |
| With capital subsidy | Household | 78 | 69 | 79 | 109 | 12 | 39 | 22 | 55 | 8.27 | 139.50 | 74.49 | 16.74 |
| | Community | 58 | 51 | 59 | 81 | 9 | 29 | 17 | 41 | 1.84 | 31.06 | 16.58 | 3.73 |

## 6.4. Concluding Remarks

Results of financial assessment indicate that improved cookstoves, DSWH and solar lanterns are viable under all scenarios in Uttarakhand. Improved cookstoves, DSWH and solar lanterns are used for distinct tasks namely cooking, water heating and lighting and hence can be promoted widely for these tasks among its potential adopters. It is also reflected in results that these three DRESs are viable even without capital subsidy and hence can be promoted without them in the state. SHS is also found to be viable under all scenarios except when an SHS with no capital subsidy replaces subsidized kerosene usage for lighting. Hence, from these outcomes, it may be inferred that the relevant DRES promotion agencies can suitably modify their capital subsidy schemes and invest the resultant savings in improving awareness and aftersales services of these DRESs. Such steps would accelerate the diffusion of these DRESs in Uttarakhand. As other DRESs (dish type solar cooker, solar PV pump and solar dryer) are not so financially attractive under household mode compared to their community counterparts, it is recommended that these DRESs may be promoted initially for community usage. In community usage, its usage and benefits can be demonstrated and then with improved distribution and aftersales facilities, households may be motivated to adopt them. Results of financial analysis also indicate that with current government subsidies on energy sources (kerosene, LPG, electricity and firewood), provision of capital subsidy is vital for most of the DRESs to be financially viable. However, under unsubsidized fuel scenario, almost all DRES considered in the study are found to be viable even without capital subsidy. Thus, as discussed in several other studies, subsidies on conventional energy sources are found to be a major barrier to the diffusion of DRESs. Removal of such subsidies would not only minimize the need to provide capital subsidy on DRESs resulting in reduced subsidy burden on government, it would also promote DRESs adoption leading to sustainable development.

# CHAPTER 7

# CONCLUSIONS AND RECOMMENDATIONS

## 7.1. Conclusions

In this study, an assessment of the utilization potential of decentralized renewable energy systems (DRESs) in the state of Uttarakhand in India has been carried out. A review and analysis of demographic, socio-economic, resource availability and climatic characteristics of Uttarakhand alongwith relevant characteristics of the DRESs considered has indicated significant potential of several solar and biomass based DRESs in the state. Subsequent study has reflected the following issues or research gaps: (a) unavailability of estimates for potential of DRESs in Uttarakhand, and (b) unavailability of information on barriers to the dissemination of DRESs in Uttarakhand. Based on the above research gaps, the following objectives were framed for the study:

i. To estimate the potential of utilization of DRESs in Uttarakhand with the factors affecting its value internalized in the approach used for estimation

ii. To assess the time-trend of dissemination of DRESs in Uttarakand and to estimate the time required for the cumulative dissemination to reach their estimated potential

iii. To identify and assess the barriers impeding the dissemination of DRESs in Uttarakhand

The study makes use of several tools for analysis that includes: (a) chain ratio method for estimation of utilization potential of DRESs, (b) engineering economics for estimating the values of several measures of financial performance such as NPV, IRR, and break-even value, (c) logistic growth model for studying the time trend of diffusion of DRESs, and (d) factor analysis (using SPSS software) of data collected through questionnaire based survey for assessment of barriers. The main findings of the study have been presented in the following paragraphs.

There is very large potential for domestic solar water heaters (DSWHs), solar lanterns and improved biomass cookstoves in the state of Uttarakhand (Table 7.1). Also, there is significant potential for solar home systems, solar cookers, solar dryers and family size biogas plants. It is worth mentioning that the actual utilization potential of a DRES would be directly dependent on the effective cost of the DRES to the user as against his/her purchasing power. Therefore, the estimates of utilization potential would also vary with the provision of incentives such as capital subsidy or soft loan or any other suitable incentive. Results also indicate that for large scale dissemination of DRESs, soft loan is a superior option compared to capital subsidy as it has bigger impact on improving the purchasing power of households.

Table 7.1: Summary of potential of DRESs in Uttarakhand

| *DRES* | *Estimated potential* | |
|---|---|---|
| | *with capital subsidy* | *with soft loan* |
| Domestic solar water heater | 113284 | 292086 |
| Solar home system | 12157 | 78055 |
| Solar lantern | 247120 | 181222 |
| Solar cooker | 53934 | 53934 |
| Solar dryer | 63250 | 63250 |
| Solar PV pump | 107 | 107 |
| Family size biogas plant | 61956 | 85786 |
| Improved biomass cookstove | 208757 | 208757 |

Assessment of the time-trend of diffusion of DRESs in Uttarakhand has indicated that the promotion of various DRESs (except solar water heater) has been highly inconsistent over the years. Only solar water heater has received persistent subsidy support since the formation of the state reflected by sustained growth in annual subsidy allocated for its promotion. The same trend is reflected in the cumulative annual dissemination of solar water heaters in Uttarakhand. A reasonably strong positive correlation between diffusion achieved and the extent of subsidy on DRESs essentially implies subsidy driven programmes and direct dependence of diffusion on subsidy. Among all DRESs, the correlation coefficient is highest for solar lanterns (1.00) and solar water heaters (0.91) reflecting strong dependence of their diffusion on the provision of subsidy. Private equity leveraged by the government expenditure on capital subsidy is significantly low (as the ratio of private equity leveraged to capital subsidy for all DRESs has been $\leq 1$) reflecting ineffective use of public finance.

A preliminary study of the time trend of diffusion of DRESs in Uttarakhand based on the logistic growth curve indicates that as per the prevailing trend a substantially long time period would be needed for the cumulative dissemination of DRESs to reach the utilization potential estimated in the study. For most of the household level DRESs, it is expected to take more than 200 years for their cumulative dissemination to reach their estimated utilization potential.

A survey of adopters and non-adopters of DRESs in Uttarakhand identifies high capital cost, lack of access to capital / loan, availability of cheaper alternative fuel, unavailability of trained manpower for installation and maintenance, lack of user training for maintenance, unavailability of retail shops, and unavailability of spares as the major barriers. Other relevant barriers are inappropriateness of technology, poor resource availability, lack of adequate awareness, and lack of socio-cultural acceptability. Lack of adequate awareness has been considered more critical by the non-adopters whereas adopters of DRESs that require regular maintenance services such as solar home system and family size biogas plant consider unavailability of trained manpower for installation and maintenance and unavailability of spare parts as more critical barriers. Also, survey of the status of adopted DRESs indicates that a satisfied DRES adopter has recommended it to others and most (about 85%) of such recommendations have resulted in adoptions. The survey responses also revealed that in rural areas of Uttarakhand, Panchayat Pradhan (elected representative of village in India) has been the main source of awareness to the villagers.

Results of financial assessment indicate that improved cookstoves, DSWHs, solar lanterns and solar home systems are financially the most attractive DRESs for promotion in the state. These are found to be financially viable under almost all scenarios even without capital subsidy. In case of dish type solar cookers, solar PV pumps and solar dryers, community usage has been found to be more viable compared to their household applications. The results obtained reaffirm the need for providing a level playing platform to DRESs either by withdrawal of direct and indirect subsidies being given on conventional energy supply or by providing suitable incentives to one or more of the stakeholders involved in the diffusion of DRESs.

Based on the results and conclusions of the study, the following policy related inferences and/or suggestions can be made:

i. Institutional support should be provided to conduct awareness campaigns regarding the utility of DRESs and relevant government financial support schemes. Suitable incentive schemes such as soft loan should be developed to minimize the impact of high capital cost barrier.
ii. There is an urgent need to ensure availability of trained manpower for installation and maintenance and availability of spare parts. This would ensure proper functioning of DRES and prevent system failure. With proper functioning of DRES, a satisfied adopter may turn as a promoter of DRESs among the neighborhood.
iii. The Panchayat Pradhan may be given a prominent role towards the promotion of DRESs in rural areas.

iv. To begin with, dissemination of the DRESs that are viable under almost all scenarios even without any capital subsidy (solar lanterns, solar home systems, DSWHs and improved cookstoves) need to be prioritized.

## 7.2. Limitations of the Study and Recommendations for Further Work

The study suffers from the limitations of data availability, restricted scope of the study (only household and community level applications), dynamics in the costs of various DRESs as well as in the policies of the state and central government.

The following additional studies are needed to develop an extensive strategy for large scale dissemination of DRESs in the state of Uttarakhand:

i. Effect of likely reduction in the costs of DRESs in future and its impact on their financial attractiveness
ii. Impact of likely extension of conventional grid on the desirability of some of the DRESs such as solar home systems and solar lanterns
iii. Potential applications of DRESs in commercial and industrial sector
iv. Possibility of benefits of carbon mitigation benefits (such as Programmatic CDM) whenever and wherever applicable
v. In addition to logistic growth model, usage of other growth models (Bass model, Gompertz model and Pearl model) for studying diffusion of DRESs

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## APPENDIX I

The following example presents the method used in the study to estimate the fraction of rural households in Uttarakhand having the purchasing power to adopt DSWH:

i. As per NSSO (2014), monthly per capita expenditure in rural Uttarakhand ($MPCE_{(r)}$) = ₹ 1725.77
ii. As per NSSO (2014), MPCE on durable goods in rural Uttarakhand ($MPCE_{dg(r)}$) = ₹ 86.70
iii. Fraction of MPCE spent on durable goods in rural Uttarakhand,
$f_{dg} = \frac{MPCE_{dg(r)}}{MPCE_{(r)}}$ = 0.05
iv. Cost of subsidized DRES (ETC type 100 LPD DSWH) ($C_{DRES}$) = ₹ 10350 (Project Officer of UREDA, Personal Communication, May 11, 2014)
v. As per ORGCC (n.d.), average household size in rural Uttarakhand, ($AHS_{(r)}$) = 5
vi. The minimum MPCE required to adopt the subsidized DRES by a household,
$MPCE_{min} = \frac{C_{DRES}}{f_{dg} \times AHS_{(r)} \times 12}$ = ₹ 3450
vii. As per the classes mentioned in NSSO (2014a), fraction of rural households having average MPCE ≥ $MPCE_{min}$
($f_{ppdswh(r)}$) = 0.07

Similarly, the same method has been used in all cases to estimate the fraction of Uttarakhand households having the purchasing power to adopt various DRESs.

# APPENDIX II

Serial no. __________

***Questionnaire for 'Assessment of Barriers to the Adoption of Decentralized Renewable Energy Systems in the State of Uttarakhand, India'***

Dear Sir/Madam,

Greetings!

The enclosed questionnaire aims at seeking information to facilitate an assessment of barriers to the adoption of decentralized renewable energy systems in the state of Uttarakhand, India. Decentralized renewable energy systems (DRESs) are suitable for distributed applications at household level. Examples of DRES are family size biogas plants (FSBPs), solar lantern, solar home systems, improved biomass cook stoves, solar water heaters (SWHs), etc. A barrier to the adoption of DRES may be defined as a factor that adversely affects its adoption and consequently hampering its widespread diffusion. Barriers to DRES may include technical, economic, social or institutional issues. This questionnaire seeks to collect information from the households in areas of Uttarakhand with significant adoption of DRES. Information is sought from both the adopter and non-adopter households to assess the barriers to DRES in some such areas of Uttarakhand. It is worth mentioning that the information shared with the enumerator is strictly confidential and will only be used for the purpose of doctoral research being undertaken under the aegis of University of Petroleum and Energy Studies. I would like to express sincere gratitude to you for your precious time and valuable inputs.

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Note from the enumerators: In addition to the interview, we shall greatly appreciate receiving any further relevant inputs by e-mail or telephone. For such inputs, please feel free to contact the following enumerators:

1. Yashashwi Gyanpuri
   E-mail – yashaswi.gyanpuri88@gmail.com
   Telephone - +91-8126930737
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   Telephone - +91-7830319932

Serial no. __________

## *Questionnaire*

1. Name:
2. Address:

   House no.: Street:

   Village/Colony: Post office:

   Block/Town/City: District:
3. Landline no. / Mobile no.:
4. E-mail address (if available):
5. Is the household electrified: Yes / No

   If yes, kindly indicate average hours of power cut per day:
6. Total no. of persons in the household:
7. Education and profession of the elder members of the household:

| Name of member | Gender (M/F) | Education | Profession |
|---|---|---|---|
| 1. | | Non-graduate / Graduate / Post-graduate | |
| 2. | | Non-graduate / Graduate / Post-graduate | |
| 3. | | Non-graduate / Graduate / Post-graduate | |
| 4. | | Non-graduate / Graduate / Post-graduate | |
| 5. | | Non-graduate / Graduate / Post-graduate | |

8. Education of the younger members (children) of the household:

| Name of member | Gender (M/F) | Current education institution |
|---|---|---|
| 1. | | Kindergarten / School / College / Any other (please specify) |
| 2. | | Kindergarten / School / College / Any other (please specify) |
| 3. | | Kindergarten / School / College / Any other (please specify) |
| 4. | | Kindergarten / School / College / Any other (please specify) |
| 5. | | Kindergarten / School / College / Any other (please specify) |

9. Annual income of the household (in lakh):
10. Current energy use pattern (note: in case of multiple fuel usage for an end use, please tick all options being used)

    a) Fuel and technology usage for various end uses

| End use | Technology used | Fuel used |
|---|---|---|
| Cooking | • LPG stove<br>• Kerosene stove<br>• Biomass stove (traditional)<br>• Biomass stove (improved)<br>• Electric heater<br>• Induction stove<br>• Microwave<br>• Family size biogas plant<br>• Solar cooker<br>• Any other (please specify) | • LPG<br>• Kerosene<br>• Biomass<br>• Biomass<br>• Electricity<br>• Electricity<br>• Electricity<br>• Cow dung<br>• Solar |
| Lighting | • Incandescent bulb, Fluorescent tubelight, CFL, LED<br>• Diesel generator<br>• Kerosene lamp<br>• Solar lantern<br>• Solar home system<br>• Family size biogas plant<br>• Candle<br>• Any other (please specify) | • Electricity<br>• Diesel<br>• Kerosene<br>• Solar<br>• Solar<br>• Cow dung<br>• Wax |
| Water heating | • Electric geyser<br>• Electric immersion rod<br>• LPG stove<br>• Kerosene stove<br>• Biomass stove (traditional)<br>• Biomass stove (improved)<br>• Family size biogas plant<br>• Solar water heater<br>• Any other (please specify) | • Electricity<br>• Electricity<br>• LPG<br>• Kerosene<br>• Biomass<br>• Biomass<br>• Cow dung<br>• Solar |
| Water pumping | • Electric pump<br>• Solar water pump<br>• Any other (please specify) | • Electricity<br>• Solar |

b) Expenditure on energy usage

| Fuel | Monthly fuel consumption (if possible) | Monthly expenditure (₹) | Fraction of fuel used for various end uses (in %) | | | |
|---|---|---|---|---|---|---|
| | | | Cooking | Water heating | Lighting | Water pumping |
| LPG | kg | | | | | |
| Kerosene | liter | | | | | |
| Biomass | kg | | | | | |
| Electricity | kWh | | | | | |
| Diesel | liter | | | | | |
| Cow dung | kg | | | | | |
| Any other (please specify) | | | | | | |

11. Are you aware of the following DRES?

| DRES | Awareness | If yes, please tick the appropriate option indicating level of awareness |
|---|---|---|
| Family size biogas plant | Yes / No | Only know about it / Have seen its function / Have used it |
| Solar Lantern | Yes / No | Only know about it / Have seen its function / Have used it |
| Solar Home System | Yes / No | Only know about it / Have seen its function / Have used it |
| Solar water heater | Yes / No | Only know about it / Have seen its function / Have used it |
| Improved biomass cookstove | Yes / No | Only know about it / Have seen its function / Have used it |
| Solar cooker | Yes / No | Only know about it / Have seen its function / Have used it |
| Solar pump | Yes / No | Only know about it / Have seen its function / Have used it |
| Any other (please specify) | Yes / No | Only know about it / Have seen its function / Have used it |

If the respondent is not aware of any DRES, please collect the following information prior to terminating the interview, otherwise proceed to the next question (question no. 12).

a) Does the household have livestock: Yes/No

   If 'Yes', please indicate

   i. No. of cattle (cow/buffalo):

   ii. No. of goat:

iii. No. of pig:
iv. Any other (please specify):

b) Availability of land adjacent to the household (in bigha):

c) Biomass (non-fodder, non-fertilizer) availability to the household:
i. Is biomass available to the household: Yes / No
ii. If ‘Yes’, amount of biomass available in kg/day:
iii. Source(s) of biomass:

d) No. of rainy months in a year:

e) Source(s) of information to the household (please tick all the applicable options):
i. Radio
ii. TV
iii. Newspaper
iv. Internet
v. Mobile
vi. Any other (please specify)

**END**

12. If the respondent is aware of any DRES, the source of awareness (note: in case of multiple sources of awareness, please tick all):
a) Advertisement (Print / Radio/ TV)
b) Workshop / seminar / demonstration by a nodal agency or any other organization
c) Door to door awareness campaign(s)
d) Opportunity to witness use of DRES in the vicinity
e) Children
f) Friends and relatives
g) Any other (please specify)

13. Have you ever adopted any DRES (FTBP, Solar lantern, Solar home system, etc): Yes / No

If ‘Yes’, please respond to the queries for ‘Adopters’.

If ‘No’, please respond to the queries for ‘Non-adopters’.

## *Feedback from the Adopters of DRES*

14. Information on the adoption of DRES

| DRES adopted | Specification | Year of adoption | Total cost of system (₹) | Type of subsidy availed (if any) | Extent of subsidy availed (if any) (₹) | Whether the system is in use?* | If not in use, reasons for discontinuance |
|---|---|---|---|---|---|---|---|
| | | | | • Capital subsidy<br>• Soft loan<br>• Any other (please specify) | | Yes / No | • Dissatisfied with performance<br>• System failure and lack of repair facility<br>• Unavailability of spare parts<br>• Useful life over<br>• Any other (please mention) |
| | | | | • Capital subsidy<br>• Soft loan<br>• Any other (please specify) | | Yes / No | • Dissatisfied with performance<br>• System failure and lack of repair facility<br>• Unavailability of spare parts<br>• Useful life over<br>• Any other (please mention) |
| | | | | • Capital subsidy<br>• Soft loan<br>• Any other (please specify) | | Yes / No | • Dissatisfied with performance<br>• System failure and lack of repair facility<br>• Unavailability of spare parts<br>• Useful life over<br>• Any other (please mention) |

* Preferably, the enumerator is advised to witness the functioning of the DRES.

15. Once being aware, who motivated you to adopt:
   a) Promoting agents
   b) Children
   c) Friends, relatives, colleagues
   d) Self-motivated (through advertisements/workshops/conferences)
   e) Any other (please specify)
16. Brief inputs of the adopter regarding their experiences on the use of DRES:

| DRES adopted | Favorable experiences | Unfavorable experiences | Overall opinion |
|---|---|---|---|
| | | | • Poor<br>• Acceptable<br>• Very good |
| | | | • Poor<br>• Acceptable<br>• Very good |
| | | | • Poor<br>• Acceptable<br>• Very good |

17. In your opinion, are there any barriers to large scale adoption of the DRES adopted by you: Yes / No

    If the answer is 'Yes', please go to the next question (question no. 16).

    If the answer is 'No', please jump to question no. 18.

Serial no. __________

18. From your experience with the DRES adopted, rate the extent of adverse impact of barriers on large scale adoption of the DRES:

| DRES adopted | To what extent the following barriers may have adversely affected large scale adoption of the DRES | Not at all | to some extent | to large extent | Can't say |
|---|---|---|---|---|---|
| | Lack of adequate awareness regarding the product and its benefits | | | | |
| | Uncertainty of resource availability (availability of solar radiation, biomass, cow dung, etc) | | | | |
| | Inappropriateness (user satisfaction and reliability) of technology | | | | |
| | Unavailability of trained manpower for installation and maintenance of DRES | | | | |
| | High capital cost of DRES | | | | |
| | Availability of cheaper fuel options such as free biomass, subsidized LPG or kerosene, etc | | | | |
| | Lack of access to capital/loan (via loan schemes of bank) | | | | |
| | Unavailability of retail shops for sale of DRES | | | | |
| | Lack of user's training for operation and minor maintenance work | | | | |
| | Unavailability of spare parts of DRES in market | | | | |
| | Lack of socio-cultural acceptability (e.g., issues regarding usage of cow dung for cooking via biogas, cooking in open area via solar cooker) | | | | |
| | Any other | | | | |

19. From your experience, list three most critical barriers to the large scale adoption of the DRES in the order of preference:

| DRES adopted | Critical barriers | Details (if any) |
|---|---|---|
| | 1.<br>2.<br>3. | |

20. What is your opinion about other DRES?

| DRES (other than those adopted) | Opinion |
|---|---|
| | |
| | |
| | |

21. Please answer the following:

    a) Do you plan to adopt any DRES in future: Yes / No

       If 'Yes', please specify the DRES:

    b) Have you recommended any DRES to others: Yes / No

       If 'Yes',

       i. Name the DRES:

       ii. Has the recommendation lead to adoption: Yes / No

           - If 'No', kindly specify reason(s) for non-adoption:

22. Recommend three measures for enhanced adoption of DRES:

    a)

    b)

    c)

*Feedback from Non-adopters of DRES*

14. From the following DRES, select the DRES having maximum utility for you:

| DRES | Reasons for selection |
| --- | --- |
| Family size biogas plant | |
| Solar Lantern | |
| Solar Home System | |
| Solar water heater | |
| Improved biomass cookstove | |
| Solar cooker | |
| Solar pump | |
| Any other (please specify) | |

15. For the DRES having maximum utility, kindly provide the reasons for non-adoption by you:

16. Do you feel there are barriers to large scale adoption of the DRES having maximum utility for you: Yes / No

If the answer is 'Yes', please go to the next question (question no. 17).

If the answer is 'No', please jump to question no. 19.

Serial no. __________

17. From your perception regarding the maximum utility DRES, rate the extent of adverse impact of barriers on large scale adoption of the DRES:

| Maximum utility DRES | To what extent the following barriers may have adversely affected large scale adoption of the DRES | Not at all | to some extent | to large extent | Can't say |
|---|---|---|---|---|---|
| | Lack of adequate awareness regarding the product and its benefits | | | | |
| | Uncertainty of resource availability (availability of solar radiation, biomass, cow dung, etc) | | | | |
| | Inappropriateness (user satisfaction and reliability) of technology | | | | |
| | Unavailability of trained manpower for installation and maintenance of DRES | | | | |
| | High capital cost of DRES | | | | |
| | Availability of cheaper fuel options such as free biomass, subsidized LPG or kerosene, etc | | | | |
| | Lack of access to capital/loan (via loan schemes of bank) | | | | |
| | Unavailability of retail shops for sale of DRES | | | | |
| | Lack of user's training for operation and minor maintenance work | | | | |
| | Unavailability of spare parts of DRES in market | | | | |
| | Lack of socio-cultural acceptability (e.g., issues regarding usage of cow dung for cooking via biogas, cooking in open area via solar cooker) | | | | |
| | Any other | | | | |

18. For the maximum utility DRES, list three most critical barriers to the large scale adoption of the DRES
in the order of preference:

| Maximum utility DRES | Critical barriers | Details (if any) |
|---|---|---|
| | 1.<br>2.<br>3. | |

19. Please answer the following:

a) Do you plan to adopt any DRES in future: Yes / No

If ‘Yes’, please specify the DRES:

b) Have you recommended any DRES to others: Yes / No

If ‘Yes’,

i. Name the DRES:

ii. Has the recommendation lead to adoption: Yes / No

- If ‘No’, kindly specify reason(s) for non-adoption:

20. Recommend three measures for enhanced adoption of DRES:

a)

b)

c)

## BRIEF PROFILE OF THE RESEARCH SCHOLAR

### About the Research Scholar

Mohammed Yaqoot is currently working as Assistant Professor (Selection Grade) in Department of Power and Infrastructure, University of Petroleum and Energy Studies, Dehradun. His areas of interest are power generation technologies, renewable energy technologies and energy policy. He is a mechanical engineering graduate who pursued his post-graduation in Energy Studies from IIT Delhi. He has conducted several training programmes on CDM and Renewable Energy Technologies. He has also offered consultancy services to L&T Infotech on 'Business Process Mapping of Power Sector'. Prior to joining the university, Mohammed Yaqoot worked with Voltas Ltd. for 4 years followed by one and half year stint with Reliance Energy Ltd. Currently, he is pursuing doctoral research work in the field of renewable energy technologies.

### Papers Published

1. Yaqoot, M., Diwan, P., Kandpal, T.C., 2014. Solar Lighting for Street Vendors in the City of Dehradun (India): A Feasibility Assessment with Inputs from a Survey. Energy for Sustainable Development 21, 7-12.
2. Yaqoot, M., Diwan, P., Kandpal, T.C., 2015. Public Financing of Solar Lanterns versus Subsidizing Kerosene for Domestic Lighting in India: A Feasibility Assessment. Renewable Energy 80, 564-572.

### Papers under Review or Draft Stage

1. Yaqoot, M., Diwan, P., Kandpal, T.C. Review of Barriers to the Dissemination of Decentralized Renewable Energy Systems. Communicated to Renewable and Sustainable Energy Reviews in May, 2015.

2. Yaqoot, M., Diwan, P., Kandpal, T.C. Financial Attractiveness of Decentralized Renewable Energy Systems – a Case of Uttarakhand, India.
3. Yaqoot, M., Diwan, P., Kandpal, T.C. Frameworks for Estimating the Potential of Decentralized Renewable Energy Systems in Uttarakhand, India.
4. Yaqoot, M., Diwan, P., Kandpal, T.C. Barriers to the Dissemination of Decentralized Renewable Energy Systems – a Case of Uttarakhand, India.