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**SENT TO LSU AGCENTER/LOUISIANA FOREST PRODUCTS DEVELOPMENT CENTER - FOREST SECTOR / FORESTY PRODUCTS INTEREST GROUP**

My doctoral student, Anand Mishra, has generated a very interesting dissertation defense PowerPoint that he has agreed to share with this group. He will return to India in June to continue work in the renewable energy field.

# Biomass Gasification for Electricity Generation: An Integrated Approach for Development of Forest Residue-based Projects in India

Dissertation Presentation
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Dissertation Defense

# Biomass Gasification for Electricity Generation: An Integrated Approach for Development of Forest Residue-based Projects in India

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February 19, 2016

## Outline

- A Review of Biomass Feedstock and Gasification Technology
- Policy and Regulatory Framework Governing Bioenergy in India
- Financial-Evaluation under Uncertainty of a Pine Needle Gasification Project in Uttarakhand, India
- Stakeholders Perspectives on Supplying Pine Needle to Gasification Project in Uttarakhand, India

# A REVIEW OF BIOMASS FEEDSTOCK AND GASIFICATION TECHNOLOGY

## Objectives

- Based on existing literature, identify desirable biomass feedstock properties for bioenergy production.
- Based on existing literature, identify current thermo-chemical gasification technologies in use across the world.

# Ideal Characteristics of Biomass Feedstock Crops

- Low energy input to produce
- Low nutrient requirements
- Low water use
- High pest resistance and low fertilizer requirement
- High yield (maximum production of dry matter per hectare)
- Low cost
- Composition with the least contaminants
- Fewer alternative uses

# Biomass Feedstock Properties in the Context of Bioenergy

Main properties of interest during processing as an energy source

1. Moisture content (intrinsic and extrinsic)
2. Calorific value
3. Proportions of fixed carbon and volatiles
4. Ash/residue content
5. Alkali metal content
6. Cellulose/lignin ratio

Dry Conversion
Wet Conversion

# Summary: Effect of Physical Characteristics of Biomass Feedstocks

| | Properties | Effects |
|---|---|---|
| Physical | Moisture content | Storage durability<br>Dry-matter losses<br>Low NCV<br>Self-ignition |
| | Bulk | Fuel logistics (storage, transport, handling) costs |
| | Ash content | Dust, particle emissions<br>Ash utilization/disposal costs |
| | Particle dimension and size distribution | Determines fuel feeding system<br>Determines combustion technology<br>Drying properties<br>Dust formation |

# Summary: Effect of Chemical Characteristics of Biomass Feedstocks

| | Properties | Effects |
|---|---|---|
| Chemical | Carbon | GCV (positive) |
| | Hydrogen | GCV (negative) |
| | Oxygen | GCV (negative) |
| | Chlorine | Corrosion |
| | Nitrogen | $NO_x$, $N_2O$, HCN emissions |
| | Sulfur | $SO_x$ emissions, corrosion |
| | Fluorine | HF emissions corrosion |
| | Potassium | Corrosion, Lowering ash melting temperatures , Aerosol , Ash utilization (plant nutrient) |
| | Sodium | Corrosion, Lowering ash melting temperature, Aerosol |
| | Magnesium | Increase in ash melting temperature , Ash utilization (plant nutrient) |
| | Calcium | Increase in ash melting temperature, Ash utilization (plant nutrient) |
| | Phosphorus | Increase in ash meting point, Ash utilization (plant nutrient) |
| | Heavy metals | Emissions of pollutants, Ash utilization and disposal issues, Aerosol |

## Thermo-chemical Conversion

Within thermo-chemical conversion processes, four options are available:

- Combustion
- Pyrolysis
- Gasification
- Liquefaction

The focus of this study is on gasification
Main Gasification Technology in use-

- Updraft Gasifier (higher energy content of producer/syngas and more ash)
- Downdraft Gasifier (lower energy content of producer/syngas and less ash)

**POLICY AND REGULATORY INSTRUMENTS GOVERNING BIOENERGY IN INDIA**

# Objectives

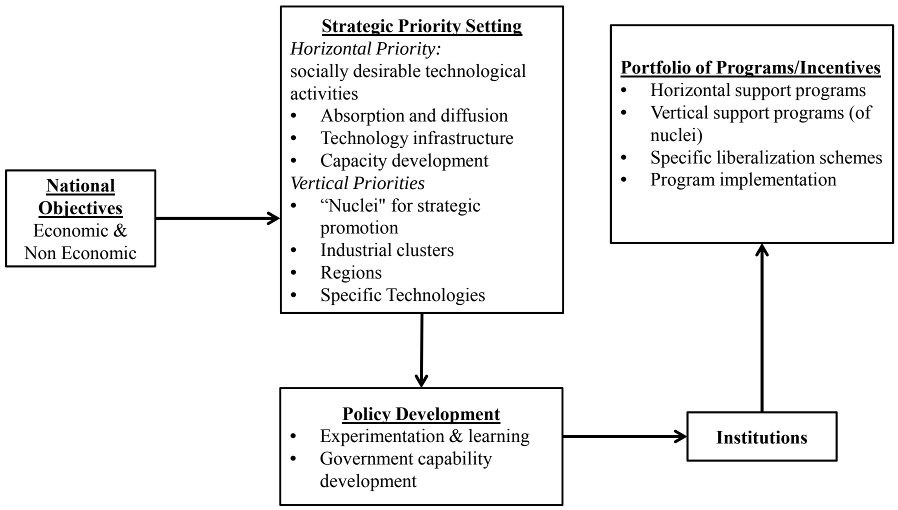
- Review literature related with bioenergy policy framework adopted by various countries.
- Identify major policy program and instrument in use to promote bioenergy in general and bio-based electricity in particular.
- Review bioenergy policy framework of India.

# Theory: Role of Government in Industrial Development

- Early development economists: optimism about competence and effectiveness role of State.
- Neoclassical economists of 1970s and 1980s: presumed inevitability of imperfect State-arguing that imperfect market is the lesser evil.
- Development economists post-1990s:
  - argue against the easy dismissal of the State.
  - point out that virtually all cases of economic development involve State intervention.

(Shapiro and Taylor 1990; Lall and Teubal 1998)

# Bioenergy-Stimulating
# Policy Formation Process Model




(Adapted from Lall and Teubal 1998)

# Drivers for Government Action
# in the Bioenergy Sector

**Key Motivation for Bioenergy Policy by Country**

| Countries | Climate Change | Environment | Energy Security | Rural Development | Agricultural Development | Technology Development |
|---|---|---|---|---|---|---|
| China | X | X | X | X | X | |
| India | | | X | X | | X |
| Mexico | X | X | X | X | | X |
| South Africa | X | | X | X | | |
| Canada | X | X | X | | | X |
| France | X | | X | X | X | |
| Germany | X | X | | X | X | X |
| Japan | X | X | | | X | X |
| Russia | X | X | X | X | X | X |
| UK | X | X | X | X | | |
| US | | X | X | X | X | X |

(GBEP 2007)

# Short-term Relationships between Goals and Programs

| | Energy Goals | | |
|---|---|---|---|
| | Maximum electricity generation | Quality and sustainability of electricity supply | Low electricity prices |
| Supply Push: Competitive tender | + | + | +- |
| Supply Push: Feed-in tariff | + | + | -- |
| Supply Push: Production credit | + | + | 0 |
| Demand Pull: Renewable obligation | + | + | - |
| Demand Pull: Tradable renewable credits | 0 | 0 | + |
| Indirect Price Support: Carbon tax | 0 | 0 | - |
| Indirect Price Support: Emissions trading | 0 | 0 | + |
| Capital Support: Grants/tax incentives | + | + | 0 |
| Technical Standards/certifications | 0 | 0 | 0 |
| Information, education, and training | 0 | 0 | 0 |
| Improved planning process | + | + | 0 |
| Research, development, and demonstration | 0 | 0 | 0 |

# Short-term Relationships between Goals and Programs

| | Environmental Goals | | Industrial/Economic Goals | |
|---|---|---|---|---|
| | Sustainability | $NO_x$ $SO_x$ $CO_2$ reduction | Local & regional economic development | Domestic employment |
| Supply Push: Competitive tender | + | + | + | + |
| Supply Push: Feed-in tariff | + | + | + | + |
| Supply Push: Production credit | + | + | + | + |
| Demand Pull: Renewable obligation | + | + | + | + |
| Demand Pull: Tradable renewable credits | 0 | 0 | 0 | 0 |
| Indirect Price Support: Carbon tax | + | ++ | 0 | 0 |
| Indirect Price Support: Emissions trading | + | ++ | 0 | 0 |
| Capital Support: Grants/tax incentives | + | + | + | + |
| Technical Standards/certifications | 0 | 0 | 0 | 0 |
| Information, education, and training | 0 | 0 | 0 | 0 |
| Improved planning process | + | + | + | + |
| Research, development , and demonstration | 0 | 0 | 0 | 0 |

# Policy Instruments used by Countries to Promote Renewable Electricity

F-Fed
S-State

| Countries | FIT/Premium | Net Metering | REC | Tendering | Capital Subsidy/Grant Rebate | Investment Production Tax Credit |
|---|---|---|---|---|---|---|
| **High Income Countries** | | | | | | |
| Australia | S | | F | S | F | |
| Canada | S | S | | F | F | F |
| France | F | | F | F | F | F |
| Germany | F | | | | F | F |
| Japan | F | F | F | F | F | |
| Russia | F | | | F | F | |
| US | S | S | S | | F | F |
| **Upper Middle Income Countries** | | | | | | |
| Argentina | F | F | | F | F | F |
| Brazil | | F | | F | | F |
| China | S | | | F | F | F |
| Malaysia | | | | | | |
| Mexico | | F | | F | | F |
| South Africa | | | | F | F | |
| Turkey | F | | | | F | |

(Adapted from REN21 2015)

# Policy Instruments used by Countries to Promote Renewable Electricity

F-Fed
S-State

| Countries | FIT/Premium | Net Metering | REC | Tendering | Capital Subsidy/Grant/ Rebate | Investment Production tax Credit |
|---|---|---|---|---|---|---|
| **Lower Middle Income Countries** | | | | | | |
| Ghana | F | | F | | F | |
| India | F | S | F | F | F | F |
| Indonesia | F | | | F | F | F |
| Nigeria | F | | | | F | |
| Sri Lanka | F | F | | | F | |
| **Lower Income Countries** | | | | | | |
| Bangladesh | | | | F | F | |
| Kenya | F | | | F | | |
| Zimbabwe | | | | | | |

(Adapted from REN21 2015)

# General Lessons from the World for Bioenergy Policy Making

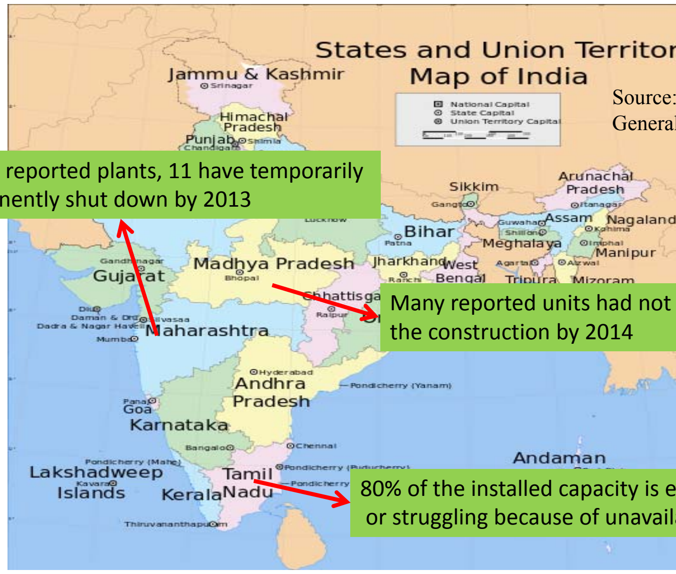
- Long-term vision for the industry
- Maturity of available bioenergy technologies
- Mechanism for access to market
- Sources of feedstock and their supply
- Supporting infrastructure

- Sustainability issues
- Policies are merely precondition but not a guarantee for success of bioenergy industry
  - Social acceptance
  - Capacity building
  - Enabling environment
  - Governance

# Status of Bioenergy in India

- Biomass Resource Atlas of India estimates the biomass-based electricity generation at 16,000 MW.
- If 50% of the waste and degraded land was used for energy-focused biomaterials, an additional 30,000 MW could potentially be generated. (Ministry of New & Renewable Energy, India)
- Until 2013, the installed capacity for bio-based electricity in India was only 1,220 MW- a contested figure due to closure of many units.

# Status of Bioenergy in India
# Examples of Capacity Reduction




Source: Controller Auditor General of India

Out of 18 reported plants, 11 have temporarily or permanently shut down by 2013

Many reported units had not begun the construction by 2014

80% of the installed capacity is either shut down or struggling because of unavailability of feedstock

# Causes of Underperformance of the Bio-based Electricity Sector in India

- Cross-subsidization in electricity market
- Low cost of electricity production from fossil fuel
- Lack of investment-domestic and foreign
- Weak technological ecosystem
- High feedstock cost

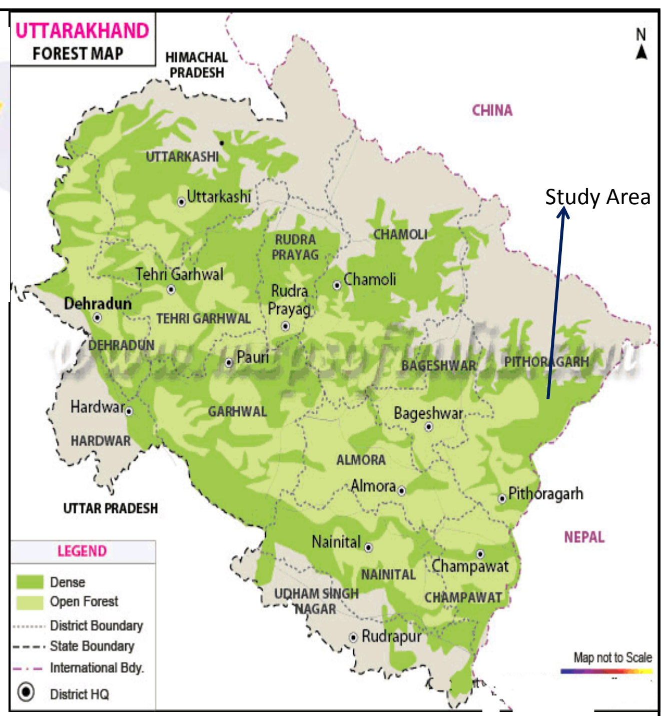
# Bioenergy in India: Reasons for Unrealized Potential

- Land vs. food controversy
  - conversion of land use from food production to energy crop production is unlikely.
- Alternative uses of biomass
  - most agricultural and forest biomass have alternative uses such as: cattle feed, cooking fuel, roof thatching etc.
- Logistics economics
  - inefficient transportation infrastructure
- Competition from other renewable energy technologies
  - Solar, Wind, and Small Hydro have received far more attention from various stakeholders.

# The Studies

# FINANCIAL EVALUATION UNDER UNCERTAINTY OF A PINE NEEDLE GASIFICATION PROJECT IN UTTARAKHAND, INDIA


Study Area



# Objective

- Establish a framework for financial evaluation of a biomass gasification project using a case-study of proposed 2.4 MW (20 x 120 KW) Pine Needle Gasification project (PNGP).
  - Identify the risk factors that are likely to impact the financial viability of a PNGP within the existing policy and regulatory framework of India.
  - Derive a risk-adjusted probability distribution of profitability indicator (Net Present Value) for the PNGP.

# Panel of Consultants and Data for the Study

The panel members include:

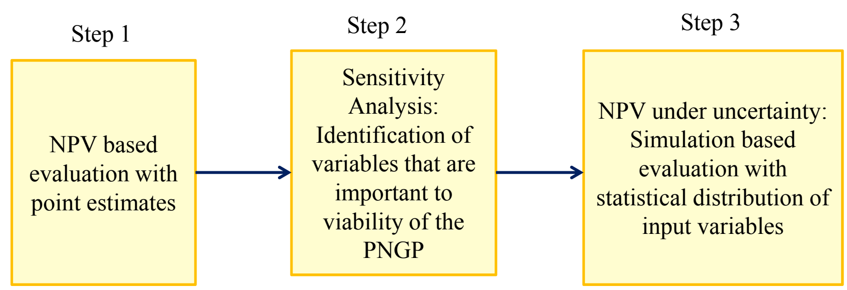
- Professionals from three public sector banks-State Bank of India, Punjab National Bank, Corporation Bank;
- Professionals from two private sector banks-ICICI bank, HDFC bank;
- Professionals from two multinational bank-Citi Bank India; HSBC India
- Professional from Indian Federal Bank-Reserve Bank of India;
- Two Associate Professors from Indian Institute of Management, Indore, and O.P. Jindal University, Delhi.

Data

AVANI-operational data from 9 KW plant for 7 years.

# Methodology

Process-flow for the Study




# Methodology: NPV & Cash Flow Model

NPV Model

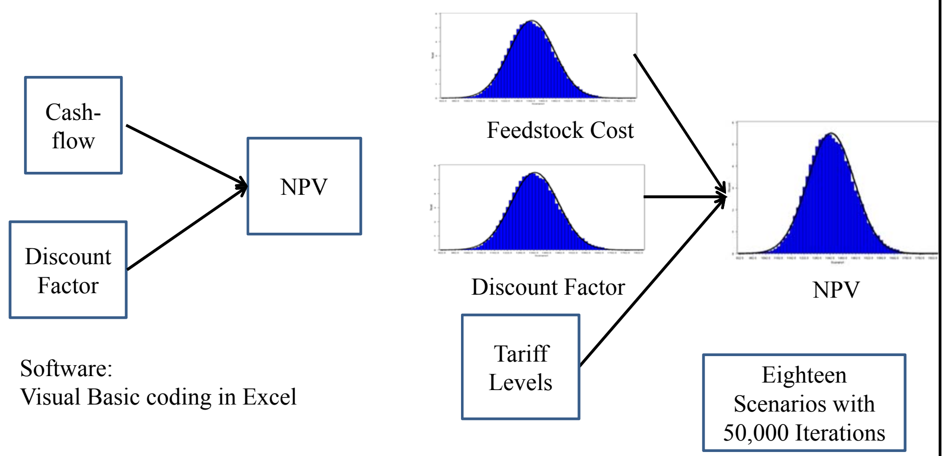
$$\sum_{t=0}^{T} \omega_t \; [\{(R_t - O_t - DEP_t - Int_t) + Dep_t\} - \{\Delta Investment_t + \Delta WC_t\} + \Delta D_t]$$

Where $\boldsymbol{\omega_t}$ (discount rate)-reciprocal of *expected post tax return on investment*, $\mathbf{R_t}$-Revenue in cash, $\mathbf{O_t}$-operating cost in cash, **ΔWC**-change in working capital, **Dep**-depreciation, $\mathbf{\Delta D_t}$-change in cash-debt, **Int**-interest payment in cash, all in year **t**.

# Simulation

Point Estimates for Input and Output

Point Estimates Replaced with Input and Output Distribution




| Feedstock Quantity and Cost (120 KW unit) | |
|---|---|
| Pine needle consumption (Kg/KWh) | 1.5 |
| Pine needle consumption per plant (Kg p.a.) | 1,140,480 |
| Pine needle loss | 20% |
| Pine needle collection (Kg/year) | 1,425,600 |
| Pine needle availability (Kg/sq.km p.a.) | 700,000 |
| Sq. Km of pine forest land required for needle collection | 2.04 |
| Landed cost of pine needles including densification/kg | $ 0.017 |
| Pine needle cost p.a. | $ 24,235 |

# Simulation: Input Variable Statistic

| Tariff (USD) | Annual Growth in Pine Needle Cost (%) | Annual Discount Rate |
|---|---|---|
| Uniform Distribution (Two Levels) | Normal Distribution | Log-Normal Distribution |
| | Mean± SD | Mean± SD (of associated Normal D) |
| 0.062 | 0 ± 0 | 15% ± 2% |
| 0.062 | 2% ± 0.5% | 15% ± 2% |
| 0.062 | 3% ± 1% | 15% ± 2% |
| 0.062 | 4% ± 2% | 15% ± 4% |
| 0.062 | 2% ± 0.5% | 18% ± 2% |
| 0.062 | 4% ± 2% | 20% ± 4% |
| 0.062 | 2% ± 0.5% | 31% ± 2% |
| 0.062 | 2% ± 0.5% | 31% ± 4% |
| 0.042 | 2% ± 0.5% | 15% ± 2% |
| 0.042 | 4% ± 2.0% | 15% ± 4% |

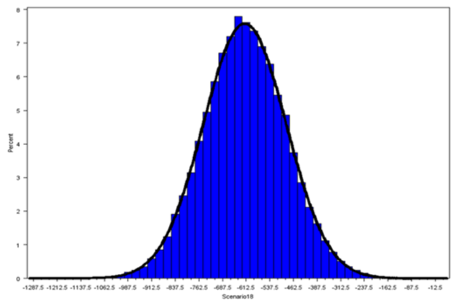
# Result: Summary

| Mean NPV (000) USD | Tariff | Growth in PN cost | Discount Rate |
|---|---|---|---|
| 1,348 | 0.062 | 0 | 15% |
| 1,096 | 0.062 | 2% | 15% |
| 951 | 0.062 | 3% | 15% |
| 1,241 | 0.062 | 4% | 15% |
| 689 | 0.062 | 2% | 18% |
| 378 | 0.062 | 4% | 20% |
| 5.86 | 0.062 | 2% | 31% |
| 22.41 | 0.062 | 2% | 31% |
| -333 | 0.042 | 2% | 15% |
| -616 | 0.042 | 4% | 15% |

Net Capital Investment over first five years = USD $1.4 million

# Example: Simulation Output Scenario 18

Tariff-.042 $
Growth in PN cost-4% (2% SD)
Exp Return: 15% post-tax
Exp Return : 4% SD



| | |
|---|---|
| Mean (000) | -616.55 |
| Standard Deviation | 131.47 |
| Kurtosis | 0.18 |
| Skewness | 0.04 |
| Minimum | -1,295.3 |
| Maximum | 8.50 |

| Quantiles for Normal Distribution | | |
|---|---|---|
| Percent | Quantile | |
| | Observed | Estimated |
| 5 | -831.4 | -832.8 |
| 25 | -704.0 | -705.2 |
| 50 | -617.6 | -616.6 |
| 75 | -528.9 | -527.9 |
| 95 | -399.9 | -400.3 |

# Conclusions

- Simulation output displays positive NPV at very high expected rate of return (discount factor) of 31% post-tax-even in scenarios of aggressive growth in pine needle cost.
- PNGP NPV is negative without FIT subsidy, even in scenarios with low discount rates (15%) and low rate of growth in pine needle cost, PNGP is not profitable.
- Among the operational variables, profitability is most sensitive to pine needle cost.

# STAKEHOLDER PERSPECTIVES ON SUPPLYING PINE NEEDLES TO A GASIFICATION UNIT IN UTTARAKHAND, INDIA

## Objectives

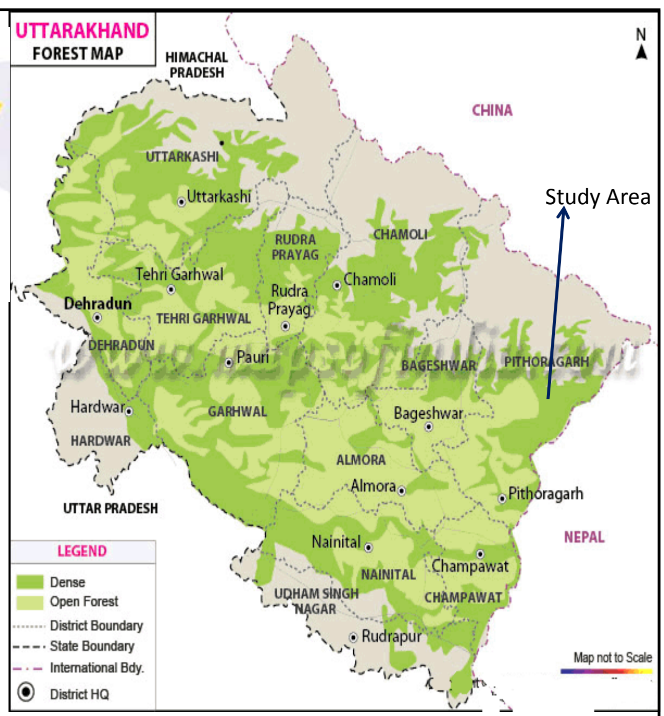
- To estimate *probabilities* of villagers' willingness to supply pine needles to the Pine Needle Gasifier Project (PNGP).
- To identify *determinants* of villagers' willingness to supply pine needles to the Pine Needle Gasifier Project (PNGP).

# Social Exchange Theory (SET): Typology of Transactions and Relationships

| Transaction | | Social Exchange | Economic Exchange |
|---|---|---|---|
| **Type of Relationship** | **Social Relationship** | 1-(Match) Social Transaction in a Social Relationship | 2-(Mismatch) Economic Transaction in a Social Relationship |
| | **Economic Relationship** | 3-(Mismatch) Social Transaction in an Economic Relationship | 4-(Match) Economic Transaction in an Economic Relationship |

(Cropanzano and Mitchell 2005)


Study Area



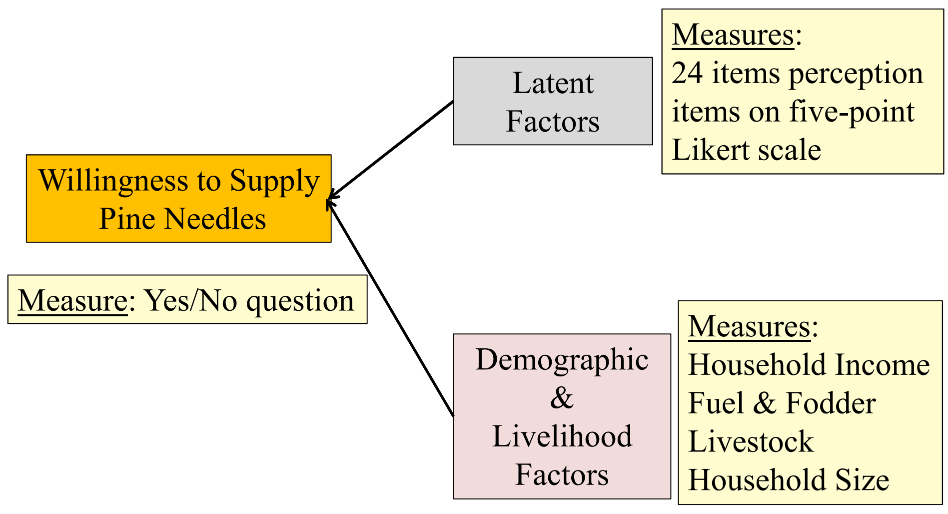
# Study Area

- For 70% of the households agriculture is the primary source of livelihood.
- Average size of farm land holding is around 0.68 hectare in the hills and 1.77 hectares in the plains.
- Subsistence nature of agriculture in the hill districts affords low and unstable annual income to rural households.
  - contributing to substantial out-migration of male members from the family.
- Approximately 36.5% of the population of the state lives below the poverty line.

# Survey

- Survey Area
  - Three villages of Kumaun hills in the Indian central Himalaya district Pithoragarh of the Uttarakhand.
  - Villages chosen for their awareness about the pine needles gasification due to presence of AVANI's pine needles gasification unit in the region.
- Sample
  - 178 households out of total 211 households in three villages
  - 155 useable surveys
- Data Collection
  - Door-to-door interviews with structured survey instrument in local language (Kumauni).
  - Survey Unit-Household Heads

## Research Model




## Model Hypotheses?

No a priori expectations about directionality or influence of modeled explanatory variables on

Willingness to Collect Pine Needles.

# Latent Dimensions Affecting Willingness to Collect Pine Needles

Second Cell Social Exchange Theory Typology: Economic transaction in a social relationship-willingness to collect pine needles is likely to have following underlying dimensions:

- Trustworthiness of the PNGP.
- Potential harm to the common forests because of the presence of the PNGP in the region.
- Viability perception of the electricity generation from pine needles.
- The economic opportunity in pine needles collection activity.
- Community and family consensus for participation in the collection activity.

Statistical Method-Exploratory Factor Analysis

**Orthogonally Rotated Factor Loading Pattern**

| **Items** | Viability | Economic Opportunity | Family& Community | Operational | Envnt |
|---|---|---|---|---|---|
| Electricity from PN is viable | **0.91** | | | | |
| PNGP will collect sufficient PN | **0.79** | | | | |
| Viable technology for electricity from PN exists | **0.76** | | | | |
| Village will supply sufficient PN | **0.75** | | | | |
| PNGP will operate for at least 5 years | **0.66** | | | | |
| Not an income enhancing opportunity for village | | **0.90** | | | |
| Not an income enhancing opportunity for family | | **0.86** | | | |
| Price for PN is inadequate | | **0.82** | | | |
| PNGP employees are not fair in dealing | | **0.70** | | | |
| Family will supply PN | | | **0.91** | | |
| Village will supply PN | | | **0.90** | | |
| Neighboring village will supply PN | | | **0.74** | | |
| PNGP will supplement energy needs of village | | | **0.68** | | |
| I possess necessary tools for PN collection | | | | **0.93** | |
| Family will find PN collection easy | | | | **0.90** | |
| Understand the process of PN collection | | | | **0.80** | |
| Negative impact on forest | | | | | **0.88** |
| PN removal will harm forests soil | | | | | **0.82** |
| PNGP will impair the air quality | | | | | **0.79** |

Explained 69.3% of variance

Mean Factor Scores

| Viability | Economic Opportunity | Family & Community Consensus | Operational Factors | Environmental Effects |
|---|---|---|---|---|
| 2.41 | 3.45 | 3.54 | 3.37 | 2.51 |

Scale

| Strongly Disagree (1) | Somewhat Disagree (2) | Neither Disagree or Agree (3) | Somewhat Agree (4) | Strongly Agree (5) |
|---|---|---|---|---|

# Logistic Regression with the Extracted Factors

| Willingness | | |
|---|---|---|
| Response | Frequency | Sample Proportion |
| No | 65 | 41.9% |
| Yes | 90 | 58.1% |

| Analysis of Maximum Likelihood Estimates | | | | |
|---|---|---|---|---|
| Parameter | DF | Estimate | Standard Error | Pr > ChiSq |
| Intercept | 1 | -1.01 | 1.48 | 0.49 |
| Economic | 1 | 0.46 | 0.20 | 0.02* |
| Family | 1 | -0.63 | 0.25 | 0.01* |
| Environment | 1 | 0.58 | 0.26 | 0.02* |
| Viability | 1 | 0.23 | 0.24 | 0.35 |
| Operation | 1 | -0.21 | 0.22 | 0.33 |

*Significant at $\alpha=0.05$

# Multiple Logistic Regression (MLR): Willingness with Demographic & Latent Variables

Variable Description

- **Willingness**: (Dependent Variable) (Binary, 0= not willing to participate in pine needles collection activity,1=willing to participate in pine needles collection activity).
- **Fodder**: (Metric) Average monthly consumption of fodder in kg by the household.
- **Household Income**: (Metric) Average monthly household income.
- **Household Size**: (Metric) Number of members in the household.
- **Fuelwood**: (Metric) Average monthly consumption of fuel wood.
- **Livestock**: (Metric) Number of livestock in the household.
- **Economic Factor**: (Metric) Economic dimension factor extracted from the FA previously.
- **Family & Community Factor**: (Metric) Family and Community factor scores extracted from the FA previously.
- **Environmental Factor**: (Metric) Environmental Dimension factor scores extracted from the FA previously

# Multiple Logistic Regression Model

Logit [π(Willingness)] =

$\beta+\alpha_1$(Household Income)+$\alpha_2$(Fodder)+ $\alpha_3$(Fuel Wood)+

$\alpha_4$(Household Size)+ $\alpha_5$(Livestock)+

$\alpha_6$(Economic Opportunity)+ $\alpha_7$(Family & Community)+

$\alpha_8$(Environmental Effect)+error

# Multiple Logistic Regression: Results

Stepwise forward selection applied
Only significant variables shown (α=.1)

| Analysis of Maximum Likelihood Estimates | | | | |
|---|---|---|---|---|
| Parameter | Estimate | Standard Error | Wald Chi-Square | Pr > ChiSq |
| Intercept | -0.43 | 0.20 | 4.73 | 0.03 |
| Household Income | 0.87 | 0.22 | 15.71 | <.0001 |
| Household Size | -1.39 | 0.53 | 6.92 | 0.01 |
| Fuel Wood | 0.89 | 0.50 | 3.20 | 0.07 |
| Livestock | -0.79 | 0.21 | 14.47 | 0.00 |
| Economic | 0.36 | 0.20 | 3.17 | 0.07 |
| Environment | 0.47 | 0.20 | 5.29 | 0.02 |

# Model Interpretation

Fuelwood Consumption
An increase of one standard deviation in Fuelwood increases the odds of indicating "no" on Willingness by 142 %

(One Std Dev for Fuel Wood=98 kg).

Livestock
An increase of one standard deviation in Livestock reduces the odds of indicating "no" on Willingness by 54%

(One Std Dev for Livestock=2.67 animals).

Household Income
An increase of one standard deviation in Household Income increases the odds of indicating "no" on Willingness by 138%

(One Std Dev for Household Income=Rs.1360)

Household Size
An increase of one standard deviation in Household Size reduces the odds of indicating "no" on Willingness by 75%

(One Std Dev for Household Size=2.25 person)

# Model Interpretation

<u>Economic Opportunity</u>
An increase of one standard deviation in Economic Dimension increases the odds of indicating "no" on Willingness by 44%
(One Std Dev for Economic Dimension=0.9 units)

<u>Environmental Effect</u>
An increase of one standard deviation in Environmental Dimension increases the odds of indicating "no" on Willingness by 60%
(One Std Dev for Economic Dimension=0.7 units)

# Study: Conclusions

- Failure to translate feedstock potential into actual supply is the major factor underlying underperformance of bio-based electricity sector in India.
  - Small scale and distributed power units based on local feedstocks that have fewer alternative uses are more likely to succeed.
- Governance and capacity deficit are other major factors for underperformance.
- Small scale power units based on locally available feedstock need some extent of subsidized FIT.
  - Conversion technology needs to be more efficient.

## Study: Conclusions

- **Power units' profitability** is highly sensitive to feedstock harvesting and collection cost even in absence of significant transportation cost.
- **Villagers' willingness to supply pine needles** is influenced by (in ranked order):
  1. Fuel Wood Consumption
  2. Household Income
  3. Household Size
  4. Livestock
  5. Environmental Effect
  6. Economic Opportunity

## Overall Dissertation Summary

- In India, vast unrealized potential for bioenergy is not due to lack of biomass availability and promotional policies; it is, instead, due to governance failure, lack of a technological eco-system, and supporting infrastructure.
- Even in cases where biomass feedstock has no other competing uses and is cheaply available, some degree of subsidy is needed for financial viability.
- Biomass feedstock resourcing requires community participation and social acceptance; this sector is suitable for social entrepreneurship.
- Small-scale and distributed bioenergy production model can have substantial positive impact on livelihood, health, and education in rural areas.
  - Can help mitigate forest degradation by weaning villagers away from fuel wood and fodder extraction from the forests.

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