PGP RE MODULE 1 (Jan – June 2025)

Assignment 2

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1. Project Introduction

Sundarpur, a semi-rural region in India with around 15,000 inhabitants, faces frequent electricity outages due to its dependence on a distant, unreliable coal-based power grid. The local economy is primarily agrarian, with small-scale food processing and textile units that operate intermittently due to unreliable power supply. Under its sustainable development goals, the state government has announced a mission to convert Sundarpur into a “Model Renewable Energy Village” by 2030. As part of this mission, we have been hired by the state’s energy department to develop a comprehensive renewable energy plan for the village.

We need to factor in the following points:

- Energy demand estimation (domestic, agricultural, commercial)
- Selection of renewable technologies suited to local resources (e.g., solar, biogas, wind)
- Social, environmental, and economic sustainability
- Integration with national energy policy frameworks and SDG goals

We are expected to address the following points:

- Evaluate different renewable energy options
- Consider technical feasibility and affordability
- Address social acceptance, employment generation, and long-term sustainability

Case-based Questions

- From the perspective of the Indian energy sector, what are the key limitations of continuing Sundarpur’s dependence on grid-connected coal-based power, and how does the shift to decentralized renewable energy align with current national energy trends?
- Based on the local context, which combination of renewable energy technologies would you recommend for Sundarpur, and why? Consider the availability of resources, load profile, seasonal variations, and cost-effectiveness.
- How can the proposed energy plan contribute to sustainable development in Sundarpur? Highlight environmental benefits, potential for job creation, and ways to ensure community involvement and energy equity.

2. Energy demand estimation (domestic, agricultural, commercial)

Introduction: We conducted a comprehensive assessment considering current and future needs. Here are the key factors to consider:

1. **Current Energy Consumption Patterns**
- **Residential electricity usage**: Average household consumption, peak loads, seasonal variations
- **Community facilities:** Schools, health centers, administrative buildings, street lighting
- **Agricultural requirements**: Irrigation pumps, processing equipment, storage facilities
- **Small businesses/commercial needs**: Shops, workshops, small-scale industries
- **Current fuel usage**: cooking fuels, heating, transportation, and agricultural machinery

2. **Population Factors**
- **Current population size,** Population growth rate**,** and **number of households**
- **Demographic distribution** (age groups, **household sizes**)
- **Economic activities** and potential changes over time

3. **Geographical and Climate Considerations**
- **Seasonal variations** affecting energy needs (heating, cooling, agricultural cycles)
- **Available renewable resources**: Solar, wind speeds, water flow, biomass availability
- **Land availability** for renewable energy installations

4. **Development Goals and Future Demand**
- **Planned infrastructure projects** (water supply, healthcare, education)
- **Economic development initiatives** that may increase energy demand
- **Electrification of processes** currently using non-renewable fuels
- **Potential new industries or agricultural activities**

5. **Technical and Implementation Factors**
- **Energy efficiency potential:** Opportunities to reduce demand through efficiency measures
- **Load management strategies:** Peak shaving, demand response capabilities
- **Storage requirements** for intermittent renewables
- **Distribution losses** in the local grid

6. **Social and Cultural Considerations**
- **Current energy (cultural, cooking) practices** and willingness to adopt new technologies
- **Energy poverty** and basic needs are currently unmet or unreliable

7. Economic Factors
- **Affordability for residents** and the ability to pay for energy services
- **Current expenditure on energy** (traditional fuels, batteries, kerosene, etc.)
- **Potential productive uses** of energy that could generate income
- **State/Central government financing mechanisms or subsidies**

Population Characteristics

Given Data	
Total population	15,000 inhabitants
Setting	Semi-rural region in India
Key economic activities	Agriculture, Small-scale food processing, textile units
	Currently, energy needs are met by a coal-based plant
Assumptions	
Average household size	4
Number of households	15000/4 = 3750
Electrification rate	90%
Electrified households	3375

Based on the above details, let us first calculate the ideal total energy consumption based on the demography.

Total energy consumption = Total electricity consumption + Total fuel consumption + Energy consumption through other sources

We will focus on electricity consumption here for simplicity, avoiding consumption from fuels like diesel and other sources.

Total energy consumption ~ Total electricity consumption

This Total energy consumption plus some surplus would be **our energy demand** for Sundarpur.

Domestic energy demand estimation

Parameter	**Value**	**Units**	**Calculation**
Population	15,000	persons	-
Average household size	4	persons/household	-
Number of households	15,000 ÷ 4	Households	3750
Electrification rate	90%	Percentage	-
Electrified households	3750 × 90%	Households	3375
Electricity Consumption			
Average monthly consumption per electrified household	100	kWh/month	-
Annual domestic electricity consumption	3,375 × 100 × 12	kWh/year	**4050000**
Lighting (non-electric)			
Non-electrified households	3750-3375	Households	375
Kerosene consumption per household	5	liters/month	-

Annual kerosene consumption	375 × 5 × 12	liters/year	22500
Kerosene energy content	35	MJ/liter	-
Annual kerosene energy	22500 × 35	MJ/year	787500
Annual kerosene energy	787500 *0.277778	kWh/year	**218750**
TOTAL DOMESTIC ENERGY		**kWh/year**	**4268750**

Agricultural Energy Demand

Parameter	Calculation	Units	Value
Cultivated land	2,000	hectares	-
Irrigated land percentage	70%	percentage	-
Irrigated land	2,000 × 70%	hectares	1400
Irrigation Pumps			
Average pump capacity	5	HP	-
Average pump capacity	5 × 0.746	kW	3.73
Number of pumps	1	pump/3 hectares	1,400 ÷ 3= 467
Average operating hours	1,000	hours/year	-
Annual electricity for irrigation	467 × 3.73 × 1,000	kWh/year	**1741910**
Agricultural Processing			
Small machinery electricity	500,000	kWh/year	**500000**
TOTAL AGRICULTURAL ENERGY		**kWh/year**	**2241910**

Commercial Energy Demand

Parameter	Value	Units	Calculation
Small Shops and offices			
Number of shops/establishments	300	Units	-
Average electricity consumption	200	kWh/month/unit	-
Annual electricity consumption	300 × 200 × 12	kWh/year	**720000**
Food Processing Units			
Number of units	25	Units	-
Average electricity consumption	2,000	kWh/month/unit	-
Annual electricity consumption	25 × 2,000 × 12	kWh/year	**600000**
Textile Units			
Number of units	20	Units	-

Average electricity consumption	3,000	kWh/month/unit	-
Annual electricity consumption	20 × 3,000 × 12	kWh/year	**720000**
Community Facilities			
Schools, health centers, and community buildings	15	Units	-
Average electricity consumption	1,000	kWh/month/unit	-
Annual electricity consumption	15 × 1,000 × 12	kWh/year	**180000**
Public Lighting			
Streetlights	500	Units	-
Average wattage	60	W/unit	-
Operating hours	12	hours/day	-
Annual electricity consumption	500 × 0.06 × 12 × 365	kWh/year	**131400**
TOTAL COMMERCIAL ENERGY		**kWh/year**	**2351400**

<u>ENERGY (ELECTRICITY) DEMAND SUMMARY</u>

Sector	**Annual Electricity Demand (kWh/year)**	**Percentage of Total**
Domestic	4,268,750	48.17%
Agricultural	2,241,910	25.30%
Commercial	2,351,400	26.53%
TOTAL	**8,862,060 KWh/year**	**100%**

3. Social, environmental, and economic sustainability

Social sustainability

- **Land acquisition challenges:** Many renewable projects (especially solar and wind) require substantial land, often leading to disputes over ownership, fair compensation, displacement, and apprehension towards food security and traditional livelihoods.
- **Community engagement**: Projects with meaningful early community consultation and participation tend to have higher acceptance rates.
- **Social equity concerns**: Gender dimension and caste dynamics could hinder the benefits of renewable energy projects for all sections of society.

Environmental sustainability

1. **Biodiversity Conservation**:
   - Comprehensive baseline studies before development
   - Wildlife corridors preservation with a minimum 100m width
   - Native vegetation integration between array blocks
2. **Water Management**:
   - Rainwater harvesting infrastructure throughout the site
   - Module cleaning systems with 90% water recycling capacity
   - Groundwater monitoring network establishment
3. **Soil Protection**:
   - Minimal grading approach to preserve topsoil
   - Erosion control measures emphasizing natural vegetation
   - Soil quality monitoring program
4. **Land Use Change:**
   - Potential impacts on food security and local economies
   - Agrivoltaics implementation to maintain dual land productivity
   - Revenue-sharing models for community-owned or utilized lands

Economic sustainability:

- 150-200 direct jobs created
- Local infrastructure improvements
- Energy expenditure savings
- Improved agricultural productivity
- Enhanced local manufacturing opportunities

4. Integration with national energy policy frameworks and SDG goals

Alignment with India's energy policy frameworks

- **India's Panchamrit declaration at COP 26**: Renewable energy projects in Sundarpur align with India's ambitious target of **500 GW non-fossil fuel capacity by 2030 and 50 per cent of its energy requirements from renewable energy by 2030.**

- **India's National Solar Mission (NSM):** Launched in January 2010, it is one of eight missions under the **National Action Plan on Climate Change** (NAPCC). It focuses on bringing reliable electricity to energy-deficient semi-rural areas, thus **promoting clean energy alternative**s.

- **The PM-KUSUM scheme** specifically targets farmers and rural landowners for solar implementation.

Alignment with UN Sustainable Development Goals

SDG 7: Affordable and Clean Energy

- Direct contribution through expanded access to modern energy services in semi-rural regions
- Increases share of renewable energy in India's energy mix
- Improves energy efficiency through decentralized generation reducing transmission losses

SDG 8: Decent Work and Economic Growth

- Creates local employment opportunities in construction, operations, and maintenance
- Enables productive energy use for local businesses and cottage industries
- Reduces energy costs for local enterprises, improving competitiveness

SDG 13: Climate Action

- Reduces greenhouse gas emissions by displacing fossil fuel generation
- Builds local climate resilience through decentralized energy infrastructure
- Supports India's Nationally Determined Contributions (NDCs) under the Paris Agreement

Case-based Questions

Q1. From the perspective of the Indian energy sector, what are the key limitations of continuing Sundarpur's dependence on grid-connected coal-based power, and how does the shift to decentralized renewable energy align with current national energy trends?

Coal-based power grid offers centralized coal power infrastructure and does not align with the distributed nature of semi-rural communities. However, there is a natural alignment between decentralized renewable energy and the actual needs of these regions.

The Problem: Grid-Connected Coal Power in Semi-Rural India

Semi-rural regions in India face significant challenges with traditional coal-based power:

- **Unreliable service**: Frequent power cuts, voltage fluctuations, and limited hours of electricity
- **Last-mile connectivity issues**: High transmission costs and infrastructure gaps leave many areas underserved
- **Economic burden**: Rising coal prices and inefficient distribution increase costs for consumers and the government
- **Environmental impact**: results in GHG emissions, leads to Global warming and climate change, and affects community health
- **Seasonal vulnerabilities**: Monsoons and extreme weather frequently disrupt transmission infrastructure

The Alternative: Decentralized Renewable Energy

Renewable energy solutions address these limitations through:

- **Local generation**: Power produced closer to where it's needed
- **Modular design**: Systems can be sized appropriately for community needs
- **Rapid deployment**: Faster implementation compared to grid extension
- **Reduced dependence**: Less vulnerability to national grid failures, options for microgrids
- **Economic growth**: Facilitates local job creation and improved infrastructure

Alignment with National Energy Trends

This shift aligns with India's evolving energy strategy:

- **Policy pivot**: Government focus shifting from centralized to distributed generation models
- **Investment patterns**: Growing public and private investment in renewable infrastructure
- **Rural electrification priority**: National emphasis on reliable power for all communities
- **Energy independence**: Reducing dependence on imported fossil fuels
- **Climate commitments**: Supporting India's NDC commitments towards the Paris agreement and emissions reduction pledges, Net Zero by 2070.

Q2. Based on the local context, which combination of renewable energy technologies would you recommend for Sundarpur, and why? Consider the availability of resources, load profile, seasonal variations, and cost-effectiveness.

Based on the energy demand estimation earlier, the proposed renewable energy projects should have a combined installed capacity of **around 2 MW**. Let us explore and evaluate different renewable energy options, along with their technical feasibility and affordability.

PEAK LOAD ESTIMATION

Parameter	Calculation	Units	Values
Annual electricity consumption	8,862,060	kWh/year	-
Load factor	0.4	ratio	-
Peak demand	8862060 ÷ (8760 × 0.4)	kW	2530 kW
Diversity factor	0.7	ratio	-
Coincident peak demand	2530 × 0.7	kW	1770 kW
Peak demand with a 20% margin	1770 × 1.2	kW	**2124 kW**

Solar energy

Here are the key technical parameters that determine whether a location is favorable for solar panel installation.

1. **Solar Irradiance (Solar Radiation)**

- **Definition**: The Amount of solar power received per unit area expressed in GHI and DNI.
- **Ideal Value:** ≥ 4.5 kWh/m²/day (India receives 4–7 kWh/m²/day across most regions).

2. **Orientation and Tilt Angle**

- **Ideal Orientation**: South-facing (in the Northern Hemisphere).
- **Tilt Angle:** Equal to the latitude of the location for maximum yearly output.

3. **Shadow-Free Area**

- **Requirement**: No shadow on the panels from 9 AM to 4 PM year-round.
- **Spacing**: Panels should be spaced to avoid self-shading if mounted in rows.

4. **Ambient Temperature**

- **Ideal Range**: 25–35°C is acceptable; higher temperatures reduce panel efficiency.
- **Derating Factor**: Panels typically lose 0.4–0.5% efficiency per °C rise above 25°C.

5. **Wind Load and Structural Stability**

- **Check**: Wind speed in the region (important for rooftop vs. ground-mount).
- **Compliance**: Design as per IS 875 (Part 3) standards in India.

6. **Roof or Land Suitability**

- **Rooftop**: Slope, strength, and material (concrete roofs preferred).
- **Ground**: Soil condition, contour, and area availability (typically ~100 m^2 per 10 kW).

7. **Grid Connectivity (for On-grid Systems)**

- **Proximity to grid**: Distance to transformer/substation.
- **Feeder Load:** Whether the local grid can absorb/distribute the power generated.

8. **Dust and Cleaning Requirements**

- **Dust Level:** High dust areas (semi-arid, industrial) need frequent cleaning.
- **Water Access:** Clean water is required for panel cleaning. A robotic waterless cleaning option can be preferred.

Sundarpur is favorably placed for solar energy with high solar radiation intensity.

The following installations are suggested for solar energy:

Rooftop Solar for Households

- **Implementation**: Government subsidies through PM-KUSUM and similar schemes
- **Cost estimate**: ₹40,000-60,000 per kW (after subsidies)
- **System size**: 1-2 kW per household

Community Solar Microgrids: A community solar microgrid is a clean, decentralized energy solution designed to bring reliable and sustainable electricity to underserved areas, especially where grid extension is costly or impractical.

As the grid is at a **far distance** and the setup is in a **semi-rural area**, these community solar microgrids are more economical as compared to setting up a solar power plant and then connecting to the grid.

- **Implementation:** MNRE (Ministry of New & Renewable Energy) subsidy schemes (up to 40–70% capex support).
- **Cost estimate:** Approx. 1 crore per 100 kW.
- **System size**: 5-6 microgrids of 100 kW each with 1.5 MWh storage = 550 kW

Solar Agricultural Pumps

- Replace 75% of irrigation pumps with solar pumps
- 150 pumps × 5 HP = 750 HP (560 kW)
- **Annual displacement**: ~562,500 kWh/year
- Implementation: Utilize the PM-KUSUM component B subsidies

Biomass Solutions

Agriculture is the major source of biomass production in India, particularly in rural and semi-rural areas. This surplus biomass can be utilized for power generation using various technologies like direct combustion, anaerobic biogas production, and biomass gasification.

Key Aspects of Biomass Energy Generation in Semi-Rural India:

- **Biomass Availability**

  Agricultural residues, particularly from cereals like rice and wheat, and animal manure, are abundant in semi-rural areas.

- **Decentralized Generation**

  Biomass power projects can be tailored to local energy demands, improving electricity quality and reliability in rural areas.

- **Environmental Benefits:**

  Using biomass reduces reliance on fossil fuels and can contribute to lower greenhouse gas emissions compared to traditional power generation methods.

- **Economic and Social Benefits:**

  Biomass power generation creates employment opportunities, boosts local economies, and improves access to energy, which can enhance livelihoods and economic activities

Below, biomass-based solutions can be suggested:

- **Community Biogas Plants**

  - **Units:** 8-10 community plants (50 m^3 capacity each)
  - **Feedstock**: Agricultural waste, animal dung
  - **Energy output:** 10 plants × 50 m^3 × 21 MJ/m^3 × 365 days = 3,832,500 MJ/year
  - **Uses:** Cooking gas for 400-500 households, displacing LPG and traditional biomass

- **Biomass Gasification System**

    - **Units**: 2 systems of 100 kW each
    - **Annual generation**: 200 kW × 70% capacity factor × 8,760 hours = **1,226,400** kWh/year
    - **Feedstock requirement**: ~1,100 tons/year of agricultural residues
    - **Applications**: Power for food processing and textile units

Wind Energy

Technical feasibility for wind energy depends on the following factors:

Factor	Requirement / Threshold
Wind speed	≥ 5.5 m/s at 80–100 m height
Land	Flat, non-forested, road accessible
Grid availability	Substation within ~10–15 km ideally
Soil	Stable for deep foundations

Wind Power of 1MW typically requires a cost: **₹6–8 crore** and land of ~ **1 acre**.

However, for Sundarpur, as the grid connectivity is a challenge and the soil is not stable, small wind turbines can be proposed for harnessing wind energy:

- 10-15 turbines of 10 kW each (based on wind resource availability)
- Total capacity: 100-150 kW
- Annual generation (at 20% capacity factor): 125 kW × 20% × 8,760 hours = 219,000 kWh/year

Total Annual Renewable Generation:

Solution Type	Capacity	Annual Generation	Units (kWh or MJ)	Implementation Details	Estimated Cost (₹)
Rooftop Solar	2.8 MW	4,106,250	kWh	1,875 households with 1-2 kW systems (50% households using 1.5 kW on average for 4 hr. daily)	112,500,000 - 168,750,000
Community Solar Microgrids	550 kW	825,000	kWh	5-6 microgrids of 100 kW each with 1.5 MWh storage	55,000,000 - 66,000,000
Solar Agricultural Pumps	560 kW	562,500	kWh	150 pumps × 5 HP	45,000,000 - 52,500,000
Community Biogas Plants	500 m^3 total	3,832,500	MJ	10 plants × 50 m^3 capacity	15,000,000 - 20,000,000
Biomass Gasification	200 kW	1,226,400	kWh	2 systems of 100 kW each	16,000,000 - 20,000,000
Small Wind Turbines	125 kW	219,000	kWh	10-15 turbines of 10 kW each	18,750,000 - 22,500,000
Community Battery Storage	1.5 MWh	-	-	-	30,000,000 - 45,000,000

- **Electricity**: ~10,771,650 kWh/year (exceeding demand by ~21%)
- **Thermal energy**: ~3,832,500 MJ/year (additional thermal energy)
- **Estimated overall Cost**: ₹29 Crores to ₹39 Crores

Implementation Strategy

The renewable energy projects can be implemented in a phased manner (1-3 years)

- **Phase 1**: Energy efficiency, Solar rooftops, Improved cookstoves, small wind turbines
- **Phase 2**: Community solar microgrids, Biogas plants
- **Phase 3**: Biomass gasification

Conclusion:

Thus, for Sundarpur, an abundance of solar radiation, availability of biomass in a semi-rural setting, and support from small wind turbines could be the perfect combination to meet the energy demands sustainably. These together will ensure **complementary** and **reliable** power generation.

Q3. How can the proposed energy plan contribute to sustainable development in Sundarpur? Highlight environmental benefits, potential for job creation, and ways to ensure community involvement and energy equity.

Renewable Energy for Sustainable Development in Sundarpur

Environmental Benefits

- **Reduced air pollution**: By avoiding GHG emissions, it improves the quality of air.
- **Water conservation**: Unlike coal plants, solar and wind systems require minimal water, crucial in water-stressed rural regions
- **Land preservation**: Dual-use designs like agrivoltaics allow continued agricultural activities alongside energy generation
- **Biodiversity protection**: Smaller ecological footprint compared to mining and large-scale power plants, thus preventing biodiversity loss
- **Climate resilience:** Distributed systems better withstand extreme weather events, providing reliable power during climate disruptions

Economic Opportunities and Job Creation

- **Infrastructure improvement**: construction of projects leads to new infrastructure such as roads, godowns, warehouses, and boosts the local economy.
- **Immediate and long-term employment opportunities**: Laborers, masons will be needed for immediate construction purposes. The plant operations and maintenance will require long-term technical roles for monitoring, cleaning, and repairs.
- **Skills development**: Skill development centers will create new pathways to energy sector careers.
- **Energy entrepreneurs**: Local businesses emerge for solar PV system sales, battery services, and appliance distribution.
- **New business opportunity**: Warehouse, agro-processing, cold storage, and digital services may come up backed up by reliable electricity.

Community engagement

Engaging with the local communities in the setup of the solar energy plant's operations and decision-making can go a long way in building trust with them. This engagement often includes understanding community needs, fostering positive relationships, and actively contributing to the social, economic, and environmental well-being of the communities in which they operate.

Some of the strategies for community engagement are listed below:

- **Conduct regular meetings**: Organize regular meetings with the community to provide updates on the benefits of the upcoming plant, such as local job creation and economic development.

- **Establish a community advisory group:** Form a committee comprising community leaders, residents, and project representatives to facilitate dialogues and address community concerns and their needs.
- **Directly support community development**: Companies implement programs that directly support community development in areas such as education, health, and infrastructure.
- **Effectively monitor community engagement initiatives:** By actively tracking the key performance indicators (KPIs) for community engagement initiatives, such as local employment rates, companies can enhance transparency and ultimately foster stronger relationships with the community they serve.
- **Build trust early on**: Effective community engagement fosters trust between companies and local communities, which is crucial for long-term success and avoiding conflict and negative publicity.

Energy Equity

Energy equity stems from the principles of social justice and assumes that affordable and reliable energy should be a fundamental human right.

- **Energy democracy**: Enables democratization and decentralization of energy production. This aligns with UN **SDG 7** (Affordable and Clean Energy).
- **Gender-sensitive design:** Addressing women's energy needs and ensuring their participation in decision-making. This aligns with UN **SDG 5** (Gender Equality).
- **Marginalized group inclusion:** Special provisions for historically excluded communities, including lower castes and tribal populations.
- **Public facility electrification**: Prioritizing schools, health centers, and community marriage halls for broader social benefit.
- **Reducing poverty and improving quality of life**: energy access enables agricultural productivity and poverty reduction. This aligns with UN **SDG 1 & 2** (No Poverty, Zero Hunger).

By addressing environmental, economic, and social dimensions simultaneously, renewable energy projects in Sundarpur can truly drive sustainable development.

Conclusion:

Based on the detailed analysis above, **solar, biomass, and small wind turbines** together will ensure **complementary and reliable generation of power**. This needs to be supported with **energy storage solutions** to provide consistent power even in non-favorable conditions like rainy, cloudy, or night, coupled with **energy efficiency measures** (LED lights, energy-efficient appliances), **roof insulation**, and **reflective paint** to cool down the homes in the summer season. These measures, when implemented, will go a long way in ensuring energy sustainability in Sundarpur and help the State government develop Sundarpur into a "**Model Renewable Energy Village**" by 2030 under its sustainable development goals.