SOLAR vs WIND ENERGY COMPREHENSIVE COMPARISON REPORT

Renewable Energy Technologies Analysis

Indian Market Edition - Costs in INR Crores

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EXECUTIVE SUMMARY

Both solar and wind energy are leading renewable energy technologies with distinct advantages and applications. This comprehensive comparison analyzes their technical specifications, costs, performance characteristics, and optimal use cases to help guide investment and deployment decisions in the Indian market.

Aspect	Solar Energy	Wind Energy
Capital Cost (per MW)	■6.5-10 crore	■11-18 crore
Capacity Factor	15-25%	25-45%
Best Location	Widespread applicability	High wind speed areas
Space Efficiency	Moderate	High (vertical)
Maintenance	Low	Moderate
Lifespan	25-30 years	20-25 years
Visual Impact	Low	High
Noise	Silent	Moderate

BOTTOM LINE: Solar energy offers lower costs and broader applicability, making it ideal for residential, commercial, and distributed generation. Wind energy provides higher capacity factors and energy density, making it optimal for utility-scale projects in high-wind regions. The best solution often involves a hybrid approach leveraging both technologies.

TECHNOLOGY OVERVIEW

Solar Energy Technology

Solar photovoltaic (PV) systems convert sunlight directly into electricity through semiconductor materials. Modern systems use crystalline silicon or thin-film technologies with efficiencies ranging from 15-23% for commercial applications. Solar installations can be ground-mounted, rooftop, or integrated into building materials (BIPV).

Key Components:

- Solar panels (modules) - Convert sunlight to DC electricity
- Inverters - Convert DC to AC electricity
- Mounting structures - Fixed tilt or tracking systems
- Balance of system - Wiring, monitoring, protection devices

Wind Energy Technology

Wind turbines convert kinetic energy from wind into electrical power through rotating blades connected to a generator. Modern turbines range from small residential units (1-10 kW) to massive offshore installations (8-15 MW). The power output increases with the cube of wind speed, making location critical.

Key Components:

- Rotor blades - Capture wind energy (typically 3 blades)
- Nacelle - Houses generator, gearbox, and controls
- Tower - Elevates turbine to stronger wind speeds
- Foundation - Supports the entire structure

COST ANALYSIS (INR CRORES)

Capital Costs (CAPEX)

Cost Component	Solar (Utility-Scale)	Wind (Onshore)	Wind (Offshore)
Equipment	■5.0-6.6 cr/MW	■7.5-10.0 cr/MW	■21-29 cr/MW
Installation	■1.2-2.1 cr/MW	■2.1-3.3 cr/MW	■12-17 cr/MW
Grid Connection	■0.4-1.2 cr/MW	■1.2-5.0 cr/MW	■4-12 cr/MW
Total CAPEX	■6.6-10 cr/MW	■11-18 cr/MW	■37-58 cr/MW

Operating Costs (OPEX)

Cost Type	Solar	Wind (Onshore)	Wind (Offshore)
Annual O&M	■0.8-1.7 L/MW/yr	■3.3-5.0 L/MW/yr	■8-12 L/MW/yr
Major Overhauls	Minimal	Every 5-7 years	Every 5-7 years
Monitoring	■0.2-0.4 L/MW/yr	■0.4-0.8 L/MW/yr	■1.2-2.1 L/MW/yr
Total Annual	■1.2-2.1 L/MW/yr	■4.1-6.2 L/MW/yr	■10-15 L/MW/yr

Note: L = Lakh (■1,00,000); Cr = Crore (■1,00,00,000)

Levelized Cost of Energy (LCOE)

The LCOE represents the average cost per unit of electricity generated over the lifetime of the project. Recent trends show significant cost reductions for both technologies, with solar achieving the lowest costs in many markets across India.

Technology	2015 LCOE	2024 LCOE	Reduction	2030 Forecast
Solar (Utility)	■5.0-6.6/kWh	■2.1-2.9/kWh	60%	■1.2-2.1/kWh
Wind (Onshore)	■4.1-5.8/kWh	■2.5-4.1/kWh	35%	■2.1-3.3/kWh
Wind (Offshore)	■12-17/kWh	■5.8-8.3/kWh	50%	■4.1-5.8/kWh

PERFORMANCE COMPARISON

Metric	Solar PV	Wind (Onshore)	Wind (Offshore)
Capacity Factor	15-25%	25-35%	40-50%
Annual Energy Output	1,300-2,200 MWh/MW	2,200-3,000 MWh/MW	3,500-4,500 MWh/MW
Efficiency	15-23%	35-45%	40-50%
Availability	98-99%	95-98%	90-95%
Peak Power Time	Midday (10am-4pm)	Variable	More consistent
Seasonal Variation	Higher in summer	Higher in winter	More consistent
Predictability	Highly predictable	Moderately predictable	Less predictable
Intermittency	Daily cycle	Variable	Less variable

Land & Space Requirements

Parameter	Solar PV	Wind
Land per MW	4-6 acres	60-100 acres (includes spacing)
Actual Footprint	4-6 acres	0.5-1 acre (turbine base only)
Land Use Efficiency	Moderate	High (vertical utilization)
Dual Land Use	Agrivoltaics possible	Agriculture between turbines
Rooftop Potential	Excellent	Limited (small turbines only)

ENVIRONMENTAL IMPACT

Factor	Solar PV	Wind Energy
CO■ Emissions (lifecycle)	30-50 g/kWh	10-20 g/kWh
Water Usage	Minimal (cleaning only)	None
Wildlife Impact	Low (habitat change)	Moderate (bird/bat mortality)
Noise Pollution	Silent	35-45 dB at 300m
Visual Impact	Low to moderate	Moderate to high
End-of-Life Recycling	85-95% recyclable	85-90% recyclable
Toxic Materials	Minor (silicon, silver)	Minimal
Land Remediation	Easy	Easy

Key Insight: Both technologies have significantly lower environmental impacts compared to fossil fuels (coal: 820 g CO■/kWh, natural gas: 490 g CO■/kWh). Wind has slightly lower lifecycle emissions, while solar has less impact on wildlife and no noise pollution.

ADVANTAGES & DISADVANTAGES

Solar Energy

Advantages:

- ✓ Lower capital and operating costs
- ✓ Widespread applicability - works in most locations
- ✓ Scalable from watts to megawatts
- ✓ Silent operation - no noise pollution
- ✓ Minimal visual impact for rooftop installations
- ✓ Predictable daily output pattern
- ✓ Low maintenance requirements
- ✓ Ideal for distributed generation

Disadvantages:

- ✗ Lower capacity factor (15-25%)
- ✗ No generation at night
- ✗ Weather dependent (clouds reduce output)
- ✗ Requires significant land area

✗ Panel degradation over time (~0.5%/year)

✗ Energy storage needed for 24/7 supply

Wind Energy

Advantages:

✓ Higher capacity factor (25-45%)

✓ Lower lifecycle carbon emissions

✓ Can generate 24/7 (if wind available)

✓ Higher energy density per unit

✓ Efficient use of vertical space

✓ Land can be dual-purpose (agriculture)

✓ Offshore wind has excellent potential

✓ Better complement to solar (winter peak)

Disadvantages:

✗ Higher capital and operating costs

✗ Location dependent - needs consistent wind

✗ Visual and noise impact

✗ Wildlife concerns (birds, bats)

✗ More complex maintenance

✗ Wind variability creates grid challenges

✗ Not suitable for urban/residential areas

OPTIMAL USE CASES

Application	Recommended Technology	Rationale
Residential	Solar	Lower cost, rooftop suitable, silent, no permits issues
Commercial Buildings	Solar	Rooftop potential, peak demand alignment, incentives
Industrial Facilities	Solar (or Hybrid)	Large roofs/land, cost savings, sustainability goals
Remote/Off-grid	Hybrid (Solar + Wind + Battery)	Complementary generation, reliability
Utility-Scale (Plains)	Wind	High capacity factor, excellent wind resource
Utility-Scale (Sunny Regions)	Solar	Lower cost, abundant solar resource
Offshore Installations	Wind	Consistent strong winds, higher capacity factor
Developing Nations	Solar	Simpler installation, lower maintenance, modular
Grid Stabilization	Hybrid (Solar + Wind + Storage)	Complementary profiles, reduced variability

FINANCIAL COMPARISON (10 MW PROJECT)

Financial Metric	Solar PV	Wind (Onshore)
Total Investment	■66-100 crore	■110-180 crore
Annual Energy Output	18,000 MWh	28,000 MWh
Annual Revenue (■4.2/kWh)	■7.56 crore	■11.76 crore
Annual OPEX	■1.2-2.1 crore	■4.1-6.2 crore
Annual Net Income	■5.45-6.36 crore	■5.56-7.66 crore
Simple Payback	12-18 years	14-32 years
IRR (over 25 years)	8-12%	6-10%
LCOE	■2.5-2.9/kWh	■3.3-4.1/kWh

Note: Actual financial performance varies significantly based on location, resource quality, financing terms, and local incentives. Wind projects in high-wind areas can achieve IRRs of 12-15%, while solar in optimal locations may reach 15-18% IRR. Revenue assumes average power purchase rate of ■4.20/kWh for utility-scale projects in India.

STRATEGIC RECOMMENDATIONS

The optimal choice between solar and wind energy depends on multiple factors including location, resource availability, budget, land constraints, and project goals. Consider the following framework for the Indian market:

Decision Framework

Choose Solar When:

- Budget is limited (lower upfront investment: ■6.6-10 cr/MW)
- Wind resources are poor or inconsistent
- Project is residential or commercial building
- Rooftop or limited ground space available
- Silent operation is required
- Located in sunny regions (Rajasthan, Gujarat, Karnataka)
- Quick payback is priority (12-18 years)
- Minimal maintenance capability

Choose Wind When:

- Located in high wind speed areas (>6 m/s average) - Tamil Nadu, Gujarat, Karnataka coastal
- Large land area available (60-100 acres per MW)
- Utility-scale project (>5 MW)
- Maximum energy generation per footprint is priority
- Winter peak generation needed
- Long-term lowest LCOE is goal (despite higher CAPEX: ■11-18 cr/MW)
- Offshore location possible (Gujarat, Tamil Nadu coasts)

Choose Hybrid (Solar + Wind) When:

- Maximum reliability and uptime required
- Both solar and wind resources available
- Utility-scale with land for both technologies
- Grid stabilization is priority
- Want to minimize intermittency
- Can benefit from complementary generation patterns
- Corporate sustainability goals (maximize renewables)

India-Specific Insights

Solar Hotspots: Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Telangana

Wind Hotspots: Tamil Nadu (40% of India's wind capacity), Gujarat, Karnataka, Maharashtra, Rajasthan

Government Incentives: • Accelerated Depreciation (40% in Year 1) • Generation-Based Incentives (GBI) for select states • GST benefits (5% on solar modules, 12% on wind turbines) • Viability Gap Funding (VGF) for certain projects • State-specific incentives and subsidies

CONCLUSION

Both solar and wind energy are mature, cost-effective renewable technologies with complementary strengths. Solar offers the lowest cost (■6.6-10 cr/MW), broadest applicability, and simplest implementation, making it the preferred choice for distributed generation, residential, and commercial applications across India. Wind provides higher capacity factors and energy density, making it optimal for utility-scale projects in high-wind coastal and plains regions.

The future of renewable energy is not solar versus wind, but solar AND wind. A diversified renewable portfolio combining both technologies, along with energy storage, provides the most reliable, cost-effective, and sustainable energy solution. Organizations should assess their specific resource availability, site constraints, and energy needs to determine the optimal mix.

Key Takeaway: For most Indian organizations starting their renewable energy journey, solar is the logical first step due to lower costs (35-40% cheaper than wind), simpler implementation, and broader applicability across states. Wind can then be added in suitable high-wind regions, creating a robust hybrid renewable energy system that leverages India's diverse geography and climate.

Winner By Category	Technology
Lowest Cost	Solar PV (■6.6-10 cr/MW)
Highest Energy Output	Wind (2,200-3,000 MWh/MW)
Most Locations	Solar PV
Smallest Footprint	Wind (vertical)
Lowest Maintenance	Solar PV (■1.2-2.1 L/MW/yr)
24/7 Generation	Wind
Best for Residential	Solar PV
Best for Utility-Scale	Hybrid or Wind (if good resource)