Cumulus Mumbai 2015:
In a planet of our own - a vision of sustainability with focus on water
http://www.cumulusmumbai2015.org/

"Agro-electric Model"- A sustainable solar plant with dual use of land and water for energy and food security

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Abstract:

Abellon CleanEnergy established 3MW solar plant adopting agricultural practices under the panels to maximize resource utilization of land and water addressing food and energy security on same land benefiting rural community. The innovative approached is first of its kind globally, known as "solar-agroelectric model".

Solar panels are washed to improve its efficiency by removing dust, reducing heat and producing 10-14 tonnes/acre/year agriculture goods by reusing 78 lac liter water/year that irrigates underlying vegetation sequestering 250 tones/Yr CO2 by vegetation. The CDM registered project reduces 1 lac tonnes of CO_2 over 25 years vis-a-vis fossil fuels. Post harvested residues are used for composting & reused as organic fertilizer. About 100 local villagers are involved for agriculture activities. In India, 1059.64 MW Solar Plants are established covering 6181.23 acre land which could sequestered about 16,00,000 tonnes of CO_2/year by photosynthesis with potentials of producing 10000 tonnes of agricultural produce employing 2000 rural villagers.

Key words: ***Solar energy, agriculture produce, land use efficiency, water efficiency, photosynthesis, photovoltaic, waste utilization***

1. Introduction

Generation of electricity using solar PV is picking up in India with policy support. However it needs a clear direction such that the solar project developers optimally utilized resources that benefit all stakeholders including land owners, local population, farmers and project developers. Agriculture is the backbone of Indian economy with nearly 60% of India's population is dependent on agriculture for its livelihood (Tripathi and Prasad, 2009). Therefore, a vibrant and progressive agricultural sector is important for overall progress of Indian economy without compromising target of energy generation for country's growth. India is located in the sunny belt of the earth, thereby receiving abundant radiant energy from the sun. The Prime Minister has launched Jawaharlal Nehru National Solar Mission to meet the economic development and energy security through ramping up target from 20,000 MW to 1,00,000 MW of solar power by 2022 (http://mnre.gov.in/file-manager/grid-solar/100000MW-Grid-Connected-Solar-Power-Projects-by-2021-22.pdf).

Food and energy security are the prime issues of the world. To address both simultaneously in an innovative way is the need of the hour. India has temperate climate with availability of sun to capture solar energy on solar cells for energy generation and food energy through photosynthesis. How to maximize solar efficiency on the same land is not addressed globally. Therefore following key objectives were incorporated during implementation of 3MW solar plant to maximize the solar energy capture on solar panels for energy generation and executing agricultural practices through photosynthesis by growing vegetables under solar panels for food security.

2. Objectives of agro-electric-model:

- Photosynthesis activities: Plantation of shade loving vegetables, fruits and spices plants below solar panels for food production and thereby achieve food security.
- Water usage efficiency: Solar panels are washed to increase solar efficiency. The washed water is reused to irrigate the underlying vegetation.
- CO_2 sequestration: Vegetation takes up CO_2 from the environment and fixes as food energy by photosynthesis.
- Soil improvement: The vegetation generates post harvested residues which are used for vermicomposting; the end product is used as organic fertilizer.
- Zero discharge Concept: Recycling of post harvested residues for composting & cattle feed and water management signifies end to end solution and zero discharge process.
- Rural development: Employment generation potential, women empowerment and local resources utilization through the project implementation reduced rural migration.

3. Implementation:

1. The project site is located in the foothills of Aravalli mountain range as shown in figure-1. The soil is rocky, porous and has less water retention capacity; less suitable for cultivation of cereal crops. As the project lies on the Tropic of Cancer, this area receives abundant sunlight (figure-2).

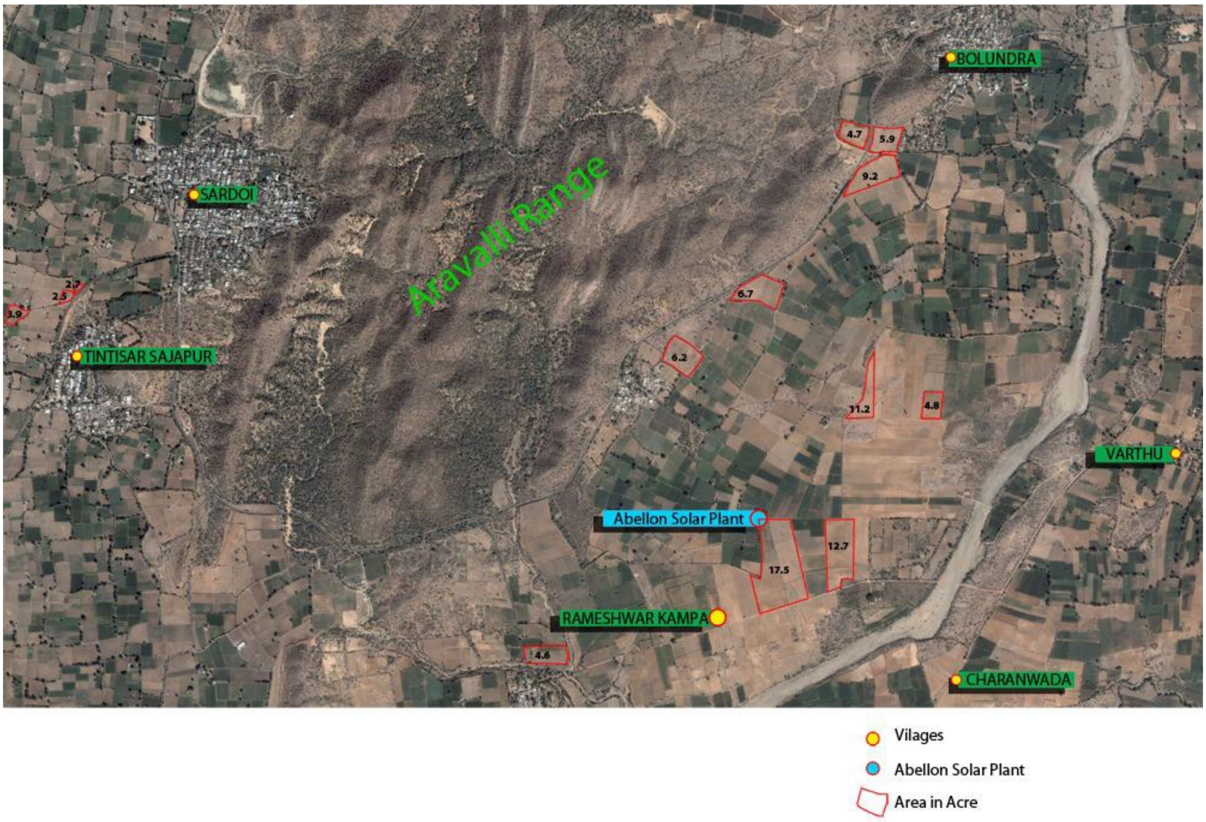

Figure-1: Arial view of project site

Figure-2: 3MW solar Project site

2. The solar panels were erected to set up 3MW solar plant [CDM Project # 6925] at

Aravali district, North Gujarat, India; occupying 17.5 acres land and accommodating 11978 solar panels as shown in table-1. The solar panels were procured from Waaree Energies Private Limited, Surat, Gujarat, India.

Parameters	**Measurements**
Latitude	23deg 33min 35.19sec N
Longitude	73deg 17min 07.95sec E &
Elevation	538 feet
Insolation details	5.5 to 6 Kwh/m2 /day with 300 sunny days/year
Type of PV Module	Crystalline Solar Photovoltaic
Solar Photovoltaic	Multi crystalline Silicon (C-Si)
Capacity	3 MW
Capacity of Each Module	230, 240 & 280 Watt
Grid Connectivity	11 KV Medasan Substation (~10 Kms from Project site)
Inverters Capacity	6 Inverters of 500 KWp each
Plant Load Factor	18%
Annual power generation/year	4.876 Million Units
Maximum exportable power	4.876 Million Units
Policy support	Gujarat Solar Policy
Date of commissioning	28 January 2012
No. of solar panels	11978
UNFCCC DCM registration	Project # 6925

Tabel-1: Solar plant fact sheet

3. Seeds of various vegetables were sown below the panels resulting in dual use of the same land. Vegetables (lady finger and bottle gourd), fruits (water melon) and spices (turmeric, chili and ginger) were sown depending upon factors like sunlight and shade, crops cycle, season, temperature, type and fertility of soil, etc. (figure-3)
4. Solar panels need to be cleaned due to dust deposition. The water used for cleaning the panels was reused for irrigation of under lying vegetation (figure-4).
5. Jute bags are laid on the soil for retention of moisture and prevention of weeds as shown in figure-5. This creates a greenhouse effect and results in lowering of the temperature, which is beneficial for efficiency of solar panels, as the efficiency decreases at higher temperatures.

Figure-3: Agricultural activities under solar panel

Figure-4: Duel use of water for solar panel wash and irrigation of agriculture produce

Figure-5: Water retention on land by jute bags.

6. The agriculture produce were distributed among the local workers, sold in the local markets and urban communities (figure-6).

A: Watermelon and bottle-gourd sales B: Turmeric packaging for sales

Figure-6: Sales of organic agriculture produce for local and urban market

7. Post harvested agricultural residues were collected for fodder purpose to feed cattle as well as decompose to get organic fertilizers to reuse for next cycle of agriculture input under solar panels (figure-7).

Figure-7: Composting of agricultural residues.

8. Compound wall was constructed along with weir fencing to safeguard solar panels from stray animals and cultivate creeper agriculture produce like ivy guard (figure-8A). It protected dust deposition carried over by wind on solar panel along with continuous harvest of ivy guards. Henna plantation was also carried out as secondary wind braking barrier encircled to solar plant (Figure-8B).

Figure-8: Wind & dust protection of solar panels by creepers and henna plants

9. More about the project: http://www.abelloncleanenergy.com/abellon-Solar-Energy-Projects.aspx. (http://youtu.be/WYXTCQWbWI4).

4. Results:

4.1 Economic Impact:

- Average 3816668 INR/acre/year can be generated from solar power (Table-2).
- Table-3 shows harvest profitability cultivated under solar panels.
- Employment opportunities leading to economic benefits to local rural.

Year	Generation (kWh)	Axillary Consumption (kWh)	Net Injection to Grid (kWh)	Generation based income in INR *[@15 INR/kWh]	Average income/acre/year
2012	4321426	13293	4308133	64621988	3816668.94 INR/Acre/Year
2013	4818700	5900	4812800	72192000	
2014	4970000	5200	4964800	74472000	
Up to Aug 2015	3220800	4300	3216500	48247500	
Total	17330926	28693	17302233	259533488	

* Gujarat state Solar Policy

Table-2: Revenue from 3 MW Solar power generations.

	Expenditure (on ~15 acre land)				Income (on ~15 acre land)			**Net Profit (on ~15 acre land in INR**
	Seed cost (INR) A	Labor Cost (INR) B	Farm Input (INR) C	Total Cost (INR) D=A+B+C	Market price (INR/kg) X	Yield/Year (tones) Y	Revenue/Year (INR) Z= X*Y	**P=Z-D**
Turmeric	70650	148750	168000	387400	100	20	2000000	1612600
						15	1500000	1112600
						10	1000000	612600
						7.5	750000	362600
	Net Profit considering average 0.866 tons/acre production= 71216 INR/Acre/tones							
Ginger	16800	148750	168000	333550	100	20	2000000	1666450
						15	1500000	1166450
						10	1000000	666450
						7.5	750000	416450
	Net Profit considering average 0.866 tons/acre production= 75361 INR/Acre/tones							
Bottle gourd	7000	148750	18842	174600	15	20	300000	125400
						15	225000	50400
	Net Profit considering average 1.16 tons/acre production= 5051 INR/Acre/tones							
Lady finger	960	148750	54960	204670	60	25	1500000	1295330
						20	1200000	995330
	Net Profit considering average 1.5 tons/acre production= 50903 INR/Acre/tone							

Ivy gourd	24300 29750 24246	78296	40	25	1000000	921704
				20	800000	721700
				15	600000	521704
				12	480000	401704
	Net Profit considering average 1.2 tons/acre production= 35650 INR/Acre/Tone					

Table 3. Profitability analysis of agricultural produce under solar panel

4.2 Social Impact:

- Employment generation through utilization of local human resources through job opportunities.
- Women empowerment by providing them employment (Figure-9A)
- Knowledge sharing through "Krishisabha", farmers' meets (figure-9B).
- ~52 tones/annum of remnant plant after harvest is partly given to local community as a cattle feed and some is composted for obtaining organic manure.
- Migration of rural villagers to urban places for seasonal jobs was reduced.

Figure-9: Women empowerment and Farmers' knowledge sharing session

4.3 Environmental impact:

- 4000 MT/annum CO_2 emission reduction through 11978 solar panels vis-à-vis fossil fuel as per UNFCCC guideline (https://cdm.unfccc.int/filestorage/6/W/S/6WSEL75KUBQD2XYPHC9ZO84VATNF1M/eb61_repan17.pdf?t=VzZ8bnVhcDM4fDBPMcMf_6kz3-QS8B5Cigfj).
- ~250 tonnes/year CO_2 is sequestered from 17.5 acre plantation leading to CO_2 fixation back in soil.
- After cleaning solar panels, ~78 lac liters wash water/annum reused for irrigation.

5. Future plans:

- Expansion: Further 2MW solar plant has been installed at the same site. Agriculture activities would also be covered as part of expansion of the model.

- Biogas plant: After harvesting the agriculture produce, approximately 52 tons of remnant dry plant biomass is generated. This biomass could be used to generate energy in biogas plant. Total 440 m^3 of biogas could be produced monthly. This could generate 440-550 Kwh electricity monthly to operate generator, water-pump, motor, lamppost etc. Biogas slurry could generate approximately 7 ton/annum organic manure. The bio-fertilizer could be used to enrich soil nutrients and to develop organic farming under solar panels. This way the project can achieve zero process discharge.
- Rain water harvesting system: The project is also planning to harvest rain water that can be used throughout the year for panel washing and irrigation.

6. Replication Potential:

- **India:** So far 1059.64 MW Solar Plants are established in India which covers 6181.23 acres land. These installed solar plants can sequester about 1600,000 tons of carbon every year. If a similar approach is applied in this area, they would generate 10000 tonnes of agricultural produce employing 2000 farmers and rural villagers.
- **Global:** Worldwide solar plants are established in ~4000 hectares land which has potential to sequester 1,43,000 MT/annum through vegetation; giving 1,00,000 MT of agriculture produce addressing food & energy security simultaneously.

7. Accolades:

The "Solar-agri electric" Project has been globally recognized and awarded by;

- United Nations Conservation to Combat Desertification (UNCCD) as Semi-Finalists 2013 in Land for Life award (http://www.unccd.int/en/programmes/Event-and-campaigns/LandForLife/Pages/Semi-Finalists-2013.aspx)
- Project of the Year 2013, Renewable Energy World Award; Viewer's choice Winners (http://www.renewableenergyworld.com/articles/print/volume-16/issue-6/solar-energy/global-excellence-project-of-the-year-award-winners-announced.html)

8. Discussion:

Solar PV is growing at a very high rate of 30%-40% among renewable energy. World annual solar PV production was close to 2 GW in 2006 with 5 times increase in 2009 crossing 10 GW. The availability of free natural resource, long term reliability with matured technology are few of the factors that many countries are targeting to achieve renewable energy generation [Goswami, 2012]. Electricity industry is

capital intensive with long gestation period and unevenly dispersed across the country. Electricity is a product that cannot be stored in the grid where demand and supply have to be continuously balanced that can meet rapidly increasing demand of the country to encounter optimal and rapid growth [Shankar, 2005].

Indian land area can produce 32,499 GW of electricity with an assumption that of 1 MW of electricity can be produce from 5 acres of land covering solar PV. The target of 1207 GW generation by year 2031 can be achieved using 6 million acres of free land for placing the solar panels (Harinarayana and Vasavi, 2014). In view of this, the solar agri-electric model is suitable model that can even be placed at farm land to maximize agriculture productivity and solar energy generation.

Shah and Zala (2006) reported 5.38 ton/acre ginger production in Gujarat with net profit of 73895 INR/acre. While in this study 0.866 tons/acre production was achieved with net profit of 75361 INR/Acre. Here productivity is compromised but resource utilization like land, water has been shared to reduced expenditure on cultivation. Meena et al (2009) reported 4.32 tone/acre bottle gourd productions in arid region with 16012 INR/acre net incomes while we found productivity under solar panel of 1.16 tons/acre with net profit of 5051 INR/Acre. Therefore, findings of productivities of these agricultural produce under solar panel along with simulation modeling studies could help in improving agriculture productivity as well as section of the agriculture produces for cultivation under solar panels. Harinarayana and Vasavi (2014) systematically examined shade effect on the crops below the solar panel through modeling studies where in different solar panel design configurations are suggested such that the crops or plants below the ground surface can be grown without compromising in the yield.

Site Selection of wind turbine for energy generation has been studies using GIS system in Gujarat considering environmental, physical and human factors as main criteria for sustainable energy generation [Borah et al., 2013]. Similar GIS based model can be design based on this current study to optimize site selection for solar energy and agriculture productivity on land pockets in India.

9. Conclusion

Solar project developers have potentials to utilize and maximize land and water use efficiency by incorporating agricultural activities under solar panel. Most of the solar projects are approved under non-agricultural barren land in India so that agricultural lands need not compromise for agriculture produce. Therefore, solar project sites can adopt dual land and water use paradigm to show case energy and food productivity on same land. This would help policy makers to improve guidelines for agriculture and solar project developers.

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