MAHAGENCO
Maharashtra State Power Generation Co. Ltd.

igef Indo-German Energy Forum

Feasibility and Economic Viability of Horticulture Photovoltaics

in Paras, Maharashtra, India

Study by:

Fraunhofer ISE

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GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

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GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

FOREWORD

India has set an ambitious target of developing 175 GW and 450 GW of installed Renewable Energy capacity by 2022 and 2030 respectively as a part of its commitments to reduce greenhouse gas emissions. The achievement of both these targets would require significant investment in solar energy capacity. Over the years, the fall in capital costs of solar energy coupled with enhanced efficiency and reliability have made solar the fastest growing primary energy source in India today.

However, one of the biggest challenges facing this large scale capacity addition in solar is the availability of land for the development of large ground mounted solar projects. It is with this background that I think this report assumes great significance. This report analyzes the opportunities for reconciling agricultural activities with the generation of solar PV power on the same land area by growing food crops as well as harvesting energy through solar PV installations. It will serve as a guide for stakeholders working on developing Horticulture PV projects in India. 'Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (**PM-KUSUM)'** –the flagship Scheme of Govt. of India has provision for the decentralized solar plants, preferably by farmers on their barren and uncultivable land. Cultivable land may also be used if the Solar plants are set up on stilts where crops can be grown below the stilt. Besides, this scheme has also provisions to replace Agriculture Diesel pumps with Solar Water pumps and Solarize Grid connected Agriculture pumps.

I would like to express my sincere appreciation to all parties who have contributed to the outcome of this study. Above all, I would like to extend my gratitude to the Indo-German Energy Forum (IGEF) for publishing the final document.

27/01/2020
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Foreword

Federal Ministry
for Economic Cooperation
and Development

Philipp Knill
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Government of Germany

The challenges India faces with regard to the effects of global warming have become clearly visible with the increase of large-scale floods and droughts across the Indian subcontinent. Besides the effects of global warming, SMOG is another challenge for the many densely populated cities of India. Not to mention that the poorest parts of society are the most vulnerable and often lack the means to adapt to these impacts. I strongly believe that global efforts are necessary to adequately meet these challenges.

Both the Indian and the German government are state parties to the Paris Climate Agreement and endorse the United Nations Sustainable Development Goals (SDG). Germany, as a pioneer in energy transition, is therefore pleased to share its experience with its Indian partners, especially within India's energy sector.

I am delighted and impressed by India's ambitious goals for renewable energies. All grand ambitions worth their salt need an adequate amount of time and energy – and we are willing to support these endeavors. Therefore, India is Germany's biggest partner in development cooperation, whereof the Indian energy sector is the largest single portfolio of the Federal Ministry for Economic Cooperation and Development (BMZ). The pillar stones of our portfolio are the promotion of renewable energies, foremost solar/PV, and the build-up of capacities for India's power grid.

To this day, the Indo-German partnership can look back on a broad variety of successful cooperation especially with regard to the Solar Partnership (SP) and the Green Energy Corridors (GEC). In the light of our beneficial cooperation we will continue to support India in implementing sustainable solutions and also role it out via such initiatives as the International Solar Alliance (ISA). The present study represents another example of our strong partnership. Herein an innovative technology labeled as Horticulture-PV can serve as a lighthouse project for further activities.

The aim of this technology is to integrate agriculture and PV energy production, thereby possibly even double the economic yields per hectare of land in a sustainable manner. As expanding energy production capacities requires scarce land, the success of future projects in India also depends on management of this precious resource. While ground-mounted photovoltaic (GM-PV) systems fully occupy up to 1.7 hectares per installed MWp, Horticulture-PV preserves ground space for agriculture: crops can keep up their respective average yields, shadow-loving crops like tomato and cotton can even increase their yields; high-mounted PV modules can generate economically feasible green energy.

With our long-standing tradition of cooperation in mind, I would like to express my deepest gratitude to all who have contributed to this study. I would especially like to thank our Indian partners, the Ministry of New and Renewable Energy for their trust and commitment, as well as our close partner, the Maharashtra State Power Generation Company, without whom engaging in such an innovative approach towards Solar/PV application would not have been possible. Furthermore, I would like to thank the Frauenhofer ISE for their excellent contributions to this innovative solar/PV approach.

Philipp Knill

Glossary

AES	Agro-Economic-Situation
CAPEX	Capital Expenditures
CAPM	Capital Asset Pricing Model
CO_2	Carbon Dioxide
CPV	Concentrated PV
Crore	1 Crore = 10,000,000
ESIA	Environmental and Social Impact Assessment
EUR	Euro
FAO	Food and Agriculture Organisation
Fraunhofer ISE	Fraunhofer Institute for Solar Energy Systems
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GM-PV	Ground-Mounted Photovoltaic
GTI	Global Tilted Irradiation
Ha	Hectare
HAM	Hectare Meters
H&S	Health & Safety
INR	Indian Rupee
INRA	French National Institute for Agricultural Research
IMWI	International Water Management Institute
IRR	Internal Rate of Return
KfW	Kreditanstalt für Wiederaufbau
KPI	Key Performance Indicator
kWh	Kilo Watt Hours
kW_p	Kilo Watt Peak
Lakh	1 lakh = 100,000
LCOE	Levelised Cost of Electricity
LCOW	Levelised Cost of Water
LER	Land Equivalent Ratio
Mahagenco	Maharashtra State Power Generation Co. Ltd.
MBGL	Meters Below Ground Level
MCM	Million Cubic Meters
MNRE	Ministry of New and Renewable Energies
MW_p	Mega Watt Peak
NGO	Non-Governmental Organisation
NPV	Net Present Value
OPEX	Operational Expenditures
PV	Photovoltaic
STC	Standard Test Conditions

TPP	Thermal Power Plant
WACC	Weighted Average Cost of Capital [%]
W_p	Watt Peak (nominal power of photovoltaic devices at STC)
PAP	Project Affected Personal
PAR	Photosynthetically Active Radiation
R&D	Research and Development
SP	Sensor Point
SDGs	Sustainable Development Goals
UN	United Nations

List of Figures

List of Tables

List of Equations

Executive Summary

In the ongoing energy transition in India, photovoltaic (PV) plays a crucial role which becomes evident when looking at both governmental PV targets and recent developments. While land-neutral roof-top PV accounts for 40% of Indian's 2022 development goals, with 60% the largest share of all PV technologies is designated for utility-scale ground-mounted PV (GM-PV, see Hairat and Ghosh 2017).

Despite cost-effectiveness speaking in favour of GM-PV, generally, a major drawback of GM-PV is the high land usage with approximately 1.2-1.7 hectare per installed MW_p for recently installed systems (Shiva and Sudhakar 2015). This seems particularly relevant in the context of Indian's high population density and – in several regions – its respective fierce scarcity of land.

Recently, these conflicting interests of land use became apparent at a site in Paras, Akola district in Maharashtra, Western India, where the major power generating company in the state, the Maharashtra State Power Generation Co. Ltd. (Mahagenco), considered installing a GM-PV system on more than 100 hectare (ha) of fertile agricultural land which today serves as the livelihood of more than 100 farmers and their families.

To seize opportunities of reconciling agricultural activities and PV power generation at the same area of land, Mahagenco and its project investor, the German development bank Kreditanstalt für Wiederaufbau (KfW), requested the Fraunhofer Institute for Solar Energy Systems ISE (Fraunhofer ISE) to assess the feasibility of a dual land use to which in the following we refer as Horticulture PV.[1]

The analyses of Fraunhofer ISE indicate that a Horticulture PV system provides sufficient solar irradiation to keep expected average yields of analysed crop (soybean, cotton, tomato, and banana) above 83% compared to conventional agriculture if bifacial glass-glass PV modules are installed at a height of 4m above ground with a proposed orientation of 208 degree to southwest, a tilt angle of 22 degree, and a row distance of 5m. For shade-loving crops like tomato and cotton, yield increases between 16% and 32% are expected.

Further, the system appears economically feasible with expected levelised cost of electricity (LCOE) of INR 1.52 (EUR 0.0184) already including initial cost on water management, rainwater harvesting, storage, and irrigation. This relatively low level of LCOE is mainly driven by low capital cost of less than 1.5%. To archive an internal rate of return (IRR) of 16%, accordingly, an electrical tariff of INR 3.79 (EUR 0.045) is required.

Regarding land use, the study suggests that Horticultural PV is likely to almost double the efficiency measured by the combined output of electricity and agriculture per unit of land (+94%).[2]

1 Other terms frequently used for this approach are agrophotovoltaics, agrivoltaics, solar sharing or agri-solar.
2 Calculated by the Land Equivalent Ratio (LER), see Section 1.2.

Further key findings:

- Higher agricultural yield may be achieved if shadow-tolerant varieties are selected.
- In order to protect local aquifers that are already stressed in Paras region, no ground water should be used neither for cleaning nor for irrigation.
- Rainwater harvesting is generally feasible and allows irrigating during dry season without deploying local aquifers potentially doubling the annual yield of certain crops (e.g. cotton). Generally, the integration of a drip irrigation system is recommended – independent of the kind of cultivated crops.
- To further increase land use efficiency and the economic performance of agriculture, investments in trainings and equipment seem appropriated.
- Shadowing effects are expected to reduce water needs due to decreased evapotranspiration. This seems particularly relevant it the cultivation period is extended to the dry season (Rabi).
- With an expected capacity of 0.51 MW_p per ha, the electrical output of the proposed Horticulture PV design is 14% lower compared to a standard PV-GM system.
- Bifacial glass-glass modules are expected to raise electrical yield by 6.8% and are recommended to increase both the economic performance and the availability of sunlight for the crops.
- An exact cultivation plan depends upon the business model and the level of farmers' involvement.
- We suggest coordinating farming activities and envisaged cultivation plans by lancing cooperation between local farmers and suitable institutions or organisations active in the agricultural sector.[3]
- To verify the suitability of the proposed orientation to south-west and to identify the most appropriated cleaning system, it is highly recommended to monitor the local soiling and irradiation conditions over a period of at least 12 months.
- With respect to labour effects, the creation of 50 new jobs is expected while farming activities remaining constant.[4] When assuming a monthly wage of INR 10,000 paid to each farmer, the LCOE rises from INR 1.53 to INR 1.68 with a required increase of the electrical tariff from INR 3.79 to INR 3.94 to keep the IRR at 16%.
- Before installing the Horticulture PV system on the entire area, a smaller pilot project seems appropriated to identify and minimise possible social, technical and economic risks. The recommended size of the pilot project should involve not less than 10 farmers on a land area between 5 and 15 ha in order to archive sufficient social experience and valid technical results.

Overall, the analyses suggest that the Horticulture PV approach serves as an attractive and economically viable solution to overcome the land use conflict at Paras site. If social criteria are considered, affected farmers are involved in the decision making, and an electrical tariff between INR 3.7 and 3.9 can be realised, the joint productivity of the agricultural and electrical layer is expected to allow for meeting both Mahagenco's ambitions of a valuable and hassle-free execution of the project and farmers' desire of a steady income. Moreover, a realisation of the proposed system appears eligible to serve as a lighthouse project for future activities with high expected reputational benefits for involved stakeholders and effective contributions to the Sustainable Development Goals (SDGs) of the United Nations.

Despite an overall positive assessment of the Horticulture PV approach, uncertainties remain with respect to legal aspects of a dual land use, potential impacts of rainwater harvesting on groundwater resources, the exact level of agricultural crop yield, and social acceptance of landscape changes, amongst others.

3 E.g. TATA Trust or the "Green Innovation Centres for the Agriculture and Food Sector – India" of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.
4 Assuming one person for monitoring, maintenance and cleaning per 1 MW_p of Horticulture PV capacity.

1 Introduction

1.1 India's Land Use Challenge

The way we produce food and generate energy substantially matters for major challenges of this century. Agricultural practices affect biodiversity, human health and quality of water; fossil-fuel power stations drive Carbon Dioxide (CO2) emissions exacerbating global warming; and efficiency of both sectors co-determines how many people do have access to food and energy supply. Hereby, the Indian food system faces multiple challenges, along with the degradation, erosion of arable land while growing populations may be the sharpest. According to World Bank figures, during the last 50 years, the arable land per capita in the subcontinent came down from 0.34 ha to 0.12 ha in 2016 (see Figure 1).

Figure 1 Arable land in India in hectare per capita.[5]

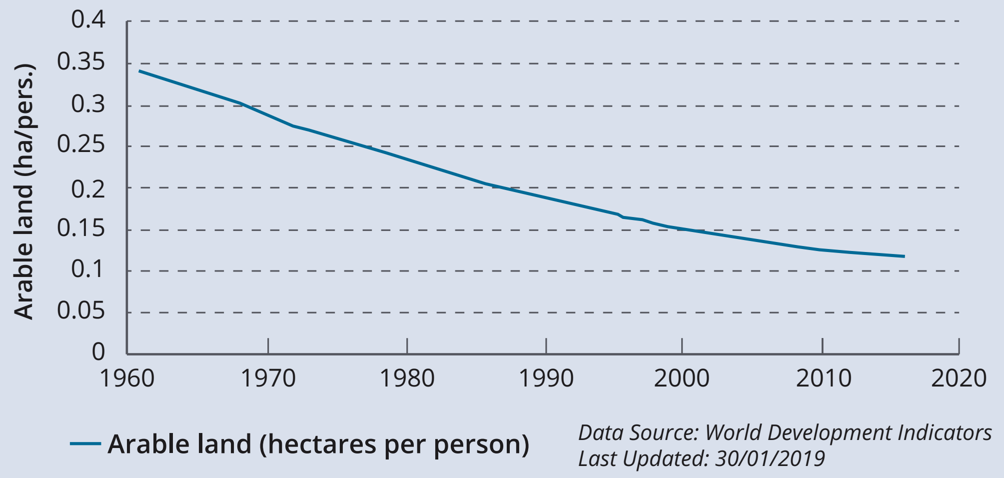


Figure 2 Historical average land consumption of PV-GM in ha per MW_p in Germany.[6]

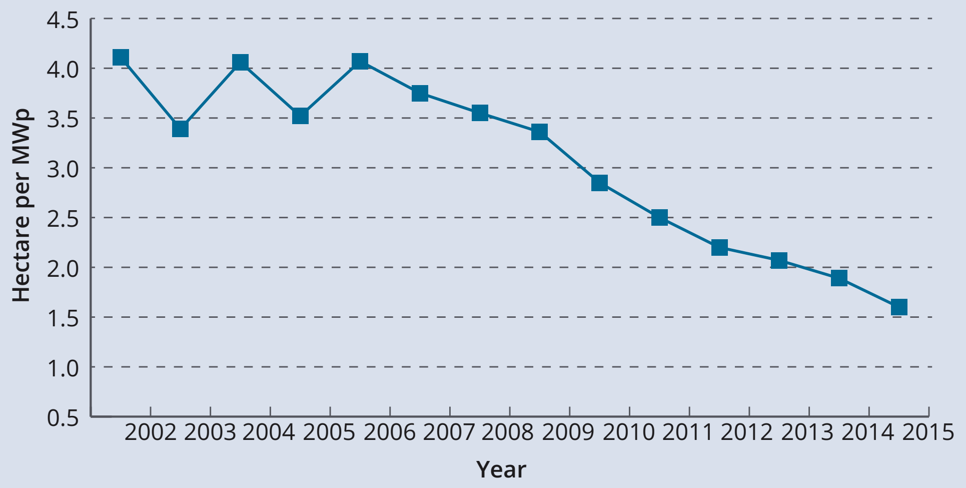


Figure 2 shows the land footprint of GM-PV in Germany. It has more than halved within the last decade and stood at 1.6 ha per MW_p in 2015 or 0.625 MW_p per ha. Current figures for Germany approaching almost 1 MW_p per ha, yet for India a current average value of 0.59 MW_p is realistic according to Shiva and Sudhakar 2015 and Indian stakeholder consultations.

5 Source: Worldbank Development Indicators and Food and Agriculture Organisation (FAO)
6 Source: Federal Grid Agency 2016.

While the demands for food and energy are increasing rapidly, also the use of fossil fuels does. Energy from biomass frequently claimed to be a possible substitute for fossil fuel, though, seems little suited to solve the problem of sustainability as the efficiency of the photosynthetic process of most energy crops varies only around 1-3% (A.S. Bhagwat 1997). Hence, the land surface required to replace fossil fuel with biofuels widely exceeds the agricultural areas of the planet. In contrast, recent GM-PV systems perform at an efficiency of 15-17% and, therefore, appear more eligible to meet future energy needs (Fraunhofer ISE 2018).

Accordingly, also India's energy transition relies on PV systems which in recent years already became a notable component of India's energy portfolio and will be an important part of India's energy mix during the next decade.

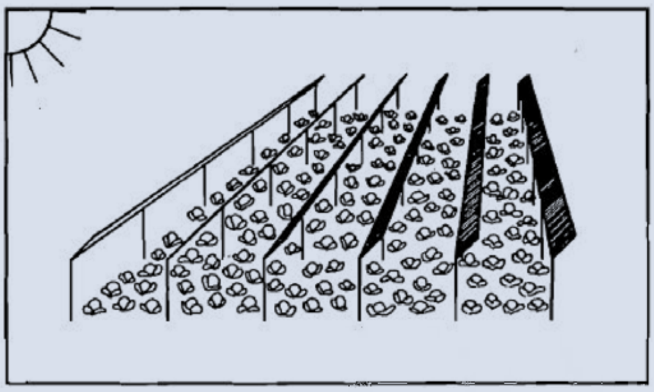
In order to achieve the national PV target of 100 GW_p installed capacity by 2022, with an assumed land use for new GM-PV systems of 1.8 ha per installed MW_p, the total required amount of land is about 1.1 lakh ha or 1,100km² (Hairat and Ghosh 2017). This corresponds to almost twice the area of Mumbai. Acquiring land for new GM-PV systems is a highly sensitive matter both economically and socially. Having a population density of 382 persons per km², among the 100 most populous countries India ranks 7 with almost twice the population density of Germany[7]. Locating and acquiring a project site that is suitable, affordable and socially acceptable is becoming more and more difficult as by now many suitable spots for GM-PV have already been allocated to earlier projects.

Bearing these challenges in mind and being aware of the rising need for action to support renewable energies that are technically efficient, economically viable and environmentally sustainable, India is exploring solutions that allow for no or only little additional land consumption of solar installations.

1.2 Horticulture PV Approach: Status Quo of R&D

One possibility to overcome conflicting interests of land use is Horticulture PV – a combined land-use of food and electricity production. Alternative terminologies frequently characterising the same and similar technological approaches are Agrophotovoltaics, Agrivoltaics, Solar Sharing or Agri-Solar[8]. In 1981, the founding father of Fraunhofer ISE, Mr. Goetzberger and Mr. Zastrow[9] were the first who proposed the concept of Horticulture PV outlining the various advantages of this system-technology. Opportunities range from a significant raise of land use efficiency, an increased added value for rural areas, and opportunities of how elements of the PV layer can support farming practices and plant growth.

Figure 3 Schematic illustration of Horticulture PV.[10]



The theoretical foundation of this increase in land use efficiency has been elaborated by R. Mead, R. W. Willey (1980) for by of intercropping systems. They introduced the concept of land equivalent ratio (LER) which is frequently applied in agroforestry, aquaponics and recently also APV (Dupraz et al. 2011). LER can be defined as the relative land area that is required for mono production in order to achieve the yield of a dual land use. Following Willey (1985), LER is specified as the sum of yield ratios of respective dual land use to mono land use:

7 See: https://www.census2011.co.in/density.php
8 Dupraz et al. 2011, Trommsdorff 2016, Schepper et al. 2012.
9 Goetzberger A. and ZASTROW 1982.
10 Source: (Goetzberger A. and ZASTROW 1982).

Equation 1 Land equivalent ration (LER).[11]

$$LER = \frac{Yield_a(dual)}{Yield_a(mono)} + \frac{Yield_b(dual)}{Yield_b(mono)}$$

Hereby a and b represent the cultivated crop and the electricity, respectively. The dual yields refer to Horticulture PV yields and mono yields to productivity of conventional horticulture and GM-PV.

While the idea of Horticulture PV traces back more than 35 years, for many years PV modules were too expensive to let the idea evolve into practise and, therefore, the research and the realisation of such systems are still in a very early stage. In Europe there are only few Horticulture PV power stations installed, most of them without scientific support. Within the European research landscape there are mainly two institutes conducting deeper research on Horticulture PV: the French National Institute for Agricultural Research (INRA) in Montpellier and Fraunhofer ISE in Freiburg/Germany.

While INRA rather focuses on an agricultural perspective, addressing questions like how farming practices can adopt to the PV system, Fraunhofer ISE rather investigates the PV system configuration and how the technical system parameters must be adjusted to provide optimal growing conditions for the agricultural layer below the modules.

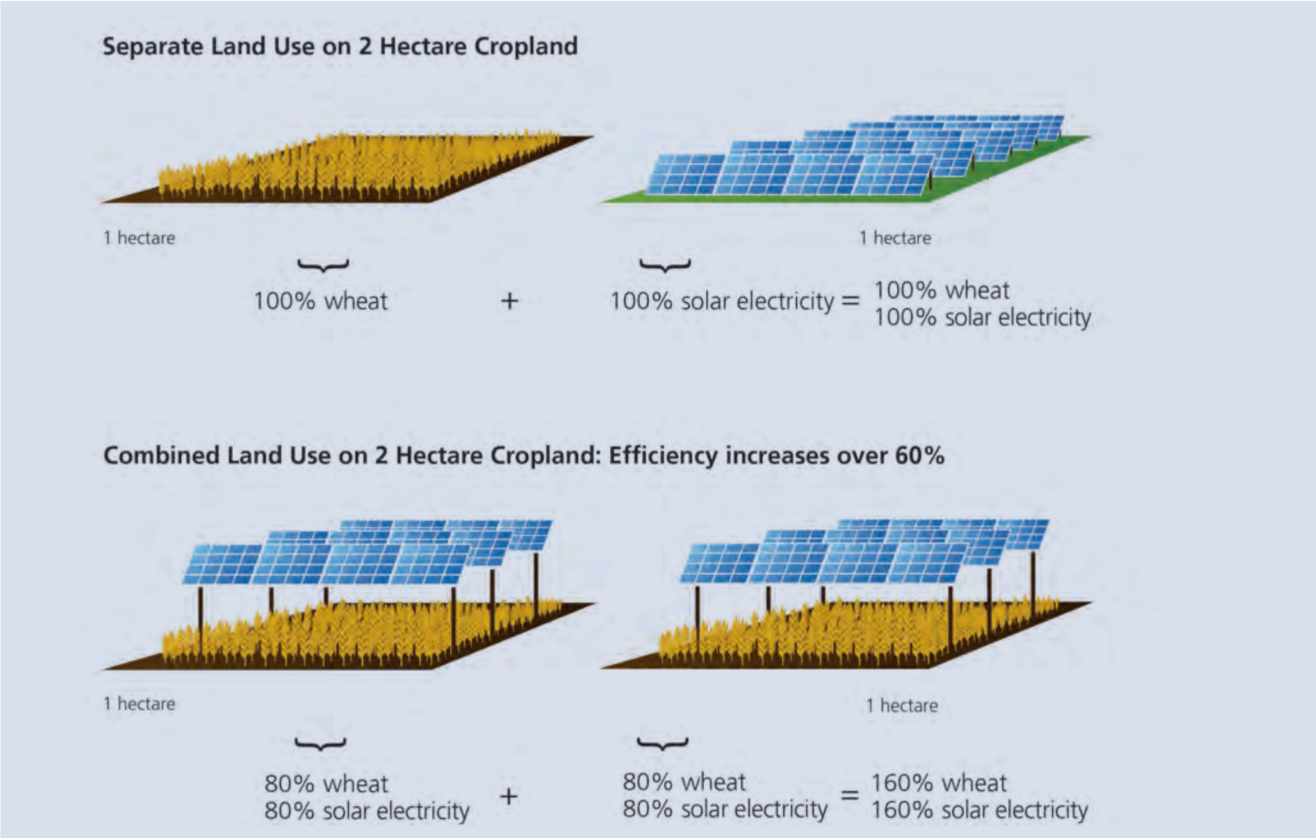
In the south of Germany, Fraunhofer ISE and consortium partners constructed and installed a Horticulture PV power station which is engineered for standard farming practices including the possibility to employ full harvesters as to be seen in Figure 4.

Figure 4 Horticulture PV at Lake Constance with full harvester.[12]

Amongst others, the beneficial character of Horticulture PV depends on the shade tolerance of cultivated plants, farming practices, and climatic conditions. Accordingly, some sun-loving crops like wheat or corn are generally less eligible for Horticulture PV since agricultural yields significantly decrease when already being exposed to minor sunlight reductions

11 Source: R. Mead, R. W. Willey 1980.
12 Source: Olivia Schmid

Figure 5 Illustration of increase land use efficiency of Horticulture PV systems.[13]



On the other hand, crops like leaf vegetables or berries can benefit from less solar irradiation. With respect to farming practices, crops that are cultivated in rows and do not require large agricultural machines usually perform economically well, as panel elevation is lower, and the mounting structure of the PV system interferes less with farming activities.

Another main benefit of an Horticulture PV system is a potential increase in land use efficiency (Obergfell 2012; Dupraz et al. 2011). Given the constant rise in global demand for food and energy, land use efficiency is a highly prevalent issue since it might ease the growing pressure on available land currently endangering both biodiversity and existing forms of traditional land use. The relevance of those concerns became apparent through recent debates about land-grabbing activities and biofuel policies as well as controversial questions attached to domestic land acquisitions in India. Figure 6 shows some variations of combined solar energy generation and agriculture. In Section 8 Benchmark Analysis more approaches can be seen.

Since the idea of Horticulture PV was first initiated, several large Horticulture PV power stations have been installed worldwide – most of them after 2015 – with an estimated global capacity of 2.1 GW_p. Still, there is little information available about the general performance of the technology and the agricultural output on a large scale

With respect to cost efficiency of Horticulture PV, studies of Fraunhofer ISE showed that for an average system of 2 hectares the overall costs are approximately 38% above GM-PV level (see Figure 7). While this is mainly caused by the costly mounting structure investment, overall operational expenditures (OPEX) are rather expected to drop mainly driven by lower land cost and drop out of cost on weed control.[14] This is partially balanced out by higher efforts for cleaning and repair services.

13 Source: (ISE 2016).
14 With respect to land cost, an equal burden sharing between the agricultural and the PV layer was assumed which overweight to the additional cost of repair and maintenance due to the higher PV modules.

Figure 6 Overview of elevated solar panel constructions worldwide

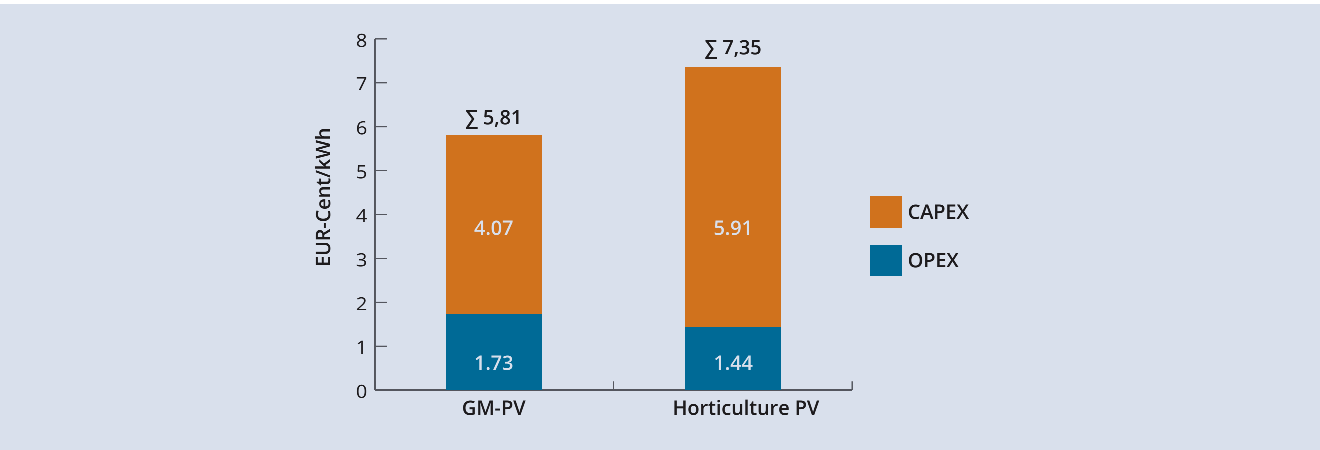
a) France, University of Montpellier, 50 kW_p, 2010

b) Italy, R.E.M. Spa, 3x3 MW_p each, 2011

c) Japan, Solar Sharing, over 1,000 power stations since 2013

d) China, Changshu, 9.8 MW_p, 2016

Figure 7 Comparison LCOE of Horticulture PV and PV-GM with break-down of OPEX and CAPEX.[15]



Concerning characteristics of Indian cropping systems, local weather conditions are a crucial factor regarding synergies between agriculture and the PV layer. In hot and sunny semi-arid climatic zones, shadowing effects of PV modules lead to less evapotranspiration and therefore to higher soil moisture and potentially better crop health. Accordingly, the need for irrigation can be reduced which is particularly relevant as India often face very limited access to water. More moderate temperatures of air and soil might reduce stress on crops and can improve the growing conditions. Being confronted with the consequences of climate change, these effects suggest that Horticulture PV systems might contribute to not only for climate change mitigation but also adaptation.

Recently, there had been voices, proposing further promotion policies for Horticulture PV systems in the foreseeable future. According to "The Wire", Gopal Krishna Gupta, joint secretary at the MNRE[16] has stated that "We are actively

15 Source: Internal Fraunhofer ISE analysis.
16 For more information see: https://mnre.gov.in/additional-secretary-joint-secretary

working on a policy to ensure that will give solar companies an option to have legal agreements with farmers wherein farming can continue if the height of the panels are increased".[17]

1.3 Societal Background of the Proposed Horticulture PV Project

Mahagenco owns and runs two 250 MW_p Thermal Power Plants (TPP) at Paras near the Horticulture PV site. Paras TPP started in 1961 with a 30 MW_p unit. By 1967, another 62 MW_p unit was added in later years. In 2008, a 250 MW_p unit replaced the earlier units and in 2010 another unit of 250 MW_p was commissioned. Since TPP became operational in 1961 it has been boosting the economy of the small village in myriad ways. There has been a symbiotic relationship between the farming community, which constitutes much of the community in the town, and the Paras TPP management.

For its expansion from 30 MW_p to 500 MW_p, Paras TPP has acquired land from farmers multiple times since its operations started in the 60s. During the expansion and land acquisition, farmers were not only given a compensation commensurate with the acquired land area (agricultural and non-agricultural) but a member of the farming household was also given employment at Paras TPP. Between 2011 and 2012, further expansion of Paras TPP was envisaged and the neighbouring 125 ha of land belonging to 124 farmers was planned to be acquired for the same.

Currently, Paras TPP employs 1,300 blue collar and 500 white collar employees, therefore each MW_p of thermal power generation provides employment to around three skilled or unskilled labour. Given the long-term benefits and steady income, a job at Paras TPP holds a high aspirational value for the agrarian community at Paras.

As per the information gathered during the fieldwork done in September 2018, in which informal and unstructured interviews were conducted with individual farmers, farmers groups, local staff of Paras TPP, and residents of Paras, it was evident that farmers were not keen to part with their land as this was the most fertile land parcel in the vicinity. But, appropriate compensation and an assured job at the Paras TPP were the incentives committed, if farmers agreed to give away their land.

According to Paras TPP management and the local government institution (leaving aside 2-4 farmers), 120 farmers agreed to give up their land entitlements. This resulted in close to 20 farmers becoming landless and 10 farmer households becoming homeless. But the envisaged expansion of Paras TPP did not happen and the farmers continued doing farming on their earlier entitled land.

Currently no part of 125 ha land, which is cultivable, is left fallow with farmers taking two crops on the same. Only 20 out of 120 farmers could get a permanent job at Mahagenco, since it required clearing an online examination, which was beyond the capabilities of majority of farmers. This lead to mistrust developed by the farmers, even though Mahagenco has not stopped farmers from using the land which officially belongs to them. Some of the project affected personal (PAP's) have gotten contractual jobs at Paras TPP and they get around INR 9,000-10,000 per month.

Figure 8 Soybean and pigeon pea in the project land.[19]

Figure 9 Crops in the project land adjacent to Paras TPP.[20]

17 For the full article see: https://www.thewire.in/energy/govt-plans-to-increase-height-of-solar-panels-so-farming-can-continue-below
18 Paras falls in Vidharbha region of Maharashtra and is infamous for farmers suicides, see Dongre and Deshmukh 2012; Gopnarayan 2017.
19 Source: Neha Durga.
20 Source: Neha Durga.

1.4 Objectives and Structure of this Study

This report assesses and evaluates the feasibility and economic viability of Horticulture PV at the site of Paras. This includes elaborating a recommendation on which agricultural crops could be grown under the PV system, developing a pre-basic design of a Horticulture PV system adapted for the site, performing agricultural and electrical yield assessments, as well as elaborating the economic feasibility of the concept.

Main objective of the study and the respective final report at hand is to provide a first basis for the upcoming decision-making process of Mahagenco and KfW. To also serve as a practical guidance, we highlight practical experiences with own Horticulture PV projects of Fraunhofer ISE and provide technical know-how and implementation strategies.

Finally, this report should give a general Idea about the principles and expected performance of Horticulture PV systems in the Indian context in order to enable Mahagenco and KfW to transfer lessons learned from the German pilot facility helping to identify other projects for which the Horticulture PV approach might serve as a viable technology to overcome land use challenges.

In Section 2 we take a look at the project site and the local conditions before discussing the principle concepts of developing a Horticulture PV design and performing electrical yield assessments for the Paras site in Section 3. The design concept also includes aspects of water management and rainwater harvesting which is a relatively new topic within Horticulture PV research.

In Section 4 we analyse possible cultivation plans with a focus on suitable shadow tolerant crops for this location and perform a rough crop yield assessment. Amongst others, we discuss three pathways that differ with respect to the level of rearrangements and adjustments of the farming methods required for the respective cultivation plan.

To provide a sound economic understanding of the Horticulture PV system, Section 5 presents a detailed record of expected cost items and cash flows on both the agricultural and the PV level. In doing so, we highlight financial aspects that differ compared to GM-PV and unsheltered, conventional agricultural practices. We perform a comprehensive calculation of LCOE and other financial parameters and discuss to which extend revenues from the agricultural layer can boost the economic performance of the Horticulture PV system.

Section 6 sheds light on social and institutional arrangements. Starting from the status quo, we conduct an analysis of stakeholders and different institutional scenarios and outline respective business cases.

To identify the environmental and social hotspots of the Horticulture PV approach in Paras, in Section 7 we carry out a preliminary scoping exercise which covers all physical, biological, socioeconomic and cultural environments related to the proposed project scope. The Scoping Report shall serve as a basis for in-depth analysis of a full ESIA for the Horticulture PV system.

In Section 8, a benchmarking exercise is performed to compare the findings and the expected performance of the proposed system with scenarios known from Europe and to check if the overall results are plausible.

2 Project Site

In this chapter we examine the environmental and bio-physical characteristics of the project site at Paras, Balapur. For this purpose, we first analyse the plot terrain and inclination profile in Section 2.1. In the following section we provide information concerning the local climate including relevant precipitation data and climate change predictions for the Akola district. In order to address further water scarcity issues, we include information regarding ground water status, recharge rate and future availability. In Section 2.3 possible atmospheric influences are identified also looking at the average dust concentration with a special focus on the effect of anthropogenic solar module soiling induced by the Paras TPP. Furthermore, we provide an overview of wind speed and wind frequency at the project site. Special focus is set on the local soil condition, its type as well as strengths, weaknesses, threats and opportunities as to be found in Section 2.4. Finally, we conduct an environmental risk assessment to identify potential deal-breakers to the project.

2.1 Geographical Location and Site Map

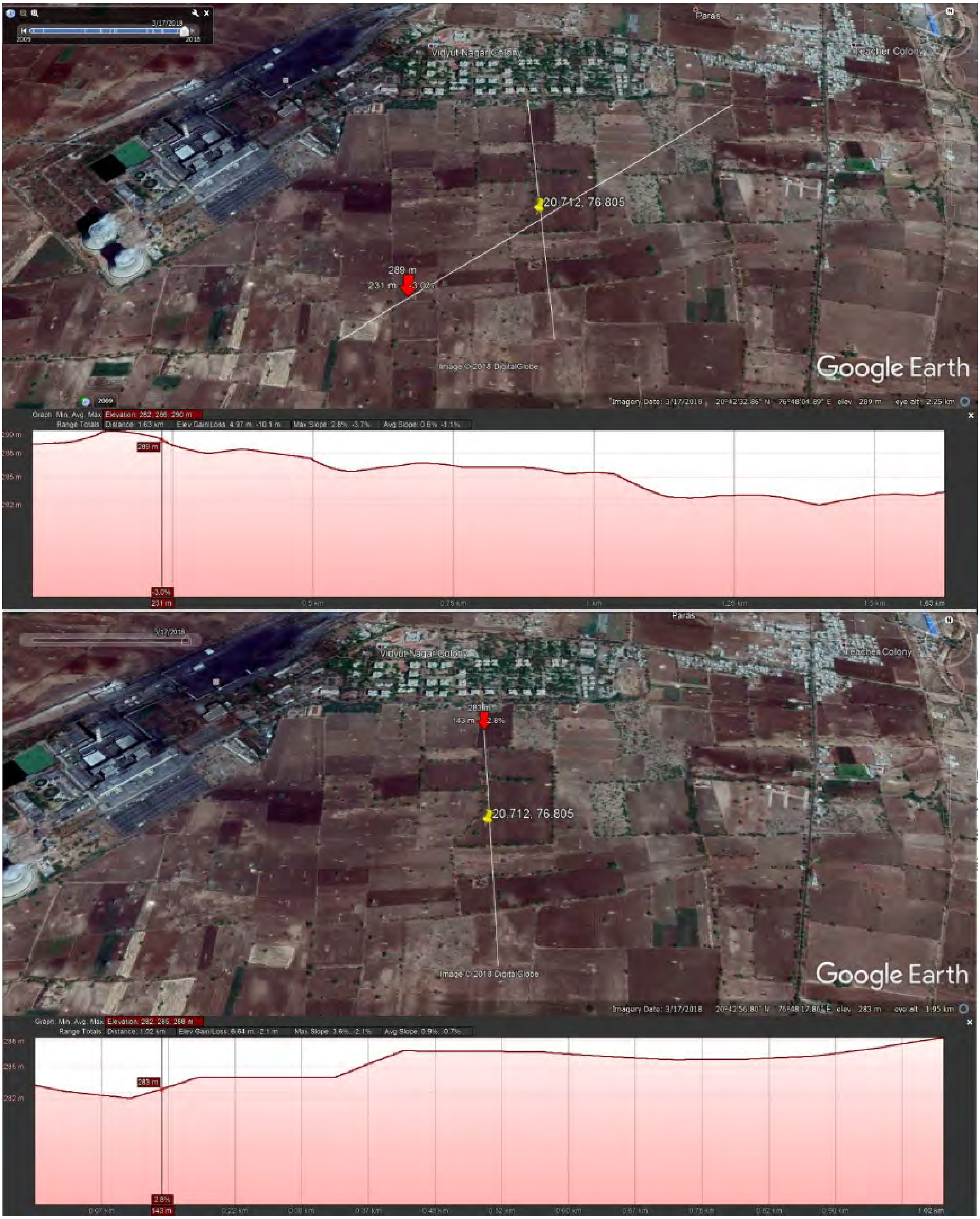
The site map in Figure 10 Project site map with a simplified representation of Horticulture PV system. shows the area acquired by Mahagenco. For the analyses in this report, we assume that from the 125 ha of available land only 100 ha will be used. To reduce the complex shape of the land parcels in the east, further acquisition of missing land areas appear recommendable. The unavailable fields separating the available surface in different islands (in the north-east) or peninsulas (in the south-east) hinder the installation of a continuous array of PV panels.

Figure 10 Project site map with a simplified representation of Horticulture PV system.[21]

The inclination profile of the site can also be seen in Figure 11. From north to south, the slope ranges from -2.1% to 3.6% with an overall slightly rising terrain. The average slope for inclines is 0.9% and -0.7% for declines.

21 Source: Google Maps

Figure 11 Slope at project site: south-west to north-east (above) and north to south (below).[22]



22 Source: Own work.

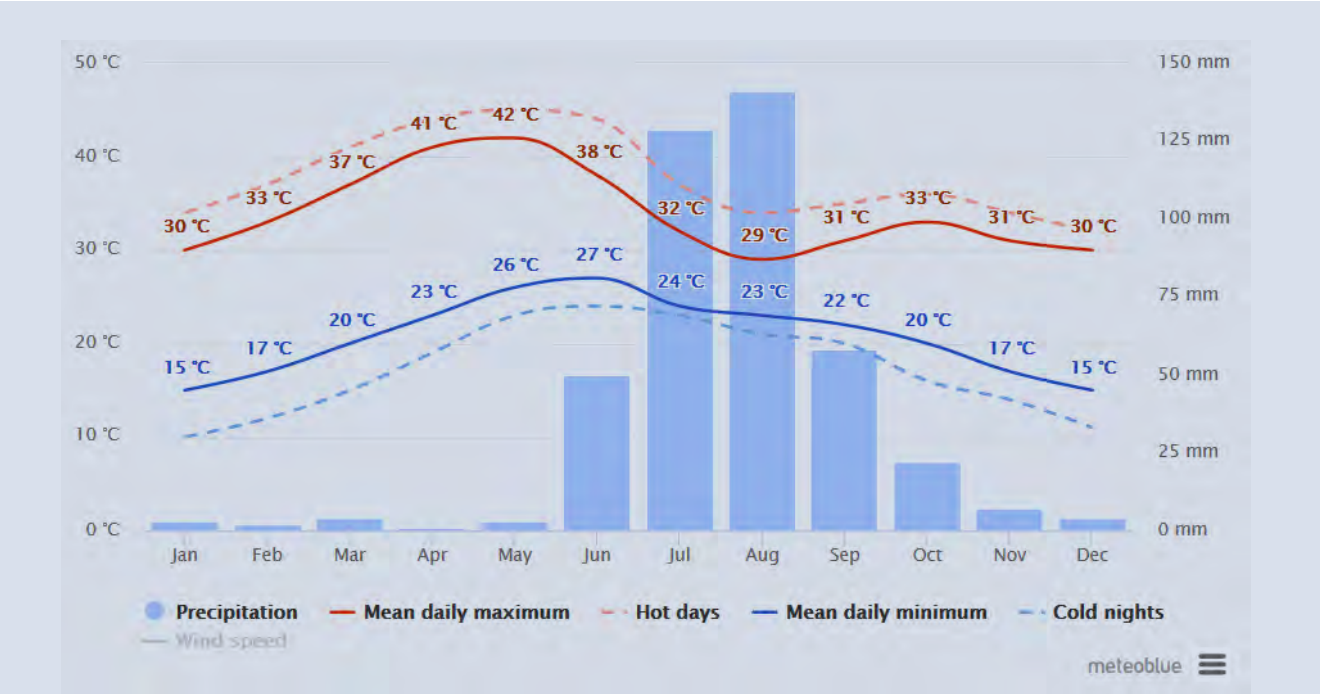
Diagonally from south-west to north-east, the slope ranges from -3.7% to 2.8% with an overall slightly declining terrain. The average slope for inclines is 0.6% and -1.1% for declines

2.2 Climate, Precipitation and Water

2.2.1 Current Climate & Precipitation

The Akola District has a semi-arid climate with a dry and wet season. Figure 12 presents an overview about the climatic conditions.

Figure 12 Average temperature and precipitation in Akola.[23]



The dry season (Rabi) and the wet season (Kharif) are characteristic for the location and represent challenges to local agriculture and irrigation. However, as elaborated in the sections to come, there could be positive effects of the Horticulture PV system on the micro-climate of the spot.

For the upcoming irrigation calculations, we have adapted the CROPWAT model default values for Akola. CROPWAT is a model to calculate theoretical crop water demand and irrigation requirements.[24] Thereby, "Average Effective Rain" is calculated by CROPWAT as the portion of rain that can serve the crop. The following table shows the precipitation figures for Akola:

Table 1 Precipitation data Akola district.[25]

Parameter	Unit	Low	Maximum	Average	Avrg. effective rain
Precipitation	[mm/m²]	305	1,661	891	646
Humidity	Avrg. %	49%	N/A	N/A	N/A

23 Source: meteoblue, https://www.meteoblue.com/en/weather/forecast/modelclimate/akola_india_1279105
24 For CROPWAT methodology see Smith and Kivumbi 2000 and Smith 1992.
25 Source: CROPWAT default values for Akola

2.2.2 Local Climate Change

In order to take future climate change impacts into account, we consulted the report "Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra: Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC) by (TERI 2014). The following parameters have been stated for the region of Akola and surrounding areas in the 2030's:

Table 2 Akola district climate change vulnerabilities.[26]

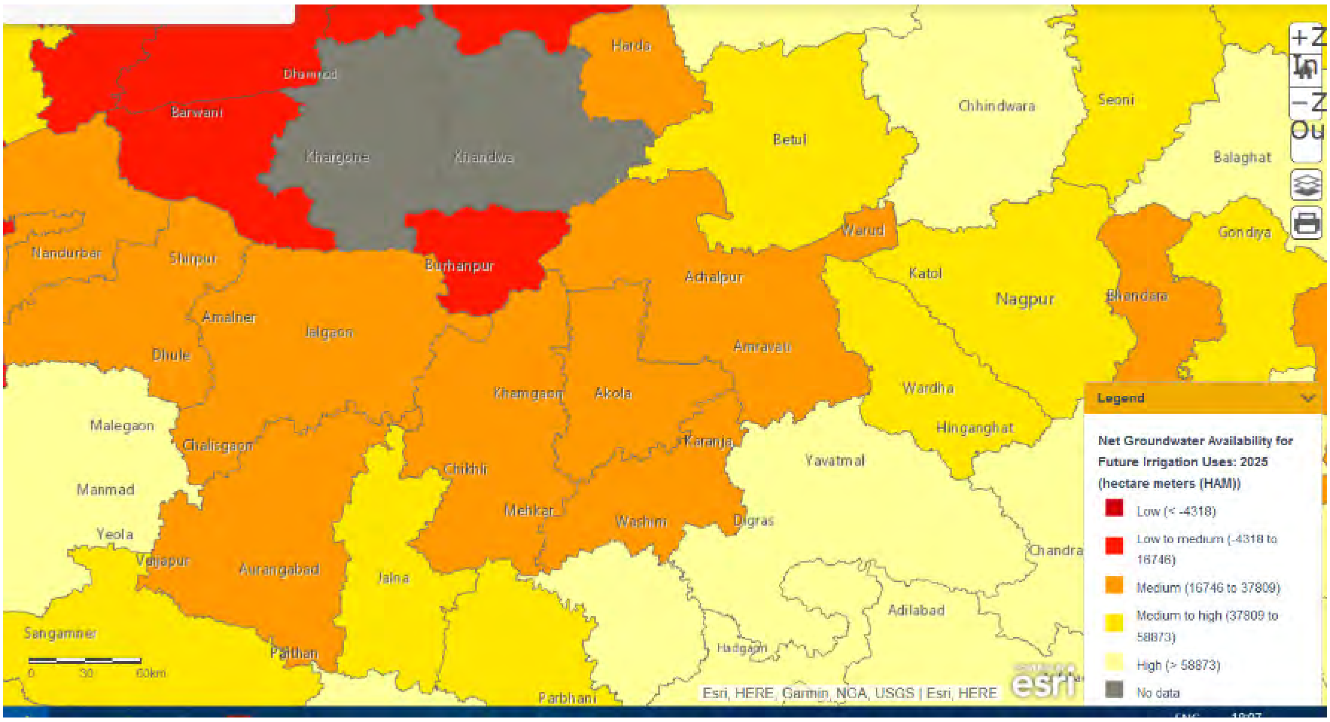
Projected	Unit	Value	Compared to development in Maharashtra
Increase in minimum temperature	[%]	53 to 58	Low increase
Increase in extreme rainfall	[%]	26 to 30	High increase
Increase in number of dry days	[%]	5 to 6	Medium increase
Increase in monsoon rainfall	[%]	22.5 to 30	High increase

The report identifies long dry spells and increasingly variable rainfall that is, however, decreasing in amount. Both seasons therefore will become more extreme. A general groundwater salinity problem in Amravati, Akola and Buldhana is also stated. Akola has also been mentioned as partly flood prone and is focused for grassland restoration activities.

2.2.3 Groundwater Status at Project Site

The Indian Water Tool (WRI 2015) projects a net groundwater availability for future irrigation uses by 2015 of a medium value of 16,746 and 37,809 hectare meters (HAM) which corresponds to 167.46 and 378.09 million cubic meters (MCM) for the Akola District.

Figure 13 Net groundwater availability for future irrigation uses: 2,025 HAM.[27]



However, despite sure rainfall, the aquifer is alluvial, and good rainfall year does not necessarily result in significant groundwater level improvement (especially if the region is groundwater over-exploited). The annual ground water recharge rate is about 5,247.67 HAM or 5.25 MCM.

26 Source: TERI 2014.
27 Source: IndiaWaterTool, http://www.indiawatertool.in/

Table 3 Groundwater scenario in Balapur as on 2008-2009.[28]

District	Administrative Unit	Type of rock formation	Aerial extent (in ha)				
Akola	Balapur	Alluvium	Total geographical area hilly area	Total geographical area hilly area	Groundwater recharge worthy area		
					Command area	Non-Command area	Poor ground water quality area
			68,832.99	1,819.91	2,820.63	62,704.45	1,488.00
			Dynamic groundwater resources				
			Recharge from rainfall during monsoon season [HAM]	Recharge from other sources during monsoon season [HAM]	Recharge from rainfall during non- monsoon season [HAM]	Recharge from other sources during non-monsoon season [HAM]	Total annual ground water recharge [HAM]
			4,366.12	64.86	336.37	480.32	5,247.67

Further information on the water balance of Akola district and Maharashtra can be found in the ANNEX page 147.

2.3 Soiling Effect & Wind

2.3.1 Soiling Effect at Project Site

Based on the global reanalysis and dust concentration data from Copernicus, the monthly average of daily dust deposition at the test station Paras are in the range of 567 and 1,104 µg/(m^2*h) using the following parameters, years 2003-2012, 0.03-20 µg and 0.75 degree. There is also significant variation in soiling during the year, with the peak values in April and December (see Table 4). Comparing with the typical soiling risk regions such as Arabian Peninsula or desert areas in Asia, the annual total of dust deposition in Paras correspond to 10-20% of these in above named regions, the peak values correspond to 30%. The comparison with Central Europe is nearly inversely proportional, 10-20% of the soiling values in Paras. However, by this estimation local factors (such as industrial or agricultural activity) are not considered. These can significantly increase the soiling at the test site.

Table 4 Dust concentration at project site based on Copernicus MACC Reanalysis.

Month	Average atmospheric dust concentration [µg/m^3]	Average daily dust deposition [µg/(m^2*h)]
1	17	605
2	21	758
3	21	743
4	31	1,104
5	23	809
6	23	832
7	27	957
8	16	587
9	20	720
10	21	733
11	16	567
12	30	1,092

The proximity to the Paras TPP is expected to have an impact on the electrical yield of the system as well as on the module cleaning requirements. The most frequent wind direction at the site location comes from the west to north-west which is expected to distribute the fumes from the TPP over and on the PV array.

The main soiling element at the project site will therefore be dust that settles from the Paras Power Plant. Seemingly comparable phenomena occurred at the solar power station at Chandrapur (5 MW_p), that is just 2km away from the

28 Source: CGWB 2017.

Chandrapur Super Thermal Power Station. Conservative derivations of the productivity loss data from Chandrapur suggest an annual cumulative loss of 3% to 6%.

Table 5 Overview soiling losses of Mahagenco's GM-PV.[29]

Generation MU's per financial year (YE)					
Solar power plant	**Commercia l operation date (COD)**	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
Chandrapur 1 MW_p (thin film)	09/04/2010	1.42	1.39	1.22	1.23
Index (per MW_p installed)	1	1.415	1.39	1.22	1.23
Percent of previous year			**0.98**	**0.88**	**1.00**
Chandrapur 2 MW_p (Crystalline)	18/10/2011	2.71	2.63	2.54	2.47
Index (per MW_p installed)	2	1.35	1.31	1.27	1.24
Percent of previous year			**0.97**	**0.97**	**0.98**
Chandrapur 2 MW (thin film)	12/02/2012	3.06	2.93	2.70	2.69
Index (per MW_p installed)	2	1.53	1.46	1.35	1.34
Percent of previous year			**0.96**	**0.92**	**0.99**

The installation of a cleaning system seems inevitable. However, from an economic point of view, the electricity sales losses must be higher than the assumed cleaning system costs. Literature suggests that soiling leading to productivity loss of up to 30% could occur.[30] Theoretically, however, there is no upper limit. For the calculations of the sales losses due to soiling we considered a cap at 25% total loss assuming, that no further particles will cumulate.

Mahagenco's Sakri solar power plant productivity numbers also show indication for a soiling effect, however at a lower rate of 1% to 2%. Developing a viable cleaning system approach seems inevitable.

To recommend a cleaning technology or the application of protection module top layers against soiling, yet, there is too little detail known to the specific type of soiling at the project site. Therefore, monitoring soiling effects at the project site over a period of at least 12 months is highly recommendable including reference modules and cleaning impact testing.

2.3.2 Wind

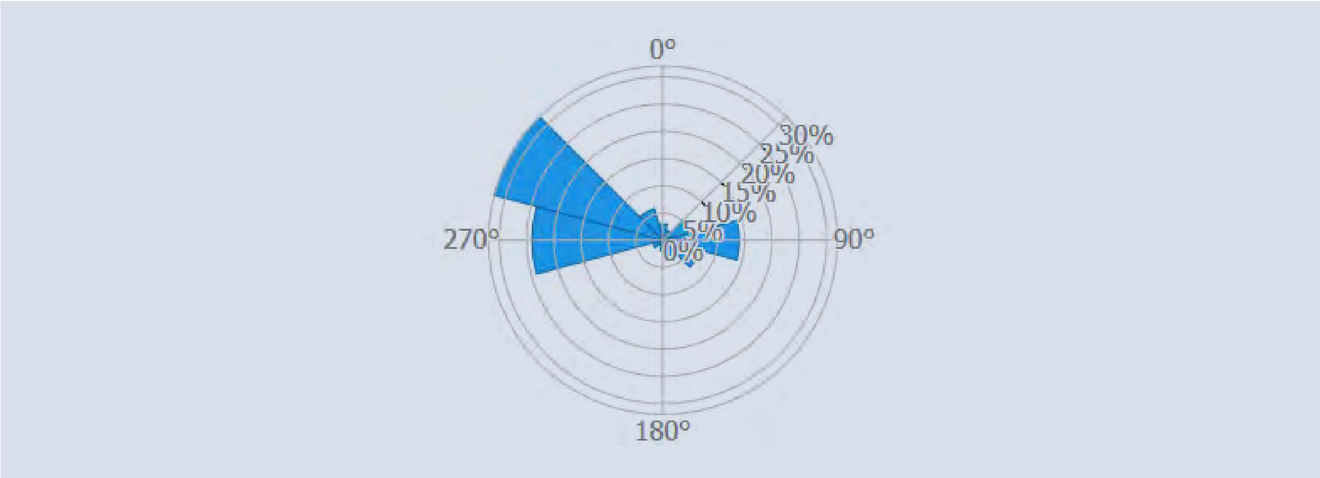
The wind direction at the installation site is important for several reasons. Where the frequency of strong wind gusts from a direction is high, the Horticulture PV system should be designed in a way that the impact of those winds on the system is reduced and controlled. Although the average hourly wind speeds for the last ten years do not exceed 10 m/s (measured at 10m height), the orientation of the array was chosen to be west-facing to align the module rows with the most frequent wind direction and thereby reduce the structural loads. Compared to a GM-PV array, a four-meter-high Horticulture PV system is expected to experience similar wind speeds.

A positive aspect of the Horticulture PV power station is the wind sheltering effect it creates for the crops grown under the system. The structural pillars of the system create wind breakers that prevent erosion otherwise caused by low level winds. A recommended measure to further improve the wind sheltering is to create a tree line to the west of the system, where trees removed during the installation phase could be replanted. This would create a natural wind breaker that would reduce wind infiltration through the lines of the system while reducing the overall impact on biodiversity of the Horticulture PV system.

As discussed in the previous section, the wind direction might cause shading and soiling issues due to the dust emissions and cloud formation from the Paras TPP.

29 Source: Mahagenco.
30 For soiling see: Bergin et al. 2017, Menoufi 2017, Ogaard 2016, Liu Liqun, Liu Zhiqi, Sun Zhiyi Liu Chunxia 2012, Weber et al. 2014.

Figure 14 Wind frequency rose for the site.[31]



However, detailed wind speed data for a resolution of days. Meteoblue[32] suggest a maximum wind speed of between 30 and 40 km/h. The design of the mounting structure will have to take high wind speeds during hailstorms into account. Such statics and structural questions must be assessed in more detail during construction planning

2.4 Soil Condition

Almost all of the land has black soil having clay loam texture. Due to heavy texture of the soil, there is low percolation of water, low drainage and the soil has tendency to develop deep cracks when it becomes dry on the surface. Fertility status of the soil needs to be checked through laboratory-based soil tests that are still pending. Such an assessment would be necessary to theoretically determine the optimal crop pattern for farming the plot. Below, we summarise the current state of our research.

A soil classification scheme can be found in the ANNEX page 138. For the location of Akola District, CROPWAT uses the following parameters to determine the irrigation requirements that we will present in this report.

Table 6 CROPWAT soil parameters.[33]

Soil parameters	Unit	Value
Soil name	[type]	Black clay soil
Total available solid moisture	[mm/m]	200
Maximum rain infiltration rate	[mm/day]	30
Maximum rooting depth	[cm]	900
Initial soil moisture depletion	[% of TAM]	50
Initial available soil moisture	[mm/m]	100

For future irrigation calculation purposes, it could be possible to adjust the CROPWAT parameters according to the laboratory findings in order to draw a more detailed model of the crop water requirements. However, the exact water requirements can only be determined by empirical research and scientific monitoring. Irrigation calculations are inherently limited and may only give orientation.

Further information is given by the Agricultural Plan by the Akola District (Akola District 2015) that categorises the district in the following "Agro-Economic-Situations" (AES). The project site is located in the "Western Balapur" sector, AES III:

31 Source: GlobalWindAtlas, https://globalwindatlas.info/
32 https://www.meteoblue.com/en/weather/forecast/modelclimate/akola_india_1279105
33 Source: CROPWAT default values for black clay soil.

Figure 15 Agro-economic-situations (AES) at the Akola district.[34]

AES	Soil Depth	Soil Type	Rainfall	Irrigation	Area	Percent
AES I	Deep Deep black Colour	Heavy pH 8.0 and above High NPK	Above 750 mm	Command Area	Northern Akot Northern Telhara	70 80
AES II	Shallow Light Colour	Medium pH 7 to 8.5 Low NPK Sandy Loam	Below 750	Rain fed	Eastern Balapur Northern Barshitakli Central Akola	10 10 80
AES III	Medium Deep black Colour	Medium pH 7.5 to 8.5 Moderate NPK Clay	Below 750 mm	Rain fed	Southern Akot Southern Telhara Western Balapur Patur Southern Barshitakli Murtijapur	20 20 60 95 30 10
AES IV	Medium Medium black Colour	Medium pH 7.5 to 8.0 Moderate to Low NPK Loamy	Below 750	Command Area	Southern Akot Central Balapur North East Patur Southern Barshitakli Murtijapur Akola	10 30 05 60 90 20

Furthermore, the following SWOT analysis is stated by the government plan:

Figure 16 SWOT analysis of AES III (Western Balapur and Patur Tahsil).[35]

AES III (Western Balapur and Patur Tahsil of the Akola district)	
Strength	**Weakness**
• Medium to heavy medium soil with heavy rains • Suitable for diversified and intensive cropping • Good irrigation	• Incidence of pest and diseases • Lack of market facility • Unavailability of agro base complimentary business
Threats	**Opportunities**
• Uncertain and erratic rainfall • Market gilt for horticulture crop • Unsuitable for electric supply (which is not given regarding the Horticulture PV system)	• Scope for agro, horticulture, forestry, animal • Husbandry farming system • Scope for creating water bodies for irrigation purpose • Scope for agro processing industries

2.5 Environmental Risk Assessment

Natural hazards at the test area should be assessed as they could turn out to be deal breaker, if they are not considered in the project planning and design. Table 7 shows the possible natural hazards and their probability of occurrence for the Paras project site.

Potential risk of extreme heat is a clear point of consideration as the prolonged exposure to extreme heat is expected to occur at least once in the next five years. More information is required for proper planning options of risk mitigation. Also, the wildfire risk is high at the test site. Therefore, the impact of wildfire must be considered in all phases of the project at Paras, in particular during design and construction.

34 Source: Copy from Akola District 2015.
35 Source: Akola District 2015.

Droughts events and water scarcity should be a point to consider as there were severe drought events in Maharashtra region in the past. However, Paras area was not directly affected by these events.

Compared to the global flooding level, the risk of flooding is moderate to high in the Paras area and therefore recommended to be considered in the project planning decisions, project design, and construction methods.

Landslide susceptibility has high level of hazard in India. However, in the Paras region the risk for landslide was classified with low or moderate index. It is difficult to determine future locations and timing of large rock avalanches and therefore it is questionable, if the potential of landslide should be better considered in the project planning decisions.

The natural hazard of earthquakes was classified as moderate. There is the chance of potentially-damaging earthquake shaking in the area in the next 50 years is about 10%. Paras area was not directly affected by the past earthquakes but for proper design of substructures and foundations more information is required.

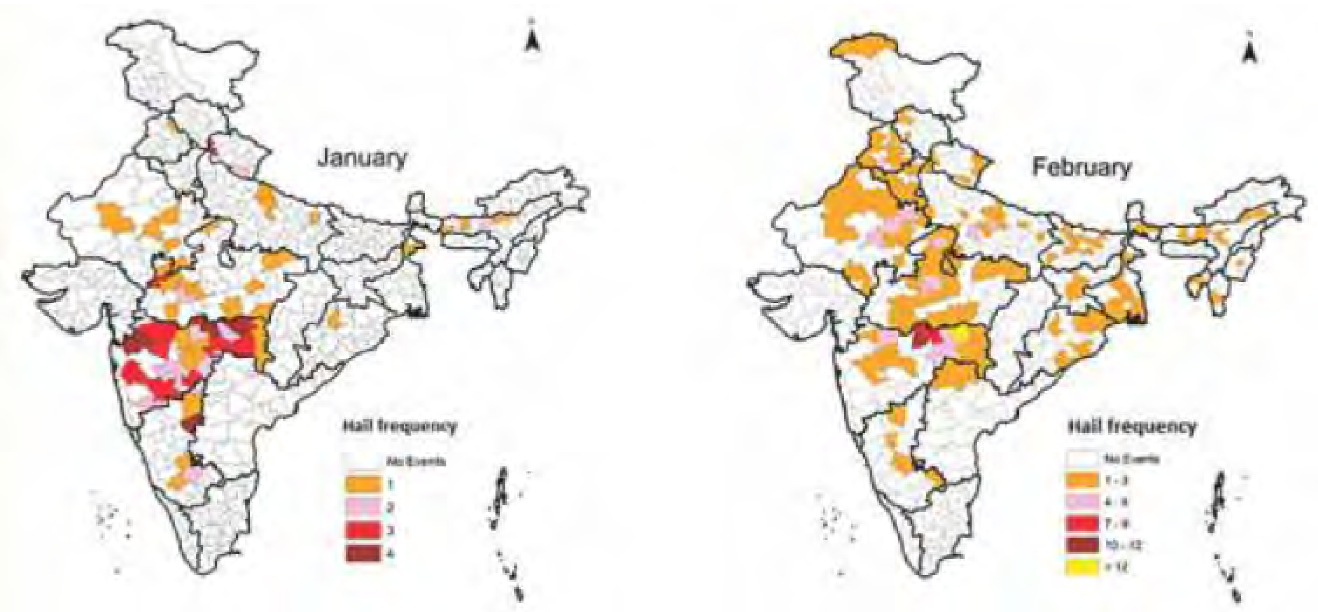
Detailed information about the environmental risk assessment for Paras and hazard maps are available in the ANNEX page 140.

Table 7 Summary overview of possible natural hazards at the project site Paras.[36]

Natural hazards	Occurrence probability on the Paras test site
Extreme heat	High
Wildfire	High
Hailstorm	High
Droughts events and water scarcity	Moderate
Floods risk	Moderate to high
Landslides	Low to moderate
Earthquakes	Moderate
Coastal flood	Low
Cyclone	Low

There are several reports of hailstorms that may come with higher frequency and intensity during the coming decades.[37] Especially central India and particularly the Akola District are most vulnerable to such storms and special care must be taken to protect employees, crops, facilities and equipment.

Figure 17 Hail occurrence in India in January and February 2014.[38]



36 Source: Global Risk Data Platform 13F, Web-based tool « ThinkHazards ! »
37 For the article see : https://www.hindustantimes.com/mumbai-news/maharashtra-most-vulnerable-to-hailstorms-imd/story-tZ9aCIC6QANx5t-KaEAxSrI.html
38 Source: Rao et al. 2014.

Figure 18 Hail size at Vidarbha region.[39]

In most cases solar modules withstand hail force up to a size of 25-30mm. However, it may be recommendable to explore necessary measures against impacts of a large and intense hail storm with corn sizes of above 30mm.

More information on hailstorms in India and respective management methods for agriculture can be found at (IMD 2014) and (NIASM 2014).

2.6 Summary

While the largest parts of the acquired land are relatively homogenous there are some gaps and islands that could hinder the continuous array of panels at some parts. The inclination profile is relatively flat with slopes not exceeding 4% for the entire area.

The climate is semi-arid with a dry and a wet season. The dry season from November to May is especially water scarce with almost no precipitation at all. It is estimated that the historical average precipitation of 891 mm will decrease in future. Meanwhile, the groundwater is under stress and future availability for irrigation is categorised only as medium. The annual groundwater recharge rate for the Akola district is identified as 5.25 MCM.

Generally, the natural dust concentration in the project region can be regarded as medium to low. However, due to the nearby TPP additional soiling is expected.

Regular wind speeds range up to 40 km/h typically from north-west. The ground-mounting structure and PV panels may serve as wind protection for the crops.

The soil at the project site is highly fertile and of black clay texture. Drainage and percolations is low. The soil is suitable for intensive cropping if irrigation can be provided and agricultural infrastructure is given.

The environmental risk assessment did not identify any deal-breaker for the project. However, there are high risks given concerning extreme heat incidences, wildfires and hailstorms. In some parts of the Akola districts flooding may also occur.

39 Source: Skymetweather, https://www.skymetweather.com/content/weather-news-and-analysis/vidarbha-weather-rain-hailstorm-strong-winds-damage-crop-in-washim-akola-nagpur-buldhana/

Recommendations

- Conduct detailed geological assessment and laboratory soil testing of the project site to evaluate foundations technologies and natural local water drainage.
- To protect local aquifers, no ground water extractions shall be conducted neither for panel cleaning nor for crop irrigation.
- Module cleaning is highly recommended given the expected degree of soiling.
- To assess viable cleaning technologies and schedules, soiling measurements of at least 12 months are recommended.
- Soil preservation is of high priority and special care should be taken during construction. To avoid soil compaction, the installation is recommended to take place during the dry season.
- More detailed analyses of the wind breaker function of the mounting structure might be helpful for more precise agriculture yield assessments.
- High wind speeds during hail storms must be considered when designing the structures.

3 Technical Design

Generally, the technical design of Horticulture PV systems follows those of GM-PV unless practicability or requirements of the agricultural layer urges to deviate from it. For that reason, in this section we start by outlining conventional GM-PV approaches to later provide a description of main technical concepts of Horticulture PV design highlighting aspects in which Horticulture PV deviates from GM-PV. Based on the site-specific conditions outlined in Section 2 we then develop a pre-basic design adjusted to the identified agricultural requirements like vertical clearance as well as work safety and conduct an energy yield assessment for the system.

Further, we analyse the performance of bifacial glass-glass modules compared to glass-Tedlar modules with conventional mono-facial cells. In Section 3.4 and 3.5 we explore different options for cleaning and water management systems that are required as a response to the environmental factors of solar module soiling and predominant water scarcity as identified in Chapter 2.

This section serves as the base for agricultural and economic analyses in Section 4 and 5.

3.1 Utility Scale GM-PV

In most cases, concepts of designing GM-PV facilities aim at maximising profits over the lifetime of the system. Strategies to arrive there can be divided in technical approaches that increase efficiency in order to achieve high electrical yield; and in economic approaches that reduce cost and increase revenues. Therefore, the subsequent sections discuss the most relevant rationales behind technical and economic optimising a GM-PV design to understand why and to which extent a Horticulture PV design follows an alternative approach.

3.1.1 Technical Approaches to Increase Efficiency

3.1.1.1 Geometric Parameters of Fixed Systems

Given the technical performance of available components, one crucial parameter is to decide on the orientation of PV modules. While some solar energy technologies such as concentrated PV (CPV) steadily require an orthogonal irradiation angle to the sun in order to operate and, hence, do rely on tracking systems, most PV technologies also perform well if the position to the sun deviates from 90 degree. In the following, we only regard silicon-based PV as this is the most often applied and most competitive technology currently available for utility scale GM-PV as well as for Horticulture PV.

PV modules of fixed GM-PV systems are typically facing to the south in the northern hemisphere at a module tilt – as a rule of thumb - corresponding to the location's degree of latitude. For Paras site, though, the optimal orientation would be an azimuth angle of -2 degree south-east and a module tilt of 26 degree according to the Photovoltaic Geographical Information System of the Joint European Research Centre (JRC).[40] The main reason why the preferred tilt at the location is mentionable higher than the latitude (20.7 degree) is due to the higher solar irradiation during dry season. Therefore, a higher tilt maximises the electrical yield over the course of the year, optimising electricity generation rather for dry and sunny than for wet months.

Another geometric parameter which determines the efficiency of the system is distance between the PV arrays. A minimum distance between these rows is necessary to avoid that PV modules shadow upon each other. Accordingly, the closer to the equator the closer the row distance can be as the optimal module tilt is flat and less likely to shadow adjacent module rows. Avoiding shadowing between PV arrays is on crucial reason why in conventional GM-PV utilities usually still a significant share of solar irradiation reaches the ground (Goetzberger A. and Zastrow 1982).

A parameter frequently reducing the efficiency of PV systems in hot climatic regions is temperature. As the efficiency of PV cells reduces with increasing temperatures, the PV design should allow for sufficient air circulation to avoid

40 http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

electric losses. This can be achieved by large enough row distances and elevation of the system. Usually, the panels of a power-output-optimised GM-PV system are held by a structure at a height of about 12m above the ground.

3.1.1.2 Tracked Systems

Globally, with a share of 70-80% single-axis PV tracking systems are the standard for large GM-PV projects and entail the potential to significantly increase the system's efficiency. Tracking systems can add additional tilt degrees of free movement in form of a rotation axis. Usually the axis is pointing towards the north to track the sun during the day. TPV panels can hereby be orientated to the position that meets chosen criteria such as maximal power output or smallest resistance to wind among others. Typically, the expected electrical yield of a single-axis tracked configuration exceeds the yield of a fixed system by 20-30%.[41]

Figure 19: Single-axis solar tracking concept.[42]

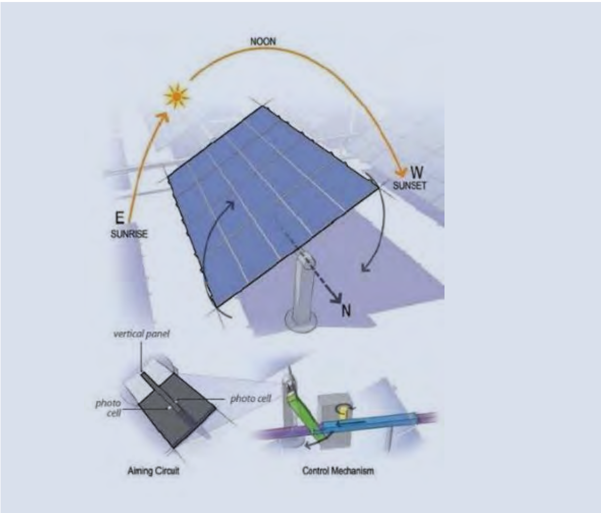
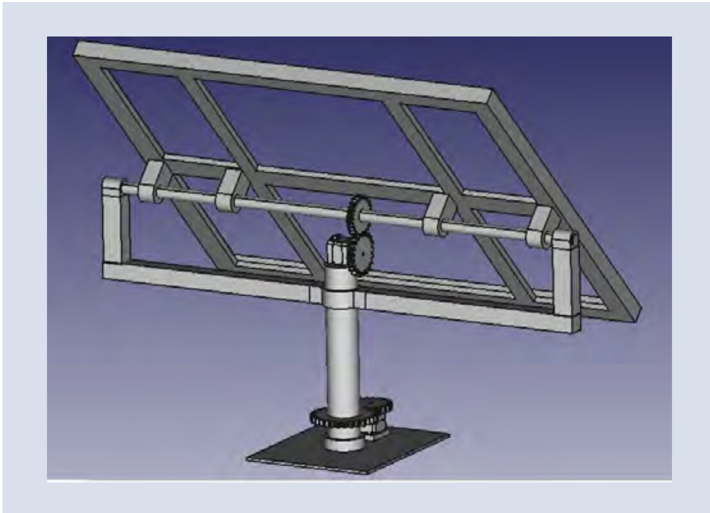


Figure 20 Dual-axis tracker model.[43]



A two-axis tracking system increases the electrical yield even further by having a second degree of free movement also in form of a rotation axis and most usually normal to the first tracking axis. While the energy yield of a dual axis tracked PV system is higher than a single-axis tracked one and exceeds the yield of a fixed system by more than 40%, the increased complexity of the system leads to higher CAPEX and higher maintenance costs. Apart from CPV, overall, for most large GM-PV systems two-axis tracking is not recommendable. For dry regions such as Spain or Nevada (USA) single-axis tracking system are considered economical (Talavera et al. 2019).

3.1.1.3 Module Choice

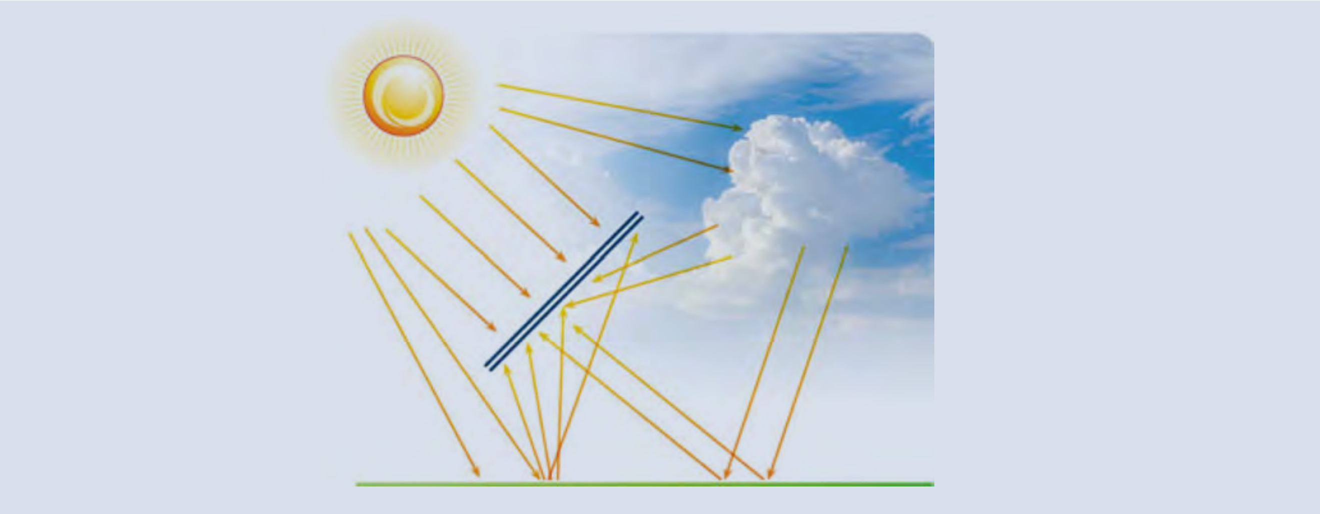
In order to focus on the most relevant technologies for the Horticulture PV system we have boiled down the choice among the vast variety of silicon-based PV modules to conventional glass-Tedlar modules and bifacial glass-glass modules.

Glass-Tedlar modules are the cost-effective choice of module when a low CAPEX is desired. Being completely opaque, glass-Tedlar modules are the most commonly used module type of utility scale GM-PV.

Recently, bifacial glass-glass modules that generate electricity also on the rear side, entered the market and became increasingly competitive. Depending on the albedo factor of the ground and other factors, bifacial glass-glass modules can increase electrical yield up to 25% (Yusufoglu et al. 2015). In GM-PV applications, bifacial modules are on the edge of competitiveness, though, 10-25% higher cost has to be considered. The market share is still just around 0.5%.[44]

41 Fraunhofer ISE (2016), Deger Studies.
42 Source: https://www.instructables.com/id/Simple-Dual-Axis-Solar-Tracker/
43 Source: https://grabcad.com/library/dual-axis-solar-tracker-2
44 Measured by accumulated capacity in 2018. See (Kopecek and Libal 2018).

Figure 21 Bifacial PV module.[45]



3.1.2 Economic Approaches to Reduce Cost and Increase Profitability

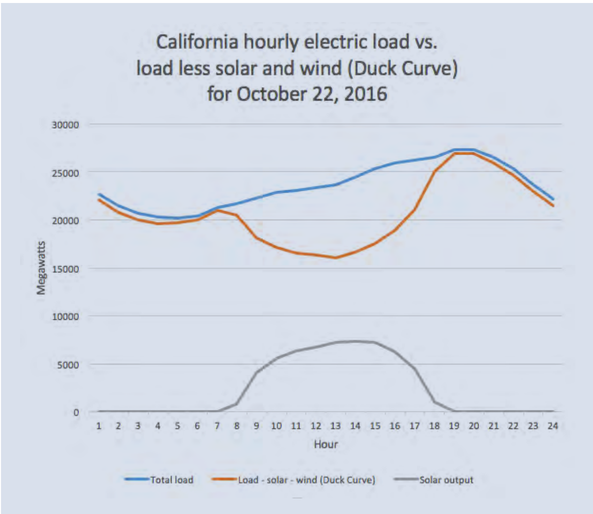
Apart from increasing technical efficiency, cost reduction and revenue maximisation are essential strategies to enhance the profitability of GM-PV facilities. To reduce fixed cost[46] per installed W_p, larger projects are favourable due to economies of scale. Similarly, in areas with high land cost smaller row distances and a respective lower tilt angle are a widely employed strategy to reduce cost. Further, a higher installed capacity can reduce cable length and, consequently, cable losses.

While efficiency rises when air circulation improves at a higher elevation, from an economic perspective higher cost of the required mounting structure usually does not justify a higher elevation. In contrast, in order to avoid shadowing of PV modules by growing weed, a distance to the ground below 1 meter is typically only recommended in areas with low vegetation. In fertile areas, though, GM-PV systems frequently require additional efforts of mechanical or chemical weed control. Another common and very economic practice in fertile areas is rotating livestock farming.

Maximising electrical yield as usually pursued when designing a GM-PV system, might not be the optimum if prices for electricity vary or a balanced supply of electricity is envisaged. As most GM-PV systems are facing south, the peak power production of regions with a high share of PV is fed into the grid at the same time, possibly causing grid instability issues. The typical daily PV power production repartition can be seen in the following figure, given the example of California:

The total load is not optimally reduced (or flattened) over the whole day. The resulting residual load (total load – renewable production) has steep declines and inclines which are difficult to handle for the grid operators. Subsequently prices in morning and evening hours might be higher incentivising PV systems to deviate from a south orientation in order to shift electricity production.

Figure 22 So-called duck-curve caused by solar production in California.[47]



45 Source: Lossen 2018.
46 Such as grid connection, due diligence, legal advisory, development & management cost, as well as most operational expenditures (OPEX).
47 Source: Reinhold, Arnold; work based on data from caiso.org, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=52529738

3.2 General Principles of Horticulture PV

In contrast to GV-PV systems, the Horticulture PV approach aims at providing best possible farming conditions for agricultural activities while keeping electric generation at an acceptable level. Basic principles of designing a Horticulture PV system can be derived from the following definition:

> **"Horticulture PV is a system technology that enables the simultaneous agricultural production and solar power generation on the same area in the open air and which seeks to optimally utilizing synergy effects and potentials of both production systems."[48]**

Hence, a Horticulture PV system must fulfil several requirements of the agricultural layer and the aspect of integration of both layers must be the guiding principle.

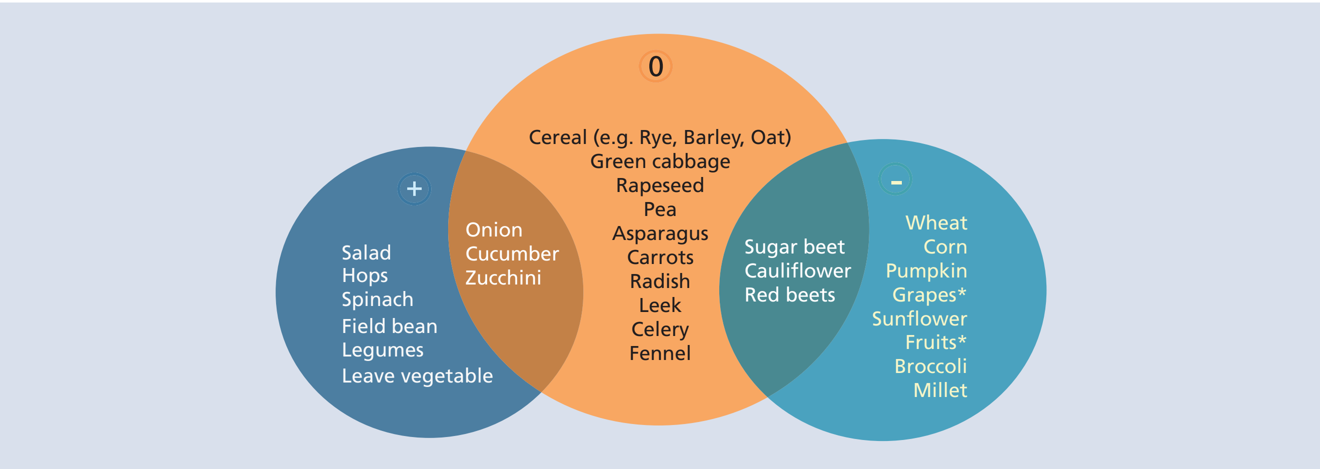
3.2.1 Crop Selection

According to the above-mentioned definition, the identification of suitable crops and agricultural practices is a crucial task for the Horticulture PV approach as the performance of the system largely depends on selected crops and their respective shade tolerance. Hence, crops like leaf vegetables or berries can benefit from less solar irradiation and are more suitable than sun-loving crops like corn, rice or wheat. Figure 23 illustrates and stylises response functions of crop yield to a reduction of photosynthetically active radiation (PAR). As it can be seen in the blue circle, representing category PLUS, shade-loving crops respond with higher yield for a reduction of PAR up to 50%.

Table 8 Crop shadow-response category.[49]

Category	Crops
+	Vegetables
0	Rape & barley
-	Corn

Figure 23 Classification of most relevant crops suited for Horticulture PV.[50]



The graph below illustrates and stylises response functions of crop yield to a reduction of photosynthetically active radiation (PAR) according to crop category.

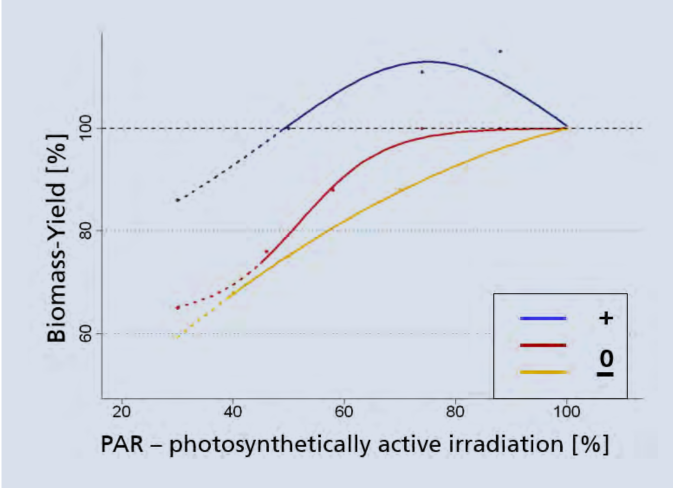
48 Definition of Horticulture PV according to Fraunhofer ISE (2018)
49 Source: Fraunhofer ISE
50 Source: (Obergfell 2012)

Further, crops that are cultivated in rows and do not require large agricultural machines usually perform better in an economic sense as crop rows integrate easier into the mounting structure of the PV.

3.2.2 Light Management

To allow for sufficient light passing through to the ground, Horticulture PV systems tend to increase the row distances compared to conventional GM-PV. Typically, PV covering ratios (covered area by PV modules from a birds eye perspective) range between 20-40% of the cultivated area. Nevertheless, even for shadow tolerant crops, light conditions below PV panels might be inadequate if the available sunlight is not evenly distributed.

Figure 24 Schematic crop shadow-response function.[51]



Technically, there are several options to create homogenous light conditions: as in the Japanese solar sharing approach, small module rows can replace the usual widths of GM-PV systems; glass-glass modules can be covered less dense with PV cells to allow for an increase penetration of sunlight; and a higher vertical clearance automatically contributes to a better distribution of shaded areas. However, these approaches are inflicting higher system cost – either because of less standardised modules or because of costly mounting structures.

Another, more economically viable method is to choose a slightly deviating orientation to the south-east or south-west. At this configuration shadows of PV rows move during the day, providing a sufficiently high distribution at relatively little electrical losses.[52] For this approach, depending on the geographic location and other parameters of the system design the deviation from south ranges between 20-70 degree. As an additional beneficial side effect, this method shifts the power production curve either to the morning or to evening hours potentially balancing out electrical losses if higher electrical prices can be realised.

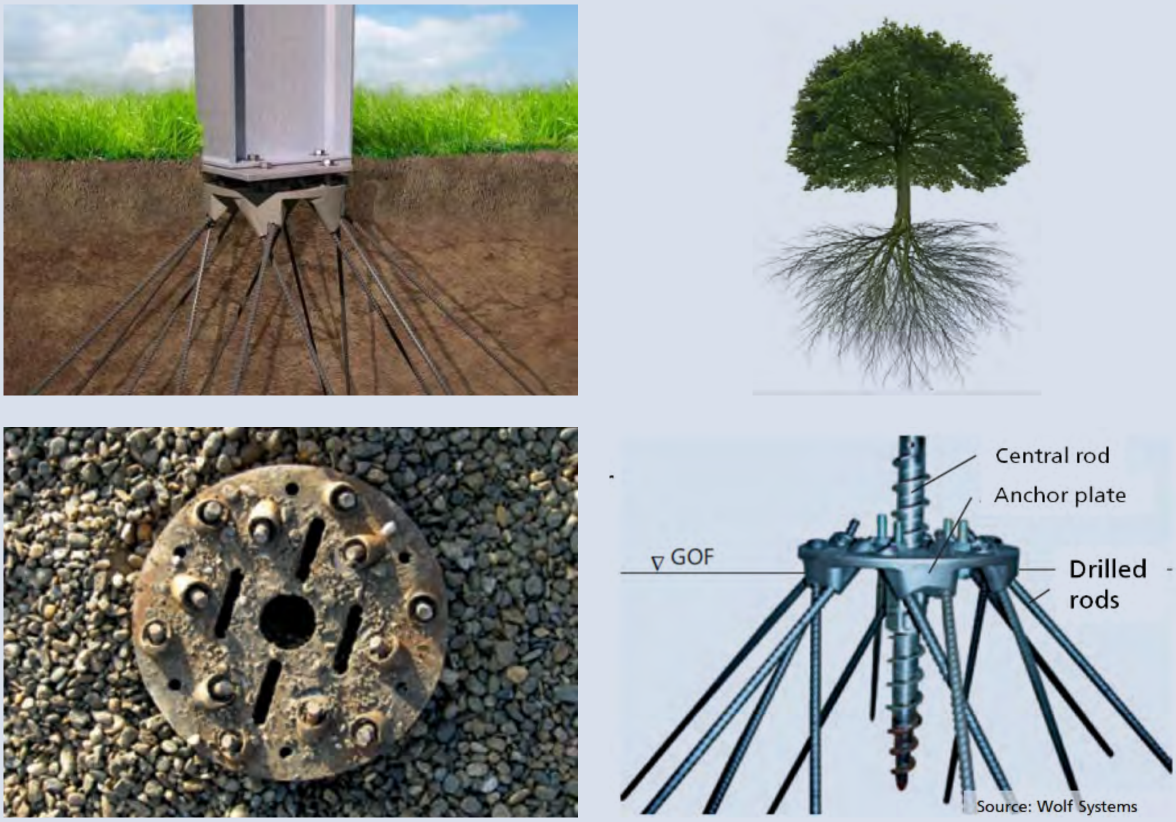
3.2.3 Mounting Structure and Foundation

Most agricultural practices rely on the application of some kind of machinery. Therefore, most Horticulture PV systems require a certain vertical clearance and aim at large pole distances. For arable farming, the benchmark for vertical clearance is usually given by full harvesters with a height of up to 5m. Other agricultural activities like horticulture tend to employ smaller or even no machinery, which significantly reduces the cost of mounting structures. This is especially true since wind loads on the structure strongly increase with a higher vertical clearance requiring more solid foundation and material input. Regarding ground work techniques, it seems generally recommendable to avoid the use of concrete on arable land. The presence of concrete reduces fertility and soil permeability with its adverse effects on crop growth. Additionally, dismantling of the mounting structure after the lifetime of the system is a costly and complex procedure in which the use of heavy machinery potentially causes soil compaction and hence soil degradation. Thus, systems that are drilled or rammed should be favoured when installing a Horticulture PV system.

An innovative concrete-free foundation solution is the Spinanchor technique. This method follows the principle of a tree root and consists of a cast iron anchor plate that is fixed to the ground by threaded rods with a length 2-8m (depending on soil type and surface structure) and has been successfully applied at the pilot facility in Heggelbach, Germany.

51 Source: (Obergfell 2012)
52 See Fraunhofer ISE EU-patent “Method for Simultaneously Cultivating Crop Plants and Utilizing the Energy of Sunlight” http://publica.fraunhofer.de/documents/N-270931.html.

Figure 25 Spinanchor method as concrete-free foundation solution.



Beneath the Spinanchor method, other foundation solutions like rammed or drilled systems are easy to mount and remove and being frequently used for GM-PV. If such methods are to be applied for high vertical clearance of a Horticulture PV system, their reliability has to be specifically verified for the specific soil conditions and local wind loads in order to avoid planning mistakes and potential damages.

3.2.4 Module Choice

In contrast to GM-PV, bifacial modules in Horticulture PV systems perform cost-efficiently since the increased row distance and vertical clearance allow for higher reflected insolation to the rear side of the modules. Since the recent competitive gains of bifacial modules, they are the preferred choice for most Horticulture PV systems even from a purely electrical perspective. Additionally, their partial transparency of bifacial glass-glass modules (estimated to be 8% for the pre-design) leads to an improved homogeneity of irradiation under the panels while still providing shelter for the plants.

Generally, bifacial modules open the opportunity to additionally increase electrical yield by applying agricultural practices that increase the albedo of the ground. This could include bright coloured crops (e.g. flowers or rape seed) or the application of reflecting plastic foils.

3.2.5 Tracking

Unlike module choice, arguments are more controversial when it comes to tracked PV systems for both singe-axis and two-axis tracking. One aspect rather arguing against the implementation of tracking in the context of Horticulture PV is the adverse light transmission. The optimised orientation to the sun increases shadowing on ground level and eliminates the positive side effect of a fixed system that allows more sunlight reaching the ground if panels are sub optimally oriented. While this can partially balance out by larger row distances, the overall economic performance reduces due to a less dense PV capacity per area. Further, if bifacial modules are used in tracked systems, the module efficiency on the rear side decreases making an implementation of bifacial modules slightly less attractive.

Other critical points to consider are health and safety (H&S) and soaring installation and maintenance cost due to additional system components and more complex maintenance requirements. Regarding H&S, moving overhead elements poses significant additional risks.

Furthermore, for two-axis tracking the heterogeneous shading is induced by typically large module tables. Adverse effects of required large concrete foundations make this technology less attractive for Horticulture PV.

A positive aspect of one-axis tracked Horticulture PV is – besides increased electrical yield – a very homogeneous solar irradiation on the ground. Usually the axis of the module row is northsouth oriented creating west-east moving shadows under each line of the PV array. Also speaking in favour or tracked systems, the option to deviate from a purely electrically optimised orientation opens up new opportunities to trigger synergy effects and potentials for the agricultural layer. Accordingly, a tracked PV system can be harnessed to increase available sunlight for the plants during critical growing periods e.g. for germination or prior to harvesting activities. Similarly, a tracked system could be employed to maximise sheltering in case of severe weather events like hail storms or heavy rain. Used for this purpose, though, additional investments in the mounting structure might be required as in the case of heavy wind tracked systems usually reduce wind loads by vertically orienting to the wind direction.

Both options, single-axis and dual-axis tracking would allow for a lower vertical clearance as modules can be positioned in a way to not hinder the employment of land machines.

However, due to the aspects discussed above, we have not considered tracking technologies for the preliminary design. There are several theoretical advantages, yet the economic viability within the given context is highly questionable.

3.2.6 Legal aspects

If land is not solely dedicated to produce either food or energy, the question of the legal status of the land area emerges. Usually, farming land is subject to privileged land use legislation with rights and obligations significantly differing from other land uses. As a technology hardly embedded in any legislation yet, at current status Horticulture PV encounters the risk of losing privileges of either the agricultural or the electrical system element when having to decide for the one or the other legal definition. One possible risk might be that a construction permit implies a reclassification of agricultural land into building land with potential adverse effects for the agricultural layer, e.g. the loss of agriculture subsidies as it is currently the case in Germany.

Another legal aspect to consider when designing a Horticulture PV system is Occupational and Community Health & Safety. In contrast to GM-PV, a Horticulture PV might have to fulfil legal regulations that are required for the safety of the persons working on the farm below the module rows. Depending on the national and regional legislation, this might include the application of certified materials or standards deviating from those of GMPV. As an example, work safety in Germany obliged the use of certified safety glass for the Horticulture PV pilot plant at Lake Constance.[53] The precautionary principle shall be applied in order to avoid adverse risks.

3.3 Proposition of the Horticulture PV System Design

In this sub-section we propose and describe a prebasic design of the Horticulture PV system based on the conditions given by the project sites. In order to provide a comprehensible documentation of our approach, we first define the appropriate geometric parameters of the system. Furthermore, we conduct an energy yield assessment and analyse the performance of bifacial glass-glass modules.

The system presented in this section serves as a pre-basic design to assess the overall efficiency of the system and does neither have the aim to fulfil engineering and construction planning, nor does it replace such. It may serve as a foundation for further planning. Water issues concerning cleaning and irrigation are discussed separately in later sections. We have dedicated comparatively large parts of the report on the cleaning and water management system, since such installations present a novelty to the Horticulture PV concept.

3.3.1 Geometry, Location, Orientation, Hardware

In our analysis we focus on fixed PV systems for mainly two reasons: the expected weaker economic performance of tracked PV systems and possible work safety issues.

53 Bauregelliste_2015.pdf, DIN-18008-Glasbau.pdf

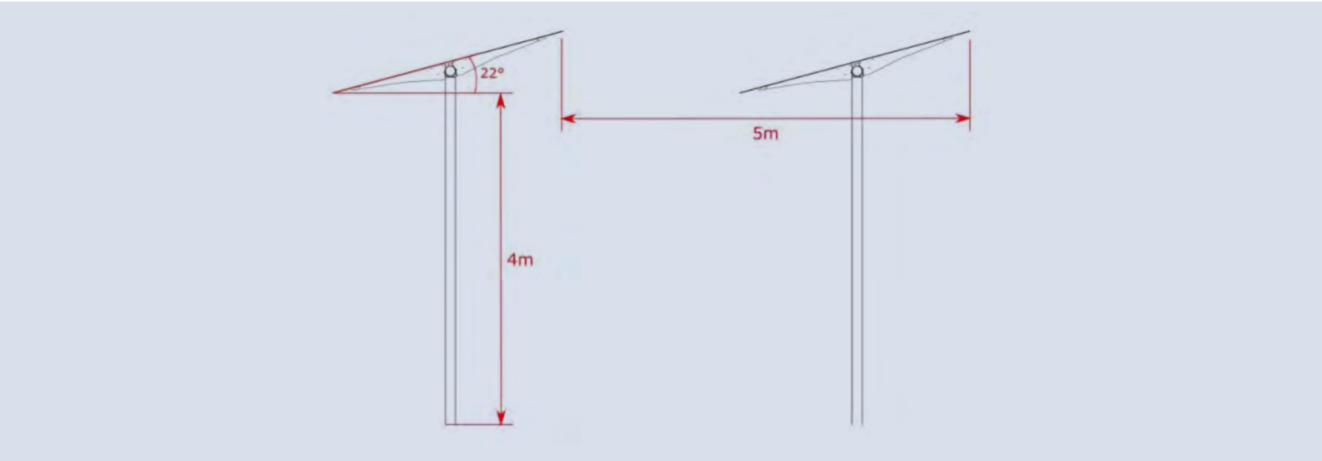
According to the irradiation simulation described in Section 4.2.3 and requirements of the four selected crops to be found in Section 4, the geometric parameters are specified at a vertical clearance of 4 meters, a row distance of 5 meters, an **orientation towards southwest of 208 degree** (corresponding to a 28 degree deviation from full south), and a tilt angel of PV modules of 22 degree. Regarding the superior performance and market prices of bifacial PV modules, we consider the installation of module type **JKM370M-72H-BDVP, Eagle Bifacial 72H, 370 W, monocrystalline of Jinko Solar.**[54]

It must be noted that the assumption of implementing this module type is by no means a recommendation of this product but rather a method of applying realistic figures of average products available on the market. For the electrical yield simulation, we have assumed the **inverter model SUN2000-60KTL from Huawei** with a maximum DC-Power of 67.3 kW and an AC-rated power of 30 kW as representative standard equipment for the analysis.

The orientation of panels to the west instead of east follows the main wind direction in order to realise maximum crop protection.[55] However, a drawback of deviating to the west is the proximity of the Paras TPP that might cause a reduction of electrical yield in the evening hours due to cloud formation. Hence, we strongly recommend measuring the PV yields for east and west oriented systems prior to the final decision on the system design for twelve months.

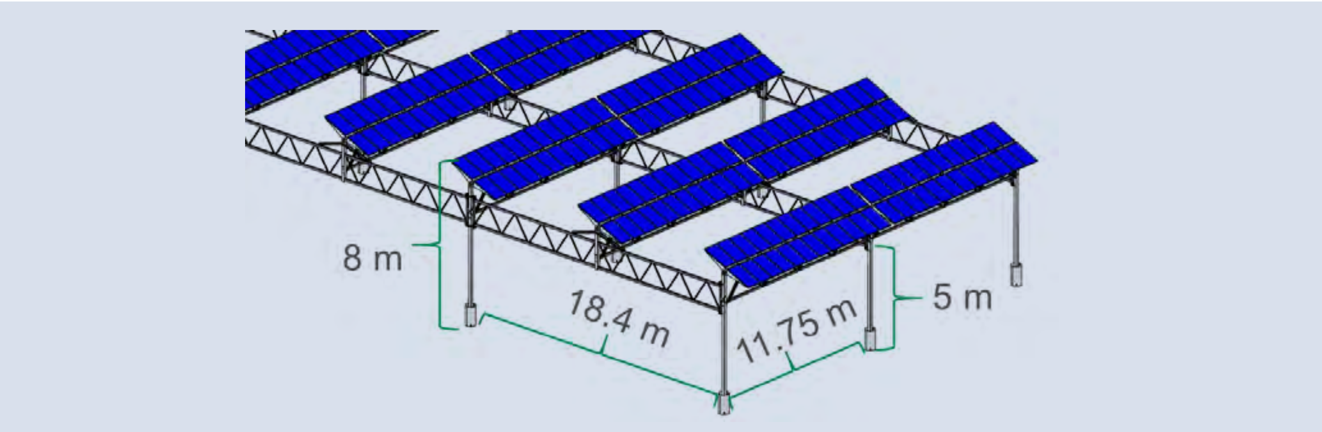
The tilt of the panels was set to 22 degree and is slightly smaller compared to typical GM-PV system in order to maximise electrical yield with the specified panel orientation. Figure 26 sketches the mounting structure and rowing as a proposition for the project site in Paras.

Figure 26: Graphical representation of proposed geometric parameters.[56]



For comparison, see the geometric parameters of the pilot facility in southern Germany.

Figure 27 Horticulture PV design of the pilot facility in Heggelbach, Germany, with crosspieces between rows to allow for large distance between the pillars.[57]



54 Datasheet version JKM360-380M-72H-BDVP-D1-EN, see https://www.jinkosolar.eu/en/download/datasheets.html?file=files/jinko/module/datasheets/en/Eagle%20PERC%20JKM360-380M-72H-BDVP-D1-EN.pdf
55 See Section 3.3.
56 Source: Fraunhofer ISE.
57 Source: Fraunhofer ISE.

The geometry represents a synthesis of the German approach and the "lighter" Japanese solar sharing concept. This synthesis is likely to reduce mounting structure cost and maintenance complexity, while realising homogenous shading conditions though both smaller width of module rows and by applying the patented deviation from south.

Table 10 summarises all technical parameters of the proposed Horticulture PV system. The following sub-sections build on these values and present the electrical yield assessment and a subsequent estimation of the capacity of the system.

Table 9 Summary of technical parameters.[58]

[Location]	
Latitude	20.71
Longitude	-76.806
Ground_albedo(%)	20
Horizontal geometry	dtmh_20.712_76.805.hor
[Module]	
Manufacturer	Jinko
Type	JKM370M-72H-BDVP
Datasheet-version	JKM360-380M-72H-BDVP-D1-EN
Modul width [mm]	992
Modul length [mm]	2,000
Bifaciality [%]	70
[Inverter]	
Manufacturer	Huawei
Type	SUN2000-60KTL
Max. DC-power [kW]	67.3
AC-rated power[kW]	60
[system, all parameters in Table 9**]**	
Pitch distance (distance between rows) [m]	5
Table height (from ground to the lowest part of module) [m]	4
ModTilt	22°
ModAzim (north=0°, east=90°, south=180°, west=270°)	208°
Nr. module per string	20
Nr. strings per inverter	10

3.3.2 Electrical Yield Assessment

To assess the typical initial annual electrical yield of the proposed design, we employed the Fraunhofer ISE software Zenith. According to our simulations, typical initial annual yield amount to 1,713 kWh per installed kW_p and thus a performance ratio of 84.8 %. With an expected probability of 10% the initial annual electrical yield ends up at 1,552 kWh per kWp or below (P90 value). On the other side, with an expected probability of 10% the initial annual electrical yield ends up at 1,874 kWh per kWp or above (P10 value). The results of the electric yield assessment are listed in the table below.

58 Source: Fraunhofer ISE.

Table 10 Energy yield simulation Horticulture PV system.[59]

Bifacial JKM370M-72H-BDVP module [yearly values]				
Calculation step	**Unit**	**Sum**	**Gain / Loss (G/L)**	**Performance Ratio (PR)**
Ghor(SolarGIS)	[kWh/m²]	1939.80		
Ghor_sim	[kWh/m²]	1,925.19	-0.8%	
Gtilt_sim	[kWh/m²]	2,019.55	4.9%	100.0%
Gtlt_1face (incl. shading)	[kWh/m²]	1,993.52	-1.3%	98.7%
Gtlt_2face (incl. shading)	[kWh/m²]	2,149.76	7.8%	106.4%
Dirt + LID	[kWh/m²]	2,063.77	-4.0%	102.2%
Non-STC operation of PV modules				
Reflection	[kWh/m²]	2,012.24	-2.5%	99.6%
Spectrum	[kWh/kW$_p$]	1,992.12	-1.0%	98.6%
Irradiation	[kWh/kW$_p$]	1,976.97	-0.8%	97.9%
Temperature	[kWh/kW$_p$]	1,798.26	-9.0%	89.0%
Mismatch	[kWh/kW$_p$]	1,783.87	-0.8%	88.3%
DC circuit	[kWh/kW$_p$]	1,767.88	-0.9%	87.5%
Inverter	[kWh/kW$_p$]	1,747.23	-1.2%	86.5%
Inverter power limitation	[kWh/kW$_p$]	1,738.62	-0.5%	86.1%
Self-consumption	[kWh/kW$_p$]	1,738.62	0.0%	86.1%
AC circuit 1	[kWh/kW$_p$]	1,728.57	-0.6%	85.6%
Transformer 1	[kWh/kW$_p$]	1,713.20	-0.9%	84.8%

Simulating the same system configuration, bifacial modules produced a result 6.4% above the electric yield of mono-facial glass-Tedlar modules. The impact of the bifacial module can be seen in line "Gtlt_2face (incl. shading)" of Table 11 with an interim increase of performance of 7.8%.

A comparative electrical yield assessment for a monofacial module with similar electrical properties results on 1,604.4 kWh/kW$_p$ and a performance ratio of 79.4%. According to industry sources, bifacial modules are usually manufactured in higher quality, hence this 6.4% represent the bottom line. In practices the losses using monofacial modules with varying electrical properties are likely to be higher.

The results strongly recommend using bifacial glass-glass modules since the rise of electrical yields clearly outweighs the higher cost as to be elaborated in Section 5.3. Additionally, glass-glass modules allow for more available sunlight for crops thanks to their transmission rate of up to 10%.

However, as a general disclaimer it must be said that the practical results may vary, and it shall be recommended to conduct field measurements using different module variants to empirically determine the electrical yield.

3.3.3 Horticulture PV System Capacity

Given an area of 100 ha almost entirely covered by module rows, we calculated a theoretical maximum capacity of about 74.5 MW$_p$ and respective 746 kW$_p$ / ha. However, this figure represents the upper limit and does not include a variety of uncertainties as well as Indian benchmark values. Among such uncertainties are the land losses through additional supporting infrastructure such as pathways, roads, transformation buildings, equipment storage among others. Further economic limitations can be given due to areas that cannot be integrated in the power stations layout in an economic manner due to e.g. rocky formations in the ground, unfavourable location in relation to the rest of the plant or other reasons.

In order to add a scenario that may provide a more accurate display of opportunity, the benchmark figure for India of 590 kW$_p$ per ha, confirmed by stakeholder consultations, has been reduced by 14% which is a value gained by experiences of studies conducted for the German context. Hence, a total capacity of around 507 kWp per ha may be a realistic value even though there might be further reduction that are unknown given the current stage of study.

59 Source: internal Fraunhofer experts.

Table 11 Capacity range of the Horticulture PV system design.[60]

		Theoretical maximum capacity	Capacity according to India benchmark
Area	[ha]	100.00	100.00
Modules	**Unit**		
Capacity per module	[kWp/m^2]	0.19	0.19
Width of module	[m]	0.99	0.99
Length of module	[m]	2.00	2.00
Module size	[m2]	1.98	1.98
Total module area	[m2]	400,000	272,075
Total modules	[No.]	201,613	137,134
Rowing			
Gap between modules	[m]	-	-
Modules per string	[No.]	20.00	20.00
Average number of strings per row	[No.]	10.00	10.00
Nr. strings per inverter	[No.]	10.00	10.00
Nr. inverter	[No.]	1,050.00	686.00
Distance between rows	[m]	5.00	5.00
Average length of row	[m]	198.40	198.40
Number of row per plant	[m]	1,008	686
Number of modules		201,613	137,134
Total capacity	**[kW$_p$]**	**74,597**	**50,740**
Capacity per ha	**[kW$_p$/ha]**	**746**	**507**
System Performance			
Global horizontal irradiation (GHI)	[kWh/m^2]	1,939.80	1,939.80
Global tilted irradiation (GTI)		2,019.53	2,019.53
Performance ratio	[%]	84.8%	84.8%
Annual decline of efficiency (d)	[%]	0.25%	0.25%
PV OUT (w/o soiling)	[kWh/kW$_p$]	1,713.19	1,713.19
Initial annual electric generation per kW$_p$	**[kWh/kW$_p$]**	**1,713.19**	**1,713.19**
Initial annual electric generation per ha	**[MWh/ha]**	**1,277.99**	**869.27**
Total initial annual electric generation	**[GWh]**	**127.80**	**86.93**

3.4 Cleaning system

In this subsection we assess different cleaning solutions for the Horticulture PV design in order to address expected soiling effects in the area. As precipitation patterns in the project area indicate, the implementation of cleaning systems or regular cleaning schedules is highly recommended to reduce electricity generation losses. To identify the most cost-effective and appropriated cleaning method, we suggest performing a thorough soiling analysis on the project site for at least 12 months. For an impact assessment and testing of the cleaning system effects on the module layer please refer to (Ferretti et al. 2015).

As well as the module choices, the mentioned cleaning systems are no purchase recommendations but exemplifications of potential technological pathways.

60 Source: Fraunhofer ISE.

3.4.1 Cleaning system Variants

Considering the geometry of the Horticulture PV system, we have compared three different cleaning system approaches. The semi-arid region and the region's fragile water balance suggest a dry-cleaning solution. The Horticulture PV system, however, could provide a rain harvest infrastructure that potentially allows reusing the water used for cleaning. Therefore, we have compared the following model systems:

3.4.1.1 Fully-Automated Dry Cleaning system

It is assumed, that every row of the conventional PV power station has a cleaning robot. The robots are fuelled by solar energy either from robot onsite panels or supplied by the PV power station. The dry-cleaning technology applied by the robot is not further specified at this point of study. The main economic parameters are the cost per robot and the robot frame installations on the rows. All robots are controlled by a small team of skilled controllers and unskilled support staff. A water management system is not considered, even though this could be an option.

This system presents a **business-as-usual case.**

3.4.1.2 Semi-Automated Wet Cleaning system

Here we discover the potentials of replacing capital investment by increasing manual human workload. We considered a small number of cleaning robots that can be shifted from row to row by switching devices that are constructed to deal with the special mounting structure of the Horticulture PV system. To conduct such shifts, a significantly higher workforce is required. Since this shifting is generally repetition and requires problem solving only within the system context, it should be possible to conduct skill training for farmers in a feasible time horizon, 1 year could be a reasonable orientation for basic operational skill and 3 years for proper apprenticeships. The system is considered to use water, but theoretically may also be open to dry cleaning technologies.

Figure 28 Ecoppia dry cleaning robots.[61]

The power station would be under continuous rotational cleaning during the daylight hours. Cleaning schedules must be coordinated with agricultural works. However, during Kharif, rainfall should reduce the required cleaning cycles significantly.

This system presents a Horticulture PV system case specific adaption with focus on employment and water. This option has not been included in the economic scenario analysis and requires specific engineering efforts to implement.

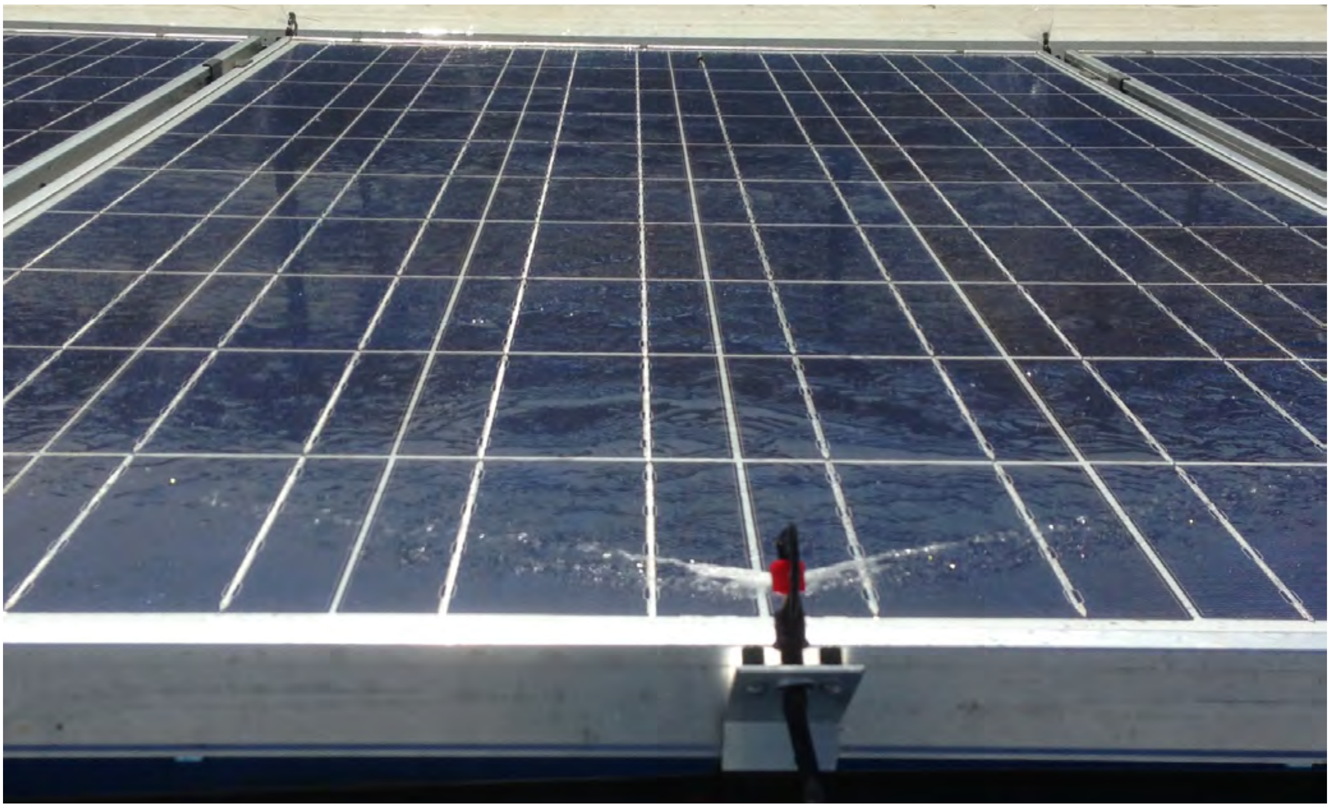
3.4.1.3 Sprinkler

A sprinkler system uses fixed installed sprinklers to clean modules by a stream of water. No robots or shifting vehicles are necessary. However, such a system has not yet been installed on a large scale. We considered sprinklers, since truck-mounted brush systems and manual cleaning seems not feasible due to the mounting structure and panel elevation. The sprinklers represent a further alternative to robots that has the potential to reduce CAPEX and OPEX significantly. Such potential economic gains may lead to an experimental approach covering some 1-5 MW_p, in case Mahagenco decides to build a Horticulture PV system. Special care must be taken on potential re-investment due to hail storm risk.

Basis for this approach has been a consultation with the company NaanDanJain (NaanDanJain Irrigation 2018). This system presents an alternative, innovative approach with promising economic potential.

61 Source: Ecoppia: https://www.ecoppia.com/

Figure 29 Example of sprinkler module cleaning.[62]



3.4.2 Comparison of Cleaning systems

3.4.2.1 Overview

The following pages show comparison tables for the scenarios including their technical requirements and parameters. Some variables, however, could not be specified in detail. Here it is vital to gain knowledge about the type and intensity of the soiling at the project site and a more detailed geometry of the potential power station. As an orientation, the requirements specified in the PI Tender Sheet had been taken as measure.[63]

Table 12 Cleaning system scenario comparison.[64]

Requirements	Remark by PI Berlin	Fully-automated dry cleaning	Semi-automated water cleaning	Sprinkler system
Technical requirements (PI Berlin)				
Cleaning technology / industrialisation readiness	State of the art	Fully given	Site specific reengineering necessary	Innovation stage
Control system	Scratch protection, error detection	Given	Given	Given
Cleaning device	Shall endure environmental factors. Perform tests, see tender sheet.	Robot	Robot	Sprinkler
Impact on module glass	Performing tests, see tender sheet	Not yet specified	Not yet specified	Not yet specified
Supplier experience	3 years of commercial experience, 5 operating PV plants of 500 kW in similar climatic regions	Party given	Party given	None on this scale

62 Source: Jain Irrigation 2018.
63 See: PI Berlin 2018a, 2018b; Kupke 2018.
64 Source: Fraunhofer ISE.

Additional requirements Horticulture PV system				
Ground-mounting structure integration		Industry standard	Site specific reengineering necessary	system must be specially conceptualised.
Integration with agricultural processes		Given	Given	Given
Operations (PI Berlin)				
Maintenance	Shall be provided			
Spare parts	Availability for 25 years			
Operator training	Shall be provided			
Additional requirements Horticulture PV system				
Cleaning frequency		Daily	As often as possible	Every 3 days
Cleaning time		Night	Preferably night because of water savings, but complexity of shifting procedures only allows constant rotational cleaning, during the day.	Night

In order to address the key issues of sustainability additional requirements must be met, such as employment potential and energy/water consumption.

Table 13 Sustainability aspects of cleaning system.[65]

Sustainability overview	Fully-automated dry cleaning	Semi-automated water cleaning	Sprinkler system
Economical			
CAPEX	High	Medium	Low
OPEX	High	High	Low
Social			
Employment	Low	High	Low
Environmental			
Energy	Solar, medium consumption (expected, no calc yet)	Solar, high consumption (expected, no calc yet)	Solar, low consumption (expected, no calc yet)
Water consumption	None, minimal	Medium due to daytime cleaning evaporation losses.	Low. Pending on system options quality/cost ratio's. Less than 15% of rain harvest expected
Land use	Medium to low, equipment housing & workshop.	High, pathways for shifting vehicle, larger equipment housing and workshops.	Low, equipment housing & workshop.
Risk exposure	Hailstorm	Hailstorm	Hailstorm

In order to replace capital intensive robot, the Horticulture PV mounting structure poses significant challenges to agricultural activities and system operator not only from a technical point of view but also in terms of H&S.

Careful planning is needed to integrate module rows, fixed vehicle pathways through the fields, irrigation and water pipes, electrical installations and other equipment.

3.4.2.2 Technical Parameters due to PI Berlin Tender Sheet

A complete application of requirements given in the tender sheet of PI Berlin has not been conducted. However, we have taken the main components to derive the impacts for the above presented scenarios.

65 Source: Fraunhofer ISE.

Figure 30 Geometry of proposed Horticulture PV system.[66]

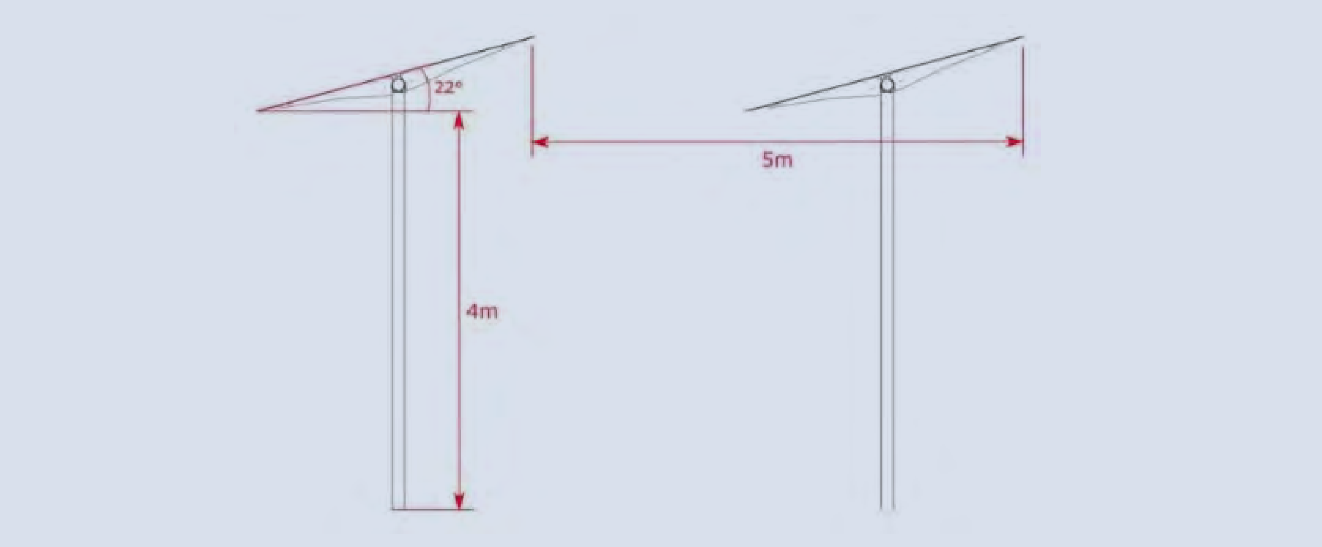
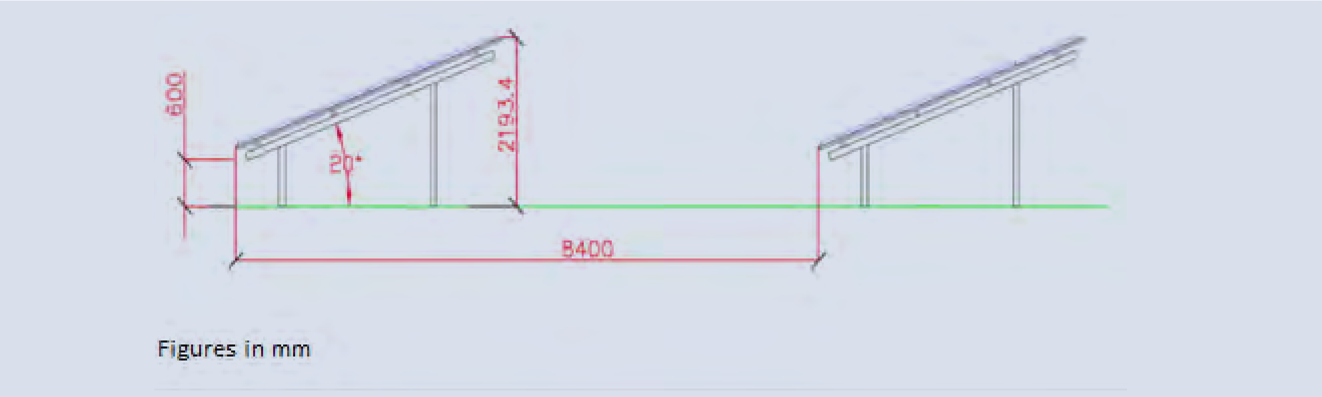


Figure 31 Geometry of conventional PV in PI Berlin tender sheet.[67]



These figures exemplify the difference of conventional and Horticulture PV geometry

Table 14 Cleaning system parameters according to PI Berlin tender sheet.[68]

Category	Unit	Value from PI Berlin tender sheet	Proposed Horticulture PV system
General			
Location	GPS coordinates		Balapur
Terrain		Optimal: flat, minimal differences in altitude and sandy soil	Slope -2.1% to 3.6%, overall slightly rising terrain. Avrg. slope for inclines is 0.9% and -0.7% for declines. Clay soil.
Environment	Own parameter set	None	Semi-arid, strong module soiling
Geometry			
Modules			
In X rows one above the other (modules)		4.00	1.00
Table height at low side	[m]	0.60	4.00
Tilt angle	[° degree]	20.00	22.00
Table height at high side	[m]	Not specified	Not specified
Sort of frame		Anodised aluminium	Not specified
Distance between the modules	[m]	Not specified	Not specified

66 Source: Fraunhofer ISE.
67 Source: PI Berlin.
68 Source: PI Berlin tender sheet and Fraunhofer ISE.

Category	Unit	Value from PI Berlin tender sheet	Proposed Horticulture PV system
Row of Tables			
Table pitch	[m]	8.40	Not specified
Inter-row distance	[m]	6.20	5.00
Row length	[m]	Depends on power station layout	198.40
Length of row in modules	[No.]	Depends on power station layout	Not specified

3.5 Integrated Water Management system

The surface of the module rows is prone to be utilised as water catchment canopies. Therefore, it is worth to explore the potentials of an integrated water management system. Just as the cleaning system, this is a novelty to the Horticulture PV concept and a potential adaption measure to the local climatic conditions. The cost estimations are very rough and may only serve as a first orientation. No water management system manufacturer has yet been consulted. Special care must be taken considering the interference of electrical and water system components. A high quality of the system elements and the installation must be ensured to prevent accidents and ensure system lifetime.

3.5.1 Rain Harvest Potential of the Horticulture PV system

It is expected that on average 38% of the rain can be captured by the module rows. This value is estimated by the covered area from a birds eye perspective and could vary with the angle of precipitation and wind during the rainfall. Accordingly, here we disregard any additional rainwater catchment that might be feasible when preventing the outflow of surface water on the ground. This water not only cleans the modules during the wet season but can also be channelled and stored. This allows redistributing the water to use it for the cleaning system or for crop irrigation. Since the irrigation could be precise in time and space the rain could overall be used more efficiently.

Table 15 Rain harvest potential.[69]

	Unit	Value
Average precipitation	[m³ per ha]	8,909.80
Share of rain harvest	[%]	38.0%
Potential rain harvest	[m³ per ha]	3,385.72
Average effective rain rate (CROPWAT)	[%]	72.5%
Average effective rain (CROPWAT)	[m³ per ha]	6,459.61
Adjusted avrg. effective rain	[m³ per ha]	7,390.68
Increase of water availability	[%]	14.4%

However, the water assessment of a potential water management system has no impact on the irrigation calculations that have been conducted using CROPWAT standard values. Even though CROPWAT already suggests optimal conditions for crop growth, it is expected that rain harvest and drip irrigation may improve agricultural water use. Both elements allow reducing evaporation losses and continuous water supply at a given schedule for the crop. Improving cropping methods using the water storage capabilities of the system have the potential to counter crop yield losses induced by shadowing.

3.5.2 Water Management system Variants

We have considered three main system variants. For the decentral variants it has been assumed, that no connection to large watershed such as the Balapur reservoir is given. However, costs could be reduced, if a connection to this central watershed is given and may replace the efforts for water storage.

Possible pump investment and pumping energy demand has not yet been assessed. All variants are equipped with a high-quality drip irrigation system at costs of INR 3.7 lakh per ha.[70]

69 Source: CROPWAT calculations.
70 Info by Neha Durga.

1) Decentral Seasonal Storage.

This variant has small tanks attached to several rows. The tank can either be elevated to save pumping costs or in the ground below the crops rooting depth. The decentral approach has only a maximum capacity 5% of the month with the maximum precipitation, which is about a day of heavy rain. It is assumed that the rain directly flows to the fields and the system serves only as a buffer for controlled irrigation.

Ground mounted tanks would have the advantage of gravity force replacing pumping energy. It is also thinkable to cover the top of the tanks by solar cells or place the tanks directly under the mounting structure of the solar cells. No significant additional land losses would occur. Average small tank cost has been considered according to the Indian market website "indiamart"[71]. Depending on the tank quality and construction material, reinvestment could occur.

2) Groundwater Storage via Holiyas

In parts of Northern India and Gujarat, positive experiences with pipe assisted underground taming as described in a report of the International Water Management Institute (IWMI, Bunsen and Rathod 2016). These so called Holiyas are pipes that reach 20-80 feet into the ground and usually have a diameter of about four inches. The structure of the pipes is perforated at the end as to be seen in schematic illustration in Figure 32. Such Holiyas mainly have the purpose of avoiding field flooding but also serve as a cost-effective way of softening impacts of erratic precipitation in general and drought mitigation. In 2016 the costs had been about INR 25,000 to 35,000 exclusive of pumps. The Holiya could also be covered by solar panels, possibly in combination with a solar pumping system that extracts groundwater from the same spot – just as much as rain had been fed directly to the groundwater. A first socio-economic assessment in Gujarat indicates a general positive impact according to farmers feedback. Further technical assessment must be conducted to identify all relevant criteria of for implementing Holiya ground water storage.

Figure 32 Schematic illustration of a Holiya, with an upper element of concrete (1), the pipe with a perforated bottom end (2) and the subsoil strata (3).[72]

3) Flow to Watershed

To present an alternative to on-site water storage we have also drawn a scenario where the rain harvest directly flows into larger watershed like the Balapur reservoir. The required pumping cost has not yet been calculated, but costs for tanks are replaced by the cost of building canals. Such on-site canals would have a depth of 0.5m and width of 1.5m per ha (1.5% land use impact in order to be able to redirect excess water during heavy rainfalls to the watershed). All on-site canals are merging to a larger canal of the width of 6m and depth of 6 m with a length of 2,000m from the Horticulture PV system to the Balapur reservoir. We considered EUR 350 (about INR 30,000) per meter of canals for material and construction for the central canal plus EUR 200,000 (about INR 1.67 crore) for the small on-site canals. The land use impact would be minimal; however, additional land might need to be acquired to build the central canal. Such a pipeline or canal connection would be required in any case, if a banana plantation was to be set up and supplied with external water. The canal could be covered by solar panels as canal solar projects in Gujarat have proven feasible.[73]

Alternatively, it could be thinkable to connect the water system of the Horticulture PV system to the water system of the Paras TPP. However, such considerations must be assessed by Mahagenco who has access to concerning information.

The table below shows a comparison of the approaches

71 https://www.indiamart.com/
72 Source:copied from Bunsen and Rathod 2016.
73 One MWp in Mehsana and ten MWp in Vadodra (Gulati et al. 2016).

Table 16 Overview of water management parameters.[74]

		Decentral tanks - sea-sonal		Flow to watershed	
Rain harvest					
Potential rain harvest per year	[m³/ ha]		**3,385**	**-**	**3,385**
Interseasonal storage	[m³/ ha]	25% of avg. annual precipitation	-	-	-
Seasonal storage	[m³/ha]	5% of maximum monthly precipitation	197	Difference of max. and avg. precipitation, per minute	
Capacity (m³)	**[m³/ ha]**		**197**	**Water flow (m³ per sec per ha)**	**0.33**
Water storage	**Unit**		**Value**		**Value**
Height	[m]		5.50	Height	6
Length	[m]		5.50	Length	0.01
Width	[m]		5.50	Width	6
Capacity per tank / well	**[m³/ha]**		**167**	**Central canal water flow [m³/sec]**	**0.36**

Based on the above established parameters, the following costs can be derived.

Table 17 Cost estimation water management system.[75]

		Decentral tanks	Flow to watershed
Tank costs / On site canal fixed cost	[INR/m³] [INR lakh]	3,500	166.67
Total cost per tank / Canal construction	[INR lakh / tank] [INR lakh / m]	5.82	0.29
Number of tanks / Length of canal	**[tank/ha] [m]**	**1.18**	**2000**
Total costs per ha	[INR lakh/ha]	6.89	7.50
Total cost plant	**[INR lakh /power station]**	**689**	**750**
Rain harvest drainage	[INR/m]	5.00	5.00

5.00This cost outline, even though the cost elements are not yet confirmed by more intensive research, suggests a decentral tank approach to be most viable. This is due to uncertainties re-garding the possible connection to a larger watershed, the land use intensity as well as the feasibility of the deep well variant. For the general electricity and crop yield assessment we have excluded the land use impact of about 5-10%, since the explo-ration of the opportunities of the water management system are on a very early stage and must be evaluated in more detail before major scenario adjustments can be made. However, the CAPEX and OPEX estimations for decentral seasonal storage have been included in the economic calculations in Section 5.5.

3.6 Summary

According to our analyses, the proposed design partially applies the Fraunhofer ISE patent of deviating from purely south oriented PV modules in order to ensure a homogenous distribution of sunlight below the PV modules. Technical sketches have been provided and the major technical parameters have been defined. Improved homogeneity is archived by additionally considering the Japanese Solar Sharing approach employing smaller width of module rows compared to the design of the Fraunhofer ISE research pilot project at Lake Constance. Reasoning behind this synthesis is to significantly reduce cost for the mounting structure and to minimise electrical losses that occur when applying the Fraunhofer ISE patent.

The comparision of bifacial glass-glass modules and glass-Tedlar modules strongly suggests bifacial glass-glass modules since increasing electrical yields of 6.8% outweighs the higher cost while allowing for more available sunlight for crops of up to 10%. However, uncertainty remains regarding the albedo factor of ground reflection.

74 Source: Fraunhofer ISE.
75 Source: Fraunhofer ISE.

Regarding the expected installed capacity per unit of land, our calculations are concluding with the range of a theoretical maximum capacity of 74.6 MWp and an Indian benchmark of 50.74 MWp for the potential power station.

Furthermore, we proposed different alternatives for module cleaning options including dry cleaning, automated and wet-cleaning semi-automated and innovative sprinkler solutions. The cleaning system design and cost will strongly depend on the power station's design and layout. However, major complexities are added due to the panel elevation. Solely manual cleaning is therefore no option and uncertainty persists regarding the employment impact of the cleaning system. Water management systems including rain water harvest that could increase water availability by at least 14.4%. Drainage from ground-mounting structure, as well as storage and irrigation appear eligible to improve the efficiency of agriculture while protecting natural aquifers. However, more research has to be conducted to utilise the natural system of drainage, the inclination of the topography and possible water storage ponds.

Recommendations

- Main parameters include a vertical clearance of 4m, a distance between rows of 5m, a module tilt of 22 degrees, and a south-west orientation of 208 degree.
- Tracking has been found as not recommendable, neither single nor dual axis options.
- Measuring electrical yields and irradiation levels of both west and eastwards panel orientation is recommended to evaluate the clouding impact by the Paras TPP.
- Conduct empirical studies including different module types to controll for the yield estimations including the specification of the albedo factor.
- Conduct further studies to identify the net land area that can be used for constructing the PV arrays in order to give a more precise estimation of the possible capacity range.
- Conduct in-depth research for decisions on cleaning and water management systems based on the agreed-upon design.

4 Agricultural Analysis and Concept

The goal of this chapter is to shed light on the key aspects of farmer livelihoods, food security, sustainable water use, and soil preservation. Hence, we develop a site-specific crop cultivation approach to be grown once the Horticulture PV system is installed. The agronomical approach focuses on the four focal crops of soy bean, banana, tomato and cotton. It considers the current state of the agriculture as described in Section 4.1 incorporating current crop patterns, irrigation potential and marketing potentials. The environmental and microclimatic impacts of the Horticulture PV system are elaborated in Section 4.2. This includes the amount of sunlight that can be used for agriculture as well as all other relevant local determinants such as wind shelter, soil parameters, water considerations and potential land losses due to the installations. In Section 4.3 we apply all previously analysed impacts in combination with empirical findings from literature to perform a crop yield assessment using interpolation functions. Irrigation requirements of the focal crops are further assessed in Section 4.4 while in Section 4.5 we explore different scenarios for potential cropping patterns including minimum changes, maximum changes and minimal changes including experimental plots.

General baseline information about the current agricultural situation can be found in:

- Comprehensive District Agriculture Plan (2012-2013 to 2016-2017) (Akola District 2015)
- Agriculture Contingency Plan for District: Akola (GOVMH 2012)
- Maharashtra Agricultural Competitiveness Project (MACP) – Marketing Strategy Supplement (MSS) District Akola (MACP 2018)
- Executive Summary District Akola by NABARD (NABARD 2016)

4.1 Current State of Agriculture in Paras

4.1.1 Crop Pattern

Cotton, soybean, sorghum and tuar dal/lentil (split pigeon peas) are the main crops grown in the Paras village. Because of menace by monkeys, vegetables etc. are grown on small scale and near to human settlements. The area acquired by Mahagenco does only have minor human settlements (2 or 3 small huts) and therefore not many vegetables or high value cropping is done, instead most of 125 ha are cultivated with soybean and tuar lentils.

Other crops to be grown include black gram, green gram, sesame and pearl millet. Except Sorghum, the crops are grown in a mixed cropping pattern where one or two rows of a crop species is neighboured by rows of another crop species. This pattern differs as per the choice of the individual farmer and there is no uniformity. However, soybean is a major crop in the area. On some of the adjacent plots cotton is also cultivated. Farmers are moving away from the cotton crop due to irrigation water scarcity and attack of pests especially cotton bollworm.

A small area, approximately 1 ha is covered by irrigated chickpea crop in the winter season. These are scattered plots near the location of open wells. There is no summer cropping and the fields generally remain fallow in the months of March to May. The shading of the cells of the table below show which crop are planted in which month.

Table 18 Common regional crop pattern.[76]

Crop	June	July	August	September	October	November	December	January	February
Sorghum									
Soybean									
Green gram									
Black gram									
Sesamum									
Pigeon pea									

76 Source: Sachin Manohar Patwardhan.

Crop	June	July	August	September	October	November	December	January	February
Cotton									
Chickpea									
(March, April and May are fallow months)									

4.1.2 Marketing Infrastructure

There are two agriculture markets 1) Akola, which is around 50km away and 2) Khamgoan which is 30km away. Akola hosts a bigger market with traders coming from across the nation to procure cotton, whereas Khamgoan is relatively a smaller market and primarily for commodities (mostly food grains, lentils etc.). Most of the produce of Paras village is sold at Khamgaon (sorghum, soybean & lentils) and Akola (primarily cotton). For irrigated crops such as tomato and banana new markets must be explored beyond the local distribution option. This may lead to an increase of food miles embedded in the product.[77]

4.1.3 Local Irrigation Potential

Currently majority of the cropping is solely dependent upon rain water. There are 6 open wells present in the plot. These are used for protective irrigation of the rain fed crops whenever there is a dry spell in the rainy season. Small plots of chickpea are cultivated using irrigation water available in the winter season. Sprinkler method is used for irrigation.

As per the information shared by Mahagenco staff, there is no excess of effluent water from thermal power plant that could be made available for irrigation, since most of the water is reused in the power station.

If cropping pattern is to be changed and vegetables and banana crop is to be introduced in the cropping scheme, it will require extra irrigation water. This need of irrigation water cannot be met from the wells that are currently available on the plot. Without external irrigation water, a potential crop schedule is limited to soybean, cotton or other seasonal crops.[78]

Potential irrigation water could come from several sources. In 2018 it had been announced that a phytorid wastewater treatment plant will start operations in 2019. According to newspaper reports[79] this power station may have a capacity of 300 lakh of litres per day[80] which will be transported to the Paras Power Station. It is suggested that the water from the Balapur reservoir may then be used for irrigation.

4.2 Impacts of Horticulture PV on Agriculture

4.2.1 Horticulture PV system and Wind

A positive aspect of the Horticulture PV power station is the wind sheltering effect it creates for the crops grown under the system. The structural pillars of the system create wind breakers that may prevent soil erosion otherwise caused by high wind levels. level winds. A possible measure to further improve the wind sheltering is to create a tree line to the west of the system, where trees removed during the installation phase could be replanted. This would create a natural wind breaker that would reduce wind infiltration through the lines of the system while reducing the overall impact on biodiversity of the Horticulture PV system. For this case study, no wind impacts on the crops have been assumed. However, the wind protection function of the Horticulture PV system is likely to be a benefit. In case of crops that are prone to fungi disease because of increased humidity as a result of lower wind levels, caution must be exercised (Obergfell, 2012).

4.2.2 Soil Moisture and lower Evapotranspiration

The most recent findings from the pilot facility in Germany indicate a positive effect of the shading on soil moisture. As measurements of soil moisture showed, during summer the soil of some crops contained up to 9.4% more water compared to the reference area and, hence, provides better crop growth conditions.[81]

77 Food miles is an indicator to measure the distance agricultural and processed goods have to travel from production to end consumer.
78 Other seasonal crops may have yield losses of more than 35%.
79 For the article see: https://swachhindia.ndtv.com/maharashtras-akola-district-protect-morna-river-via-recycling-waste-water-heres-plan-18180/
80 30,000 m^3 per day or 10.95 million m^3 (MCM) per year.
81 Source: University of Hohenheim, APV-RESOLA.

4.2.3 Irradiation Simulation

In order to perform the irradiation simulation for the pre-definition of the geometry, we employ 20 years of average irradiation data.[82] The graphs below show results of the simulation for each month indicating the standard deviation and average irradiation compared to an unshaded field for different orientations one meter above ground level as performed with the internal Fraunhofer ISE tool ASSIST to pre-define an optimised Horticulture PV geometry. In all months the standard deviation at an orientation of 28 degree is below 0.1. Regarding the criterion of sufficient average light conditions, annual values on ground level aim at 62% of total available PAR. This deviation from south represents an application of the Fraunhofer ISE patent "Method for Simultaneously Cultivating Crop Plants and Utilizing the Energy of Sunlight". In India, the described method is not patented. Figure 34 and Figure 35 illustrate an example of different analyses performed to determine the orientation, tilt angle, panel row width, and row distance in order to archive suitable light conditions at minimum electrical losses.

One possibility to favour sunlight conditions for crops during summer season would be a higher tilt as this would cause less shadow during summer and more shadow during winter (according to the sun position). However, since it is desired to prolong cultivation periods also to winter month, we kept a tilt that maximises electrical yields. This should be analysed in more detail once a realisation of a pilot Horticulture PV system is envisaged.

Figure 34 Results irradiation simulations January to June.[83]

82 Source: SolarGIS. See: https://solargis.com/maps-and-gis-data/download/india.
83 Source: Internal Fraunhofer ISE experts.

Figure 35 Results irradiation simulations July to December.[84]

Table 20 shows the results for the given geometry of the Horticulture PV power station over a full year (2014 as a representative year of the data sheet). For the irradiation simulation we employ Radiance, developed at the Lawrence Berkeley Labs, USA, as a lighting simulation software. It has been in use within the daylighting research and application community for decades and offers great flexibility in the description of surface properties and structural geometry. The Radiance calculation scheme uses absolute properties of radiance and irradiation in adequate physical units of W/m^2sr or W/m^2. Models of the natural light sources sun and sky are provided via the gendaylit tool, which creates a complete sky radiance distribution for any pair of global and diffuse irradiation Ghor and Dhor given as input values. Radiance can both render images and provide numerical values of local irradiation as "seen" by virtual irradiation sensors. Comparison with monitoring data of real bifacial PV plants ensures the accuracy of the simulation results.

This report considers the PV module mounting geometry in all details (module type, varying module tilt angle, row-to-row distance, and components of the mounting structure). As the site is relatively flat, we assume no external shading of the site. Internal shading losses of the diffuse fraction of irradiation are considered implicitly by the raytracing approach. For the simulation we used purchased Solar-GIS data for the location. The average PAR of 62% is employed and used as input for the crop yield assessment.

84 Source: Internal Fraunhofer ISE experts.

Table 19 Ground irradiation simulation for the proposed design.[85]

Irradiance colour table (W/m²)	% of GHI	Irradiance colour table (W/m²)	% of GHI
1242.63	64.55%	1150.41	59.76%
1242.82	64.56%	1140.98	59.27%
1244.09	64.62%	1140.56	59.24%
1244.29	64.63%	1138.67	59.15%
1239.67	64.39%	1145.44	59.50%
1243.16	64.57%	1150.94	59.78%
1238.78	64.35%	1148.39	59.65%
1234.01	64.10%	1149.51	59.71%
1230.81	63.93%	1156.61	60.08%
1225.29	63.65%	1162.39	60.38%
1219.49	63.34%	1170.69	60.81%
1212.67	62.99%	1173.01	60.93%
1203.14	62.49%	1178.60	61.22%
1201.44	62.41%	1189.26	61.77%
1201.37	62.40%	1193.97	62.02%
1197.95	62.22%	1204.55	62.57%
1192.94	61.96%	1207.82	62.74%
1188.63	61.74%	1214.02	63.06%
1184.78	61.54%	1216.01	63.16%
1186.00	61.60%	1217.39	63.23%
1178.49	61.21%	1227.14	63.74%
1164.40	60.48%	1234.84	64.14%
1153.55	59.92%	1241.84	64.50%
1147.94	59.63%	1241.30	64.48%
1150.08	59.74%	**1194.28**	**62.03%**
1151.46	59.81%		

4.2.4 Land Losses due to Dual Land Use

In typical Horticulture PV systems, the actual coverage of the mounting structure is below 1% of the land. Therefore, if land is cultivated manually, almost 99% of land can be utilised. However, if land machines are employed and the working direction follows straight lines there remain stripes between the poles that might sum up to 10% of the land. This is the case at Fraunhofer ISE research Horticulture PV system where 8% of land account for these stripes.

As cost of labour is significantly lower in India and the level of mechanisation is also lower, it is likely that farmers will avoid these stripes by either driving additional routes with the tractor or by manually cultivating the land between the poles. Further, for crops grown in rows like tomatoes and bananas we would generally assume lower land losses even at full mechanisation because the crop's row systems fit better into the PV row system. Additionally, perennials like bananas perform better as a full ploughing only takes place after some years. Table 21 shows the estimated land losses due to agricultural mechanisation.

85 Source: Fraunhofer ISE.

Table 20 Assumed land losses due dual land use.

		Cotton		Tomato		Soybean		Banana	
Land loss mechanisation		Conv.	Horticulture PV	Conv.	Horticulture PV	Conv.	Horticulture PV	Conv.	Horticulture PV
Area	ha	100	100	100	100	100	100	100	100
Land loss low mechn.	%	-	2%	-	3%	-	4%	-	2%
Land loss high mechn.	%	-	6%	-	4%	-	9%	-	3%
Total available land for agriculture	ha	100	94	100	96	100	91	100	97

However in case of a power station design, further land must be used for equipment storage, transformer buildings etc. Since such land losses are typical for solar power stations, we have not included a special parameter for this.

4.3 Agricultural Yield Assessment

Available literature on the effects of reduced light intensity on currently cultivated crops was scanned. Also discussion was done with the scientists at Dr. Panjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola on the possibility of cultivation of crops underneath the solar panels. There is not much of research done in India on the response of the crops to the reduced light intensity, especially those which are being currently cultivated in the Mahagenco land. Looking at the general crop physiology knowledge, scientists at PDKV have suggested for introducing tomato and flower crops under the solar panels however that will require additional irrigation water availability.

Based on empirical results in the literature, we derived shadow response functions for each crop in order to estimate the yield response. However, the true impact of shadowing can only be determined by on-site testing since crop growth models are inherent reductions of the complex crop physiology and environmental factors. We have assumed an acceptable loss of 20% of standard conventional yield.

The following list gives an overview about the empiric sources we have consulted:

Table 21 Overview empirical crop-shadow response sources.

Crop	Source	Countries of empirical study
Soy bean	(Avila et al. 2013), (Odeleye et al. 2004), (Zanon et al. 2016)	Brazil, Nigeria
Banana	(Ghosh et al. 2018), (Israeli et al. 1995), (Pawar et al. 2017)	India, Israel
Tomato	(Abdel-Mawgoud et al. 1996), (Hernández et al. 2015)	Egypt, Spain
Cotton	(Singh 1986)	India
Chickpea	(Verghis et al. 1999)	New Zealand
Sorghum	Reduction in yield happens, no figures available.	

For crops that partly react with yield increase when shading is given, we have chosen a Calibrated Normal Distribution Function in order to model a schematic response curve which is derived from the given empirical evidence

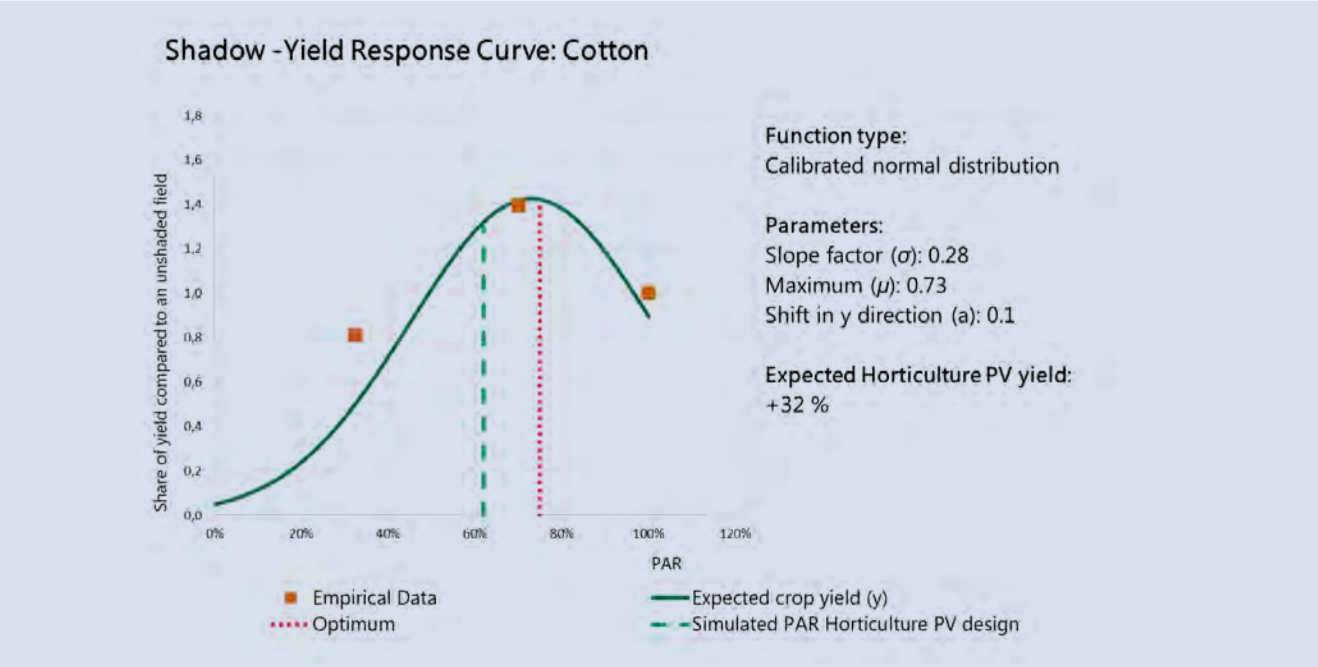
Equation 2 Calibrated normal distribution function.

$$y(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} + a$$

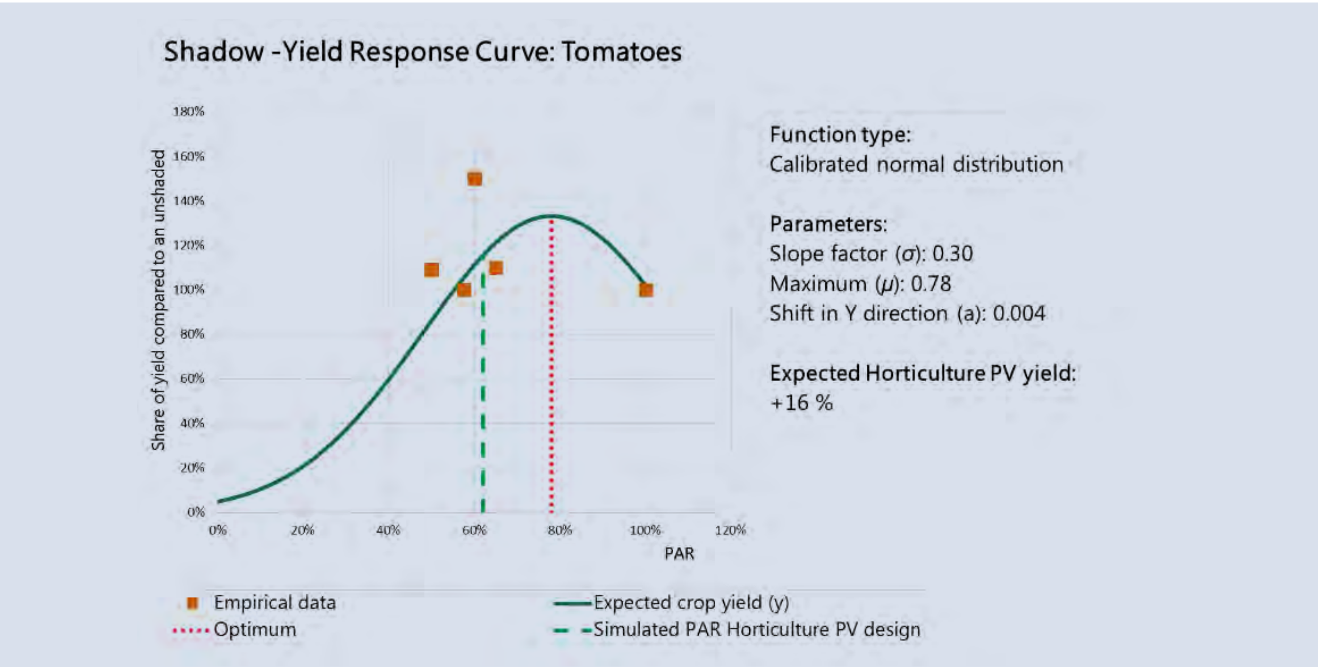
$$\text{Crop Yield}\ (PAR,\mu,\sigma) = \frac{1}{0.315\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{PAR-0,78}{0.315}\right)^2} + 0.1$$

The following parameters for formula calibration have been used:

Graph 1 Estimated shadow-response function cotton.[86]



Graph 2 Estimated shadow-response function tomatoes.[87]



For crops that partly react with yield increase when shading is given, we have chosen a Calibrated Logistic Function in order to model a response curve:

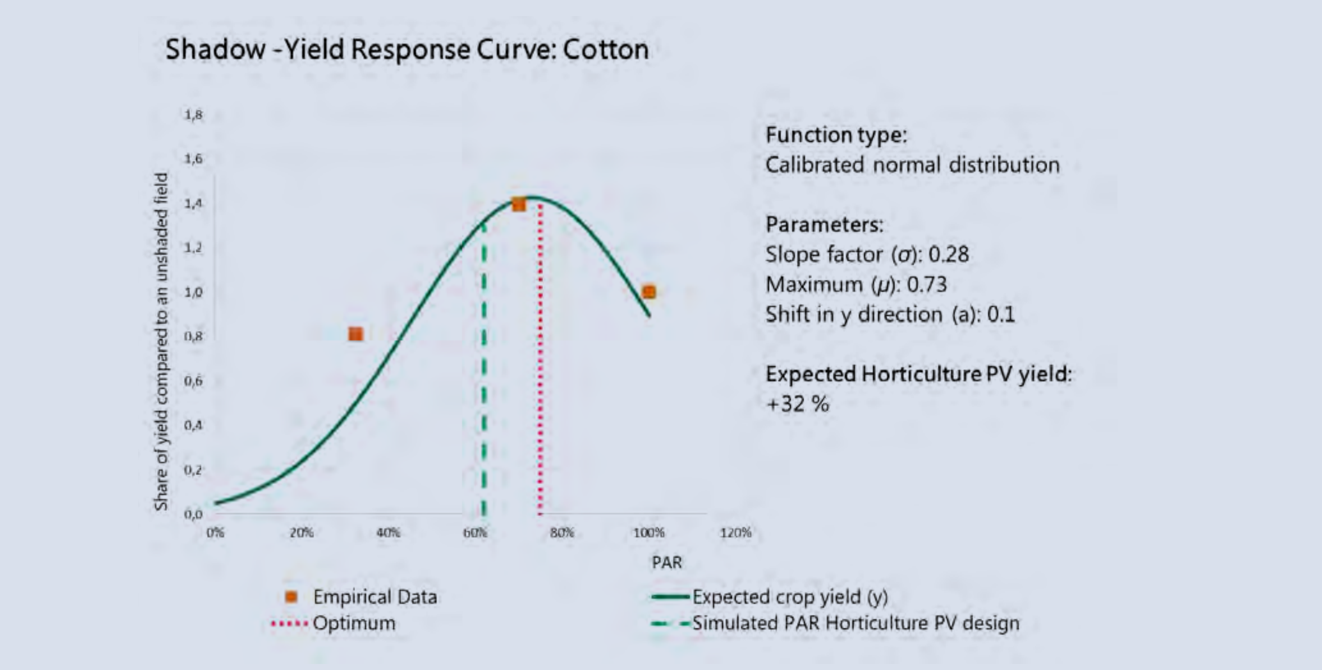
Equation 3 Calibrated logistic function.

$$y(x) = \frac{1}{1+\alpha e^{\beta(-x+\gamma)}}$$

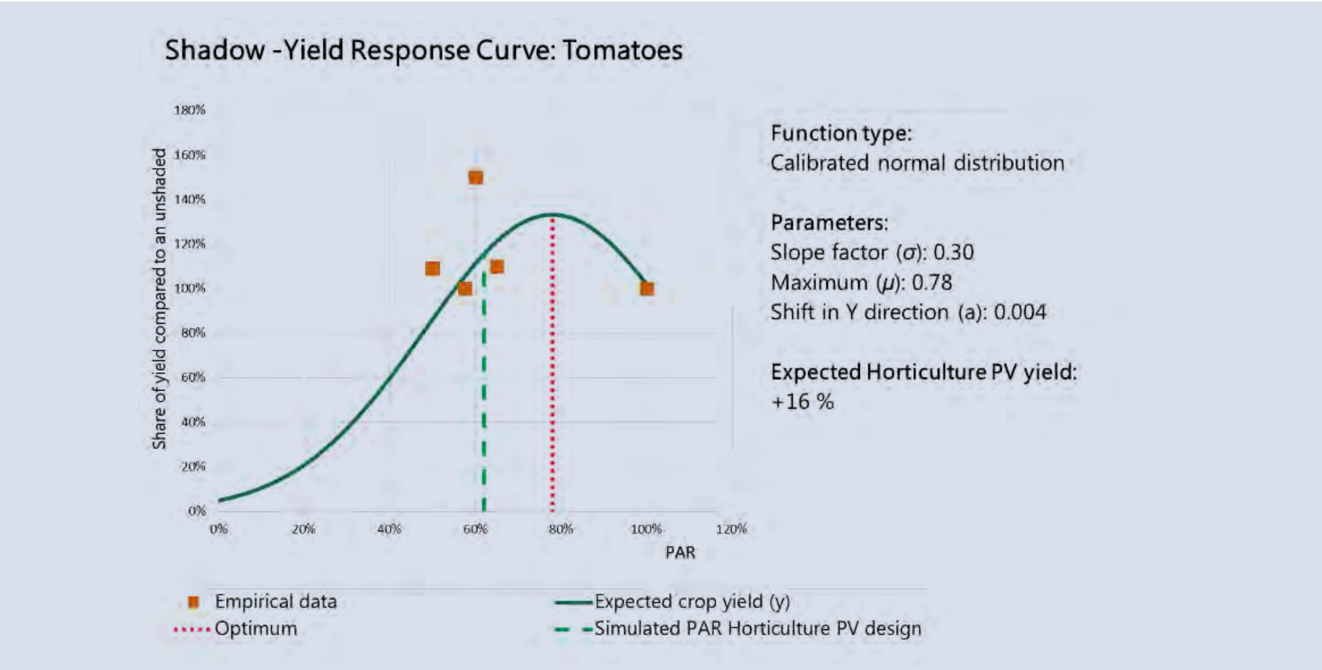
$$\text{Crop Yield }(PAR) = \frac{1}{1+0{,}01e^{8(-PAR+1)}}$$

86 Fraunhofer ISE.
87 Source: Fraunhofer ISE.

Graph 3 Estimated shadow-response function soybeans.[88]



Graph 4 Estimated shadow-response function bananas.[89]



Based on the above evaluated impacts by the Horticulture PV system, the following yield estimation can be derived. In all cases high mechanisation is assumed.

88 Source: Fraunhofer ISE.
89 Source: Fraunhofer ISE.

Table 22 Crop yield assessment under Horticulture PV system.[90]

		Cotton		Tomato		Soybean		Banana	
Land loss mechanisation		Conv.	Horticult. PV	Conv.	Horticult. PV	Conv.	Horticult. PV	Conv.	Horticult. PV
Area	ha	100	100	100	100	100	100	100	100
Land loss low mechn.	%	-	2%	-	3%	-	4%	-	2%
Land loss high mechn.	%	-	6%	-	4%	-	9%	-	3%
Total available land for agriculture	ha	100	94	100	96	100	91	100	97
Yield parameters									
Standard yield	[kg/ha]	3,750		18,000		2,600		56,000	
Yield productivity factor		-	1.42	-	1.16	-	0.91	-	0.83
Simulated PAR Horticulture PV design	[%]	-	62%	-	62%	-	0.62	-	62%
Total yield	[kg/ha]	3,750	5,002	18,000	19,993	2,600	2,155	56,000	44,928
Change in %	[%]		33%		11%		-17%		-20%

Clearly, cotton sees the largest yield increase, however, the crop is prone to disease and access to external irrigation water remains uncertain. Due to the implementation of rain harvesting and irrigation systems, the growth period of cotton can be extended and two harvests are possible. For the same reason, the baseline yield figure for soy bean has been increased from 1,600 kg currently being harvested to 2,600 kg. There is lot of scope for improvement of the yield of crops. In Brazil productivity of soybean is 3,200 kg per ha whereas project area it is 1,625 kg per ha. There is need for extension of improved technological knowhow to the farmers to enable the farmers to increase their yield and the resultant income.

Since there is not much of research done on the response of the crops to the lower light intensities in the Indian conditions, building of Horticulture PV needs to be coupled with an agricultural research component where response of the crops to the lowered light intensities under Horticulture PV are assessed properly and yield enhancement measures are developed based on the research findings.

Other crops that are part of the current crop pattern, but not yet considered in the yield assessment are listed. The yield impacts are rough estimations and pend empirical confirmation.

Table 23 Yield reduction estimations secondary crops.[91]

Crop	Yield reduction at 30% reduced light intensity [%]	Current yield [kg/ha]	Yield in Horticulture PV (at 30% reduction in light intensity) [kg/ha]
Green gram	-7.8	700	645
Black gram	-7.8	600	553
Pigeon pea	-7.8	1,200	1,106
Chickpea	-48	800	416

90 Source: Fraunhofer ISE.
91

4.4 Crop Irrigation Requirements

All calculations have been conducted with CROPWAT and are deeper empirical research must be conducted to gain more detailed information. The irrigation requirements represent additional water, that must be added to the precipitation to ensure theoretical optimal crop growth.

Table 24 Crop irrigation requirements.[92]

Irrigation requirements	Unit	Cotton	Tomato	Soy bean	Banana	Avrg. precipitation
1st year	mm per m²	249	83.6	14	6,595	890.98
	m³ per ha	2,490	836	140	6,595	8,909.80
2nd year	mm per m²				1,315	
	m³ per ha				13,150	
Total farm (million cubic meter)	MCM	0.249	0.084	0.014	1.315	0.891

As tomato and soybean seem theoretically feasible without more than 10% additional irrigation water during Kharif, cotton would benefit of the Horticulture PV system's water management system but where likely to require at least 500 to 1,000 m³ per ha additional water. The creation of a banana plantation of 100 ha would clearly impact the ground water resources of the district. The annual ground water recharge rate is about 5.25 MCM compared to 1.3 MCM annual irrigation demand of such a banana plantation.

The case for banana must be considered carefully and considering the districts water balance, it seems unsustainable to plant 100 ha of this crop. However, smaller plots are thinkable. Banana may generate high revenues, but the water consumption is at a level, that requires integration into the local water management plan so that the water balance of the district shall not be further depleted.

4.5 Agricultural Scenarios

In this section, we explore different pathways of future agricultural activities. Thereby we focus on three major scenarios, based on crop choice and the degree of diversification.

4.5.1 Pathway 1: Minimum Change in Existing Cropping Pattern

Mostly soybeans, pigeon pea and sorghum are grown. However, the area under the three crops is not mapped. As per the agriculture experts, the sorghum is highly sensitive to sunlight and therefore cannot be grown under partial sunlight. Soybean and pigeon pea can be grown but the shading or reduced number of sun hours may result in reduced yield of the crops.

Farmers are highly skilled in growing the current crops because of traditional practice. Therefore, they can better manage the reduction in sunlight in the current cropping pattern. Also, the input cost of growing these crops is much lower than other high value horticulture crops, therefore they are exposed to a lower input risk.

Although, the current practice could be described as low risk low value agriculture. This is primarily, because of a lack of clarity regarding future of land usage among farmers. Since the land is also owned by Mahagenco, no irrigation mechanisms have been further developed in the last eight to ten years. It is safe to expect that farmers will be able to manage their crops better under partial sunlight also, if they have traditional understanding of growing crops and if irrigation arrangement is further developed.

4.5.2 Pathway 2: Maximum Change in Existing Cropping Pattern

The second pathway would be to utilise the highly fertile land to grow high value horticulture crops, provided irrigation is assured. This will be a high-risk high return pathway and may not be the most suitable one considering the current skillset of the farmers and available market around the village. Even though the value, which can be

92 For all the parameters used by CROPWAT. A CROPWAT manual can be found here: (Clarke 1998).

generated by growing horticulture crops can be multiple times compared to the value generated from existing the cropping pattern but there are following risks associated with the same:

1. Farmers have not been traditionally growing horticulture crops and therefore it will be difficult for them to envisage the impacts of reduced sunlight on crops. Hence, lack of judgement and experience will make it difficult for them to manage partial shading, exposing them to production side risks.

2. Horticulture and other high value crops are input cost intensive. Without prior knowledge and experience, the increased input cost of crops will also reduce farmer's interest to participate in the model.

3. There are no major horticulture markets around Paras. Most of the horticulture crops arrive in the village and the neighbouring cities from Nagpur and Mumbai at highly competitive rates. Lack of a developed market and fierce competition from the existing system will expose farmers to the market risks.

4.5.3 Pathway 3: Minimum Change with Few Plots for Experimenting High Value Crops

The third pathway can be a mix of pathway 1 and 2. That is, certain high value crops having high demand in the local market and which are suitable to be grown in partial shade can be cropped by few enterprising farmers on some experimental plots. Systematic guidance can be provided to such willing and enterprising farmers to grow the high value crops. These farmers can also take the initiative in developing the market for these crops and creating some market linkages. Based on the result of initial experiments and market response, other farmers can create a portfolio mix of high-risk high value and low risk low value crops. Also, once few enterprising farmers gain the knowledge and skill set of growing high value crops, peer learning may eventually lead to change in cropping pattern from low to high value agriculture.

4.6 Summary

Present agriculture at the project site is primarily based on low mechanised pulse cropping. The yields are marketed at local markets, however there are no distribution channels or close-by markets for banana and tomato. The local irrigation potential in terms of water availability is strongly limited and no investment in irrigation has been done in the recent years.

The Horticulture PV system is expected to improve cropping conditions in terms of wind shelter, reduction of evapotranspiration, and increase of soil moisture especially if the seasons become more extreme due to climate change. The irradiation simulation based on the proposed system geometry concluded with an average annual PAR of 62%. We considered high mechanisation as a precondition for the expected land losses in order to anticipate further agricultural development. Such losses were estimated to be 6% for cotton, 4% for tomato, 9% for soy bean and 3% for banana. The agricultural yield assessments suggest an yield increase of 33% for cotton and 11% for tomato. Yield reductions can be expected for soy bean (17%) and for banana (20%). The irrigation analysis has found, that cotton, tomato and soybean may be within the scope of a water management and irrigation system. For banana, however, significant amounts on additional water would be required.

In the present case, experiences during the scoping mission at the project site in September 2018 as well as analyses of our local expert for social and institutional aspects, Neha Durga, indicated that at this stage a specification of cultivation plans does not seem appropriate. Main reason for this is that a successful and sustainable implementation of the Horticulture PV approach strongly depends on the support of the local farming community. This in turn means that it seems strongly recommendable to decide in mutual agreement with the local farmers on which crops will be grown – regardless to the fact that Mahagenco is legally entitled to decide on its own. Hence the agricultural analysis serves as a basic orientation and starting point for a stakeholder engagement process.

A strong focus on certain agricultural practices inherently bears the risk of path dependency, especially if a plantation system is set up. If circumstances or preferences of involved stakeholders change over time, a too narrow technical approach reduces future flexibility and opportunities to adapt to a changing environment. This appears especially relevant as PV systems have the potential for extended lifetimes and might be in use even 30-40 year after the installation. In general, it appears recommendable to choose a crop mix in order to spread risks and reduce vulnerabilities given by monocultural systems.

Recommendations

- Explore marketing options and new distribution channels for tomato and banana.
- Conduct an in-depth analysis on how much water can be saved through drip irrigation and for how many months the growing period can be extended.
- Conduct further experimentation on-site to gain empirical data on the microclimate impacts of the Horticulture PV system. Identify potential crop varieties that could grow well under such circumstances and could be introduced.
- Limit the cropping of banana to a small proportion of the project site. Otherwise serious damage to the local water resources might occur.
- Start a stakeholder participation process in order to specify possible crop patterns in alignment with the farmers interests and based on local traditional knowledge and in respect of biodiversity.

5 Economic Analysis

This section sheds light on the economic performance of the proposed Horticulture PV system in order to provide a sound basis for the upcoming investment decisions of Mahagenco and KfW. After outlining the underlying assumptions and methodologies for the economic analyses, we present a detailed record of expected cost items and revenues on the agricultural and the PV layer as well as the cleaning and water management systems.

Most crucial assumptions of the economic performance assessment are a share of debt of 95% with weighted annual capital cost of 1.74%, a debt financing via KfW of 1%, and electrical producer prices per kWh of INR 3.79.[93]

5.1 Economic Methodology and Parameter Assumptions

5.1.1 General Approach

Conventional agricultural practices and GM-PV approaches with their respective cost structure, yields, and earnings as observed in the Indian context serve as the baseline for our economic analyses in this section. Relevant cost items were identified and adjusted according to experiences and analyses of former Horticulture PV projects of Fraunhofer ISE in Germany, Japan, Chile, and France.

All assumptions regarding agricultural and electrical yield are based on findings presented in Sections 5.3 and 4.3. Prices and market conditions were assumed as recommended by our Indian experts Neha Durga and Sachin Manohar Patwardhan and according to figures found in literature and relevant statistical source. To derive the economic performance of the proposed Horticulture PV system, methods of LCOE, NPV, and IRR were employed supplementing results of the PV layer by agricultural revenues and expenses. The LCOE is derived by comparing all costs arising during the lifetime of the power system for construction and operation, with the sum of the generated amount of energy throughout the life cycle. The calculation of the system's LCOE follows the formula:

Equation 4 Levelised cost of electricity (LCOE).[94]

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

The parameters of the LCOE formula are listed in the table below:

Table 25 Parameters of LCOE.[95]

Parameter	Symbol	Unit
Levelised cost of electricity in	*LCOE*	[EUR/kWh]
Investment expenditure	I_0	[INR]
Annual total cost	A_t	[INR/a]
Produced amount of electricity	$M_{t,el}$	[kWh/a]
Real interest rate	i	[%]
Economic lifetime	n	[a]
Year of lifetime	t	(1, 2, … n).

93 As discussed during the final workshop in Mumbai with KfW and Mahagenco, in February 2019 the local feed-in tariff amounted at INR 2.72 and is expected to decrease to INR 2.45 until 2020.
94 Christoph Kost et al. 2018.
95 ibid.

The LCOE calculation bases on the NPV method in which all expenses and revenues during the lifetime of the system are discounted. To estimate an appropriate discount rate, we employ the Weighted Average Cost of Capital (WACC) assuming the same financial parameters in the farming and the energy sector.

Generally, the WACC method represents a standard approach to discount future cash flows to their present value in case an investment comprises capital of both equity and debt (Brealey et al. 2011). Generally, for the Horticulture PV project a 100% debt financing via KfW is envisaged. However, as payments by Mahagenco for the acquisition of the land have already been carried out and further contributions of own equity appear realistic, we assume a share of own equity of 5%.

Generally, the WACC consists of the share of equity and debt and its respective prices. Additionally, the corporate tax co-determines the WACC since it mirrors the tax advantage of debt capital if expenses for interest payments reduce the tax base. Therefore, the WACC can be formulated as

Equation 5: Weighted average cost of capital (WACC).[96]

$$WACC = i = P_e C_e + P_d C_d (100 - t)$$

where P_e is the proportion of equity, P_d the proportion of debt, C_e and C_d its respective costs, and t the corporate tax rate.

In contrast to C_d and t which are given by the financial and legislative environment, C_d can be derived endogenously employing the systematic risk of an investment (French 2003). This is done employing the Capital Asset Pricing Model (CAPM) which sets the expected return of an investment equal to a risk-free interest rate plus an investment specific risk premium. This relation can be expressed by

Equation 6 Cost of equity (Ce).[97]

$$C_e = r_f + \beta (r_m - r_f)$$

in which r_f is the risk - free interest rate, β stands for the risk or, in other words, the volatility of the expected return of the investment, and r_m is the expected return of the market.

Finally, the IRR is derived by calculating the required discount factor to realise a NPV of zero.

Equation 7 Net present value (NPV).

$$NPV = \sum_{n=1}^{N} \frac{CF}{(1+i)^{-n}} = 0$$

with *CF* representing the annual cash flows. Large values are rounded up to whole INR units. All calculations are carried out using Microsoft Excel.

5.1.2 Assumptions and Parameter

The discount rate i, or WACC, is calculated based on the assumed parameter values shown in Table 27. Generally, the risk free interest rate rf can be approximated by governmental bonds – here we employ a rf of 1.5%. With a rm of 9% we account for a rather conservative long-term market return for an investment. As an investment decision with considerable risks we apply a risk factor of 2 (see e.g. Bordemann 2015). All parameters of the CAPM are listed in the table below. Following KfW’s recent credit conditions for Mahagenco we assume a cost of debt of 1%. The average corporate tax rate in India is given by approximately 35%.[98]

96 Brealey et al. 2011.
97 Ibid.
98 See: https://tradingeconomics.com/india/corporate-tax-rate).

Table 26 WACC parameters.[99]

Parameter	Symbol	Unit	Value
Share of equity	P_e	[%]	5
Share of debt	P_d	[%]	95
Cost of equity	C_e	[%]	16.5
Cost of debt	C_d	[%]	1.0
Corporate tax rate	T	[%]	35
Interest rate (risk free)	r_f	[%]	1.5
Risk factor	β	[-]	2
Expected market return	r_m	[%]	9
Durability	N	[a]	25

If not stated otherwise, for all analyses we consider a time horizon of 25 years with electrical yields generated from January 2020 until December 2044. To translate currencies from INR to EUR, we regard an exchange rate of 1.2 EUR Cent per INR.

Table 27 Assumption of economic parameters.

Parameter assumptions	Unit	Value
Exchange rate	[EUR/INR]	0.012
General inflation	[%]	3
Inverter replacement reserve inflation	[%]	-7
Electricity producer price inflation	[%]	0
Electricity producer price	[INR/kWh]	3.79

To allow for a dynamic calculation of OPEX we assume an inflation rate of -7% for inverter replacement services and 3% for all other cost items. For agricultural sales prices we assume INR 40 per kg of cotton, INR 5 per kg of bananas, INR 30.5 per kg of soybeans, and INR 9 per kg of tomatoes. On the PV layer, we assume an electricity producer price of INR 3.79 INR per kWh.

5.2 Agriculture

According to Section 4.3 Agricultural Yield Assessment, for assessing the economic performance on the agriculture level here we regard soybean, cotton, tomato, and banana as we expect them to perform within the proposed Horticulture PV system. Figures for crop specific cost items, yield per hectare, and crops' market prices base on the primary information from the farmers during the scoping mission in September 2018, on market research, and on assessments of our Indian expert Sachin Manohar Patwardhan. Further, in our baseline scenario we consider an integrated water management system providing irrigation. All values are annual figures.

The following table summarises the agricultural results per year assuming the entire 100 ha would be cropped with only the respective single crop.

Table 28 Agricultural economic assessment.[100]

Crop	Total cost [INR/ha]	Yield [kg/ha]	Sales price [INR/kg]	Gross income [INR/ha]	Net income [INR/ha]
Soybean	27,250	2,155	30.5	65,736	38,486
Cotton	66,500	5,002	40.0	200,076	133,576
Tomatoes	85,550	19,993	9.0	179,939	94,388
Banana	181,750	44,928	5.0	224,639	42,888

For cotton and banana the expected net incomes would be high enough to provide an average monthly income for farmers of more than INR 10.000.

99 Source: Stakeholder dialogue, project requirements.
100 Source: Fraunhofer ISE.

This overview of cost and earnings from agricultural activities just provides a first assessment and, hence, more detailed analyses are recommended involving agricultural institutions like TATA trust or the “Green Innovation Centres for the Agriculture and Food Sector – India” of the GIZ.

5.2.1 Soybean

In comparison to other crops considered in this study, soybean requires low cost at relatively low earnings and, hence, can be regarded as a low risk crop.

Table 30 lists expected cost items with total cost summing up to INR 27,250 (EUR 327). As we also consider irrigation, we assume a rise of agricultural yield of 60% compared to non-irrigated soybean yields reported by the farmers during the scoping mission (see Section 3).

Assuming sales prices of INR 30.5 per kg, the expected gross income sums up to INR 65,736 with a respective net income of INR 38,486 (EUR 462) per hectare and year.

Table 29 Annual cost and earnings of soybean cultivation at project site.[101]

Operation	Unit	Material & Equipment	Labour cost	Total
Irrigation	[INR/ha]	4,000	3,000	7,000
Ploughing	[INR/ha]	2,000	-	2,000
Levelling	[INR/ha]	2,000	-	2,000
Seed sowing	[INR/ha]	3,750	500	4,250
Fertiliser application	[INR/ha]	1,500	500	2,000
Weeding	[INR/ha]	2,000	500	2,500
Pesticides	[INR/ha]	2,000	500	2,500
Harvesting	[INR/ha]	-	2,000	2,000
Marketing costs	[INR/ha]	3,000	-	3,000
Total cost	[INR/ha]	-	-	27,250 (EUR 327)
Yield	[kg/ha]	-	-	2,155
Sales prices	[INR/kg]	-	-	30.5
Gross income	[INR/ha]	-	-	65,736
Net income	[INR/ha]	-	-	38,486 (EUR 462)

5.2.2 Cotton

Given the assumed parameters and market conditions, economically, cotton performs best among all considered crops with an expected net income of around INR 133,580 (EUR 1,603) per ha and year. Table 31 lists the expected cost items with total cost summing up to INR 66,500 (EUR 798). As we also consider irrigation, we assume two harvests per year with a rise of agricultural yield of 100% compared to non-irrigated cotton yields.

Assuming sales prices of INR 40 per kg, the expected gross income sums up to round INR 200,000 per hectare and year.

Table 30 Annual cost and earnings of cotton cultivation at project site.[102]

Operation	Unit	Material & Equipment	Labour cost	Total
Irrigation	[INR/ha]	4,000	3,000	7,000
Ploughing	[INR/ha]	2,000	-	2,000
Levelling	[INR/ha]	2,000	-	2,000
Ridge making	[INR/ha]	2,000	-	2,000
Seed sowing	[INR/ha]	4,000	2,500	6,500
Fertiliser application	[INR/ha]	7,500	2,500	10,000

101 Source: Sachin Manohar Patwardhan.
102

Operation	Unit	Material & Equipment	Labour cost	Total
Weeding	[INR/ha]	2,000	5,000	7,000
Pesticides	[INR/ha]	7,500	2,500	10,000
Harvesting	[INR/ha]	-	12,500	12,500
Marketing costs	[INR/ha]	7,500	-	7,500
Total cost	[INR/ha]	-	-	66,500 (EUR 798)
Yield	[kg/ha]	-	-	5,002
Sales prices	[INR/kg]	-	-	40
Gross income	[INR/ha]	-	-	200,046
Net income	[INR/ha]	-	-	133,567 (EUR 1,603)

5.2.3 Tomato

Overall, economic parameters of tomato cultivation perform in the middle range. With expected total cost of INR 85,550 (EUR 1,027) and sales prices of INR 9 per kg, per hectare and year the expected gross and net income sum up to around INR 180,000 and INR 94,355 (EUR 1,132), respectively. According to discussions with stakeholders during the final workshop in Mumbai in February 2019, experts suggest that much higher yields for tomatoes might be achieved.

Table 31 Annual cost and earnings of tomato cultivation at project site.

Operation	Unit	Material & Equipment	Labour cost	Total
Irrigation	[INR/ha]	4,000	3,000	7,000
Ploughing	[INR/ha]	2,000	-	2,000
Levelling	[INR/ha]	2,000	-	2,000
Ridge making	[INR/ha]	2,000	-	2,000
Seed sowing	[INR/ha]	10,000	200	10,200
Transplanting of seed-lings	[INR/ha]	-	8,000	8,000
Staking	[INR/ha]	5,000	600	5,600
Fertiliser application	[INR/ha]	10,000	1,000	11,000
Weeding	[INR/ha]	2,000	5,000	7,000
Pesticides	[INR/ha]	10,750	5,000	15,750
Harvesting	[INR/ha]	-	10,000	10,000
Marketing costs	[INR/ha]	5,000	-	5,000
Total cost	[INR/ha]	-	-	85,550 (EUR 1,027)
Yield	[kg/ha]	-	-	19,993
Sales prices	[INR/kg]	-	-	9
Gross income	[INR/ha]	-	-	179,939
Net income	[INR/ha]	-	-	94,355 (EUR 1,132)

5.2.4 Banana

Cultivating bananas requires the highest initial investment of all considered crops (approximately INR 182,000 per ha). Though, once the investment is made banana perform relatively well as ratooning allows for only minor cost in subsequent 2-3 years. Table 33 depicts the expected high initial investment expected cost items for the first year. With sales prices of INR 5 per kg, in the first year the expected gross and net income per hectare and year amount to approximately INR 225,000 and INR 48,890 (EUR 515), respectively.

In subsequent years, the expected net income sums up to 113,750 (EUR 1,365).

Table 32 Annual cost and earnings of banana cultivation at project site.

Operation	Unit	Material & Equipment	Labour cost	Total
Irrigation	[INR/ha]	4,000	3,000	7,000
Ploughing	[INR/ha]	2,000	-	2,000
Levelling	[INR/ha]	2,000	-	2,000
Ridge making	[INR/ha]	4,000	-	2,000
Seed sowing	[INR/ha]	50,000		50,000
Transplanting of seedlings	[INR/ha]	-	2,000	2,000
Staking	[INR/ha]	10,000	2,000	12,000
Fertiliser application	[INR/ha]	30,000	5,000	35,000
Weeding	[INR/ha]	2,000	10,000	12,000
Pesticides	[INR/ha]	10,750	5,000	15,750
Harvesting	[INR/ha]	-	20,000	20,000
Marketing costs	[INR/ha]	20,000	-	20,000
Total cost	[INR/ha]	-	-	181,750 (EUR 2,181)
Yield	[kg/ha]	-	-	44,928
Sales prices	[INR/kg]	-	-	5
Gross income	[INR/ha]	-	-	224,639
Net income (first year)	[INR/ha]	-	-	42,890 (EUR 515)
Net income (subsequent years)	[INR/ha]	62,750	40,000	113,750 (EUR 1,365)

Both, soybean and banana are running close to generating losses under Horticulture PV conditions. For cotton and tomato revenue improvements are likely. However, only minor improvements towards optimal irrigation or enhances cropping methods have been considered.

5.3 PV system

Generally, the economic performance of a PV system depends on initial and operational cost – CAPEX and OPEX – as well as on earnings during the system's lifetime. We first analyse CAPEX and OPEX before we take further scrutiny on the revenues and the dynamic investment analysis.

Overall, highest uncertainties exist regarding cost on mounting structure and racking hardware components. This is particularly relevant as this cost items are one mayor cost driver expected to amount up to twice the level compared to GM-PV. If not stated otherwise, all cost items are given in INR per kW_p.

5.3.1 Cost Analysis

Over 25 years, the expected present value of the PV system's total cost sum up INR 53,480 per kW_p, and a total NPV of INR 64,400 with CAPEX of INR 40,600 and a present value of total OPEX of INR 12,860.

5.3.1.1 Capital Expenditure (CAPEX)

Apart from PV modules for which specific offers were obtained, we determined the level of all cost items applying average market values. With approx. INR 21,250 the bifacial PV modules account for the largest single cost item of the CAPEX (52.3%) ranging 10 to 25% above the level of conventional glass-tedlar modules followed by the mounting structure equipment (INR 5,500 or 13.5%). While interviews with EPCs and PV module producers suggest that prices of modules remain relatively stable within the next 2 years, prices for the mounting structure (see Table 34, pos. 3) were derived by experiences with other Horticulture PV projects and by conducting interviews with EPC partners and mounting structure developers from both Europe and India. For Europe, typical cost on mounting structure amount to approx. INR 7,700.[103] In contrast, for India typical costs are around 60% below EU level. Assuming twice the cost

103 Source: BayWa r.e.

of this amount for a Horticulture PV system with the discussed vertical clearance and pole distances, uncertainties remain with respect to wind load, requirements to structural integrity, soil conditions, and the applied ground works technology (see Section 3) which might induce deviating cost of up to 30% in both directions.

The third largest cost item of CAPEX is cost on inverters with INR 2,400 or 5.9% followed by cost on mounting and construction works with approximately INR 1,900 or 4.7% of all CAPEX. This item also deviates from GVPV (+50%). In contrast to cost on mounting structure equipment, though, fewer uncertainties exist since mounting and construction works mainly depend on labour which is relatively cheap in this area.

Together, PV modules, mounting structure equipment, inverters, and mounting & construction works, account for 76.5% of all CAPEX. Remaining cost items encompass transformer stations (4.2%), cleaning system (4.4%, baseline scenario), combiner boxes & string inverters (3.7%), DC/AC cables (2%), land acquisition (2%), system design and management & administration (1.3%), grid connection (1%), site preparation (<1%), due diligence (<1%), and legal advisory (<1%). Usually not part of CAPEX of GM-PV we consider also cost on water management of INR 1,535 or 3.8%. This encompasses facilities for rainwater harvesting, inter-seasonal water storage, and drip irrigation.

As per information received from Mahagenco, the land acquisition occurred at the average rate of INR 4,68,515 per hectare in the year 2010. To account for the fact that this investment has already been done, in the low-cost scenario (see Table 36) we present figures disregarding land cost. A description of the assumed cleaning and water management system with its single cost items can be found in Sections 5.4 and 5.5.

Table 33 CAPEX of the proposed system.[104]

Capital expenditures (CAPEX)	INR per kW_p	INR lakh per ha	EUR per kWp	EUR per ha	Share of total CAPEX
Solar panels	21,250	107.8	255.00	129,387	52.3%
Inverter	2,400	12.2	28.80	14,613	5.9%
Mounting structures & racking hardware components	5,500	27.9	66.00	33,488	13.5%
Combiner boxes & string invert-ers	1,483	7.5	17.80	9,030	3.7%
Transformer stations	1,723	8.7	20.68	10,492	4.2%
Site preparation	305	1.5	3.66	1,858	0.8%
Mounting & construction costs	1,907	9.7	22.88	11,610	4.7%
DC / AC cables	797	4.0	9.56	4,850	2.0%
system design, management & administration	528	2.7	6.34	3,216	1.3%
Due diligence	99	0.5	1.19	602	0.2%
Legal advice	109	0.6	1.31	662	0.3%
Grid connection	424	2.2	5.08	2,580	1.0%
Land acquisition	794	4.0	9.53	4,835	2.0%
CAPEX conventional	**37,318**	**189.35**	**447.82**	**227,224**	**91.9%**
Cleaning system	1,770	8.98	21.24	10,777	4.4%
Water management system	1,535	7.79	18.42	9,349	3.8%
Total CAPEX	**40,624**	**206.12**	**487.48**	**247,349**	**100.0%**

104 Source: Fraunhofer ISE.

5.3.1.2 Operational Expenditures (OPEX)

With INR 629 per kW_p the annual OPEX amount to less than 2% of CAPEX. Over 25 years total OPEX sum up to a present value of INR 12,858 and 31.6% of total cost. To account for inflation and future relative price changes, we regard an annual inflation rate of inverters of -7% and 3% of all remaining O&M cost items. With 25.4% and INR 160, the largest share of OPEX arises for inverter replacement services equal to the level of GM-PV. In contrast to CAPEX, here we disregard cost of water management assuming that operational cost are born by the agricultural layer.

Regarding the third largest OPEX cost item – cost on repair services – we consider a 20% rise of cost to account for additional efforts for conducting operations at 4-6 meters heights instead of ground level or if services cannot take place at any time of year but only during fallow periods. Accordingly, cost on repair services amount to 28.3% of CAPEX or INR 178. Similarly, we regard a 30% rise of insurance cost compared to GM-PV with INR 116 or 18.4% of OPEX. While some insurance companies also provide services for Horticulture PV at the same conditions as for GM-PV, here we regard conservative figures to account for possible contingencies that might occur due to a higher risk of damage through accidents with land machines or the lack of reliable risk experiences with Horticulture PV.

Remaining cost items encompass commercial management (12.9%), surveillance (3.6%), and miscellaneous expenses, which we have planned as a buffer (11.2%).

Table 34 Operational expenditures (OPEX) of proposed Horticulture PV system.[105]

Operational expenditures (OPEX)	INR per kWp	INR lakh per ha	EUR per kWp	EUR per ha	Share of total OPEX
Inverter replacement reserve	160.00	0.81	1.92	974	25.4%
Provision of repair services	178.16	0.90	2.14	1,085	28.3%
Surveillance	22.88	0.12	0.27	139	3.6%
Commercial management	81.36	0.41	0.98	495	12.9%
Insurance	115.81	0.59	1.39	705	18.4%
Miscellaneous expenses	70.62	0.36	0.85	430	11.2%
Total OPEX	**628.94**	**3.19**	**7.55**	**3,829**	**100.0%**

5.3.2 Revenues

Based on the electrical yield assessment of Section 3.3 and assuming electricity producer prices of INR 3.79 per kWh, over 25 years the present value of total sales sums up to INR 132,065 per installed kW_p.

Given an electricity generation loss of 6.8% when using monofacial modules as elaborated in Section 3.3.2 would come at cost of at least 4,100 INR with potential of sales losses up to 8,000 INR per $kW_{p.}$

5.3.3 LCOE, IRR, and Overview of Different Scenarios

According to the assumptions and figures presented above, the LCOE amount to INR 1.53 per kWh. Given the expected revenues, the IRR of the investment presumably varies around 16%. To account for existing risks and contingencies, in the table below we frame the discussed Baseline Scenario with one of lower and higher cost, respectively. In the lower cost scenario (Low Scenario) we disregard earlier investments made on land acquisition, assume 30% and 15% lower cost on mounting structures and mounting & construction, respectively, no rise of insurance cost compared to GM-PV, and a higher future solar irradiation leading to 2% higher initial annual electric generation compared to the Baseline Scenario. In contrast, in the High Scenario we assume 30% and 15% higher cost on mounting structures and on mounting & construction, respectively, and 2% lower initial annual electric generation.

As for the LCOE, the expected cost per kWh range from INR 1.41 (Low Scenario) up to INR 1.62 (High Scenario).

105 Source: Fraunhofer ISE.

Table 35 Economic performance in three scenarios.[106]

	Unit	Baseline Scenario [INR]	[EUR]	Low Scenario	Change	High Scenario	Change
CAPEX	[INR/kWp]	40,624	487	37,894	-6.7%	42,560	+4.8%
OPEX	[INR/kWp/a]	629	8	602	-4.3%	629	0.0%
OPEX (NPV)	[INR/kWp over 25 years]	12,858	154	12,205	-5.1%	12,585	0.0%
Total cost (NPV)	[INR/kWp over 25 years]	53,479	642	50,097	-6.3%	55,414	3.5%
Electricity generation	[kWh/kWp]	1,713	1,713	1,747	+2.0%	1,679	-2.0%
Revenues Electricity Sales (NPV)	[INR/kWp over 25 years]	132,065	1,585	134,706	+2.0%	129,424	-2.0%
Net Earnings (NPV)	**[INR/kWp over 25 years]**	**78,586**	**943**	**84,610**	**+7.7%**	**74,009**	**-6.2%**
LCOE	**[INR/kWh]**	**1.53**	**1.84**	**1.41**	**-8.2%**	**1.62**	**+5.4%**
IRR	**[%]**	**16.00**	**-**	**18.2%**	**+13.6%**	**14.6**	**-9.7%**

5.4 Cleaning system

To assess the economic performance of the cleaning systems discussed in Section 3.4, here we consider the dry cleaning system of Ecoppia and the wet sprinkler system of NaanDanJain. As the Ecoppia system performs better under the assumed conditions, for the calculation of the different scenarios listed in Table 36 we only regard the Ecoppia system.

The highest expected initial investment cost is given by the full-automated dry cleaning system of Ecoppia with INR 1,770 per installed kW_p.[107] The lowest initial cost is expected for the sprinkler system of NaanDanJain with INR 1,351. Over the long run, the warranty of the Ecoppia system fully balances out the higher investment cost.

5.4.1 High Investment Scenario (Ecoppia)

In a query, Ecoppia stated that at an optimal power station layout, costs amount to INR 1,070 to 1,420 per installed kW_p. However, if deviating from an optimal layout, cost may rise largely. In order to account for contingencies and additional requirement of the Horticulture PV design (e.g. the high vertical clearance), however, here we assume INR 1770 per installed kW_p. Due to the given warranty of 25 years we assume no maintenance cost.

5.4.2 Low Investment Scenario (NaanDanJain)

According to information of NaanDanJain, overall installation cost amount to INR 1,400 per installed kWp. Though, in contrast to the Ecoppia system, there is less variability of initial cost as investment depends not on an optimised design. Further, replacement of the sprinkler equipment has to be taken into account since the life expectancy is shorter. Hence, additional to labour cost we consider annual provisions for replacement of approximately 7% of the acquisition value. The table below depicts investment cost, maintenance cost, and overall cost of the three scenarios.

Table 36 Different cleaning systems for the proposed Horticulture PV system.[108]

Scenario	High investment (Ecoppia) [INR/kW_p]	Low investment (NaanDanJain) [INR/kW_p]
Robot/sprinkler cost	1,770	1,351
Annual maintenance cost	0	144
Total maintenance cost (25 years)	0	3,051
Total cost (present value)	**1,770**	**4,402**

106 Fraunhofer ISE.
107 Note that for an optimal PV layout the cost of Eccopia system is around INR 1,300. However, since several characteristics of the Horticulture PV system might require deviating from an optimised PV design, here we regard cost being 150% higher.
108 Fraunhofer ISE. Based on company survey and PI Berlin market review.

5.5 Water Management

5.5.1 Cost Analysis

For the study we have considered different water management systems as discussed in Section 3.5. The information in the table below serves as an orientation over single cost items of rainwater harvesting system.

Since the system components are the same for both decentral and central variants at the Horticulture PV system in order to ensure sufficient water quality for irrigation and cleaning, it seems favourable to invest into a central watershed connection. A certain water filtration technology has not been specified. The estimations are very rough and may only serve as an orientation. For repair and maintenance, we have considered 0.2% of the CAPEX. We also considered two times reinvestment for the drip irrigation system

Table 37 Economic analysis of the water management system variant interseasonal storage.[109]

Capital Expenditures (CAPEX)	Unit	Decentral Tanks
Water filtration	[INR lakh]	42
Pipes & pumps	[INR lakh]	42
Rain harvest drainage	[INR lakh]	14
Tank costs / watershed connection	[INR lakh]	344
Drip irrigation	[INR lakh]	338
CAPEX	[INR lakh]	779
Operational Expenditures (OPEX)		
Maintenance incl. drip irrigation	[INR lakh]	42.58
Labour cost	[INR lakh]	21.21
OPEX	[INR lakh]	63.79

In sum, the CAPEX of a wet cleaning semi-automated cleaning system combined with a water management system connected to a central watershed could be within the range of a single fully-automated dry cleaning system.

5.6 Summary

The analyses in this chapter suggest LCOE of INR 1.53 for the Horticulture PV system varying between INR 1.41 and 1.62 per kWh. This is far below European values that range between EUR 0.07-0.12. The expected overall investment cost ranges from INR 37,900 to 42,600 per kWp while the present value of operational and maintenance cost over 25 years are expected to vary between 12,200 and 21,800 per kWp with respective net present values (NPV) of 74,000 to INR 84,600 per kWp and internal rates of return (IRR) from 14.6% to 18.2%. For an electrical tariff of INR 3.79 an IRR of 16% is expected.

When applying a typical market based debt financing rate of 10% instead of 1%, with INR 2.73 the LCOE still appear competitive according to analyses of IRENA (2018) that estimates LCOE of GM-PV for India to be around INR 2.82 per kWh. However, recent electrical tariffs in Maharashtra suggest that cost of GM-PV dropped even faster as predicted by IRENA. Major cost drivers of Horticulture PV are the mounting structure and racking hardware components that are expected to amount to twice the level of GM-PV.

Main uncertainties of the economic analyses remain with respect to cost and revenue items that cannot be assigned clearly to the agricultural or the PV layer and, hence, depend on the business case arrangement with farmers. These cost items encompass cost on water management, surveillance, and possible contributions or payments between agricultural activities and Mahagenco as the land owner.

109 Source: Own estimations.

Recommendations

- From Mahagenco's view, high initial costs on water management might seem as an unproductive burden at first sight. Though, if employed wisely, this could be a valuable and helpful asset for future discussions with the agricultural and political stakeholders.
- Upcoming negotiations with regulatory authorities and stakeholders should clarify whether the required electrical tariff of INR 3.79 can be achieved or not. In the discussion, highlighting the expected beneficial social and environmental aspects as well as the future potential of Horticulture PV systems seems important to justify a higher electrical tariff.
- Further studies on quantifying the societal added value of Horticulture PV systems in the Indian context might help to provide a solid basis for public decision makers.
- To assess the economic performance of the Horticulture PV system in more detail and to overcome remaining uncertainties, the institutional arrangement and collaboration schemes between Mahagenco and affected farmers should be clarified soon.
- We suggest measuring the local solar radiation over a period of 12 months to minimise uncertainties with respect to the expected electrical yield.

6 Social Assessment

This chapter addresses the social question and the complexity around the relationships of the different stakeholders. The current state is described in Section 6.1 while the findings of the field research are provided in 6.2. Based on this a stakeholder scenario and three different institutional scenarios are anylsed. Finally, a qualitative cost and benefit comparison of the institutional scenarios regarding the three stakeholder Mahagenco, KfW and Farmers will be presented.

6.1 Current State

The relationship between the farmers and Mahagenco has been complicated because of the livelihood uncertainties created by the decision not to build a coal power plant. Currently they are averse to any solar power station because the man-power absorption in a solar power station would be negligible compared to a TPP. Given the political economy associated with land acquisition and assured jobs, it may be difficult for Mahagenco to utilise the land without getting farmers on board.

Hence, it would be imperative to include the farmers in the project to create a win-win situation and long-term benefits for both the parties. Thus, using the land for co-production of food-energy through a Horticulture PV would be a feasible option if a model is devised where the project affected people (PAP's) can be converted into partners. Effective stakeholder management will be a key challenge, even in the proposed Horticulture PV.

6.2 Field Research & Farmers Community

We met close to 5-6 farmers groups and spoke with around 30 farmers at Paras. As per information gathered during the fieldwork done in September 2018, in which informal and unstructured interviews were conducted with individual farmers, farmers groups, local staff of Paras TPP and residents of Paras, it was evident that farmers were not keen to part with their land as this was the most fertile land parcel in the vicinity.

Appropriate compensation and an assured job at the Paras TPP were the incentives committed, if farmers agreed to give away their land. Trusting the Paras TPP management and the local government institution, leaving aside 2-4 farmers, 120 farmers agreed to give up their land entitlements. This resulted in close to 20 farmers becoming landless and 10 farmer households becoming homeless. But the envisaged expansion of Paras TPP did not happen and the farmers continued doing farming on their earlier entitled land. Since the land officially belongs to Mahagenco, no farmer invested in irrigation arrangements or wells after 2011.

Currently no part of 125 ha land, which is cultivable, is left fallow with farmers taking two crops on the same. Only 20 out of 120 farmers could get a permanent job at Mahagenco, since it required clearing an online examination, which was beyond the capabilities of majority of farmers, therefore there mis-trust developed for Mahagenco, even though Mahagenco has not stopped farmers from using the land which officially belongs to them. Also, the rest of the PAP's have got contractual jobs at Paras TPP, which requires them to be present at the TPP premises for 8-hour shifts and they get around INR 9,000-10,000 per month, which is only a share of a regular job salary.

6.3 Stakeholder Analysis & Institutional Scenarios

In this section different institutional models for effective stakeholder management are discussed. Strategic stakeholder management will result in long term benefits not just for both farmers and Mahagenco, but for KfW bank also.

6.3.1 Stakeholder Analysis

Table 38 Stakeholder overview.[110]

Stakeholder	Interest	Power
Mahagenco	To maximise returns from their land asset by utilising it for producing electricity while minimising social and environmental externalities	High, influence on local economic and environmental resources.
KfW Bank	To invest in development projects having multi-sectoral benefits while building a positive brand in South Asia.	High, finance loan for project implementation.
Farmers	To maximise their income/returns from the available resources and choices.	Low, protest and social unrest only leverage to express interests in case interests are neglected by other stakeholders.

6.3.2 Institutional Scenarios

Table 39 Social scenario overview.[111]

Scenario	Characteristics
1) Mahagenco to lease out land for farming	Mahagenco builds a boundary around the land (as was being suggested by few Mahagenco engineers) to reinforce the ownership. A Horticulture PV can be built by them. A bidding process can be done and land can be given to the highest bidder for farming. Bidder can be the existing farmers or any third party. Mahagenco builds and maintains the Solar Horticulture PV power station. Farmers or land tenants can choose the crops they want to grow with the sunlight available. There is minimum transaction and interaction between the electricity and crop production.
2) Minimum partnership-sub-optimal benefits	Mahagenco can build a Horticulture PV power station and can let the farmers use the land for agriculture (as they are currently doing). They allow farming on their land in-lieu of the jobs committed earlier and do not charge land rent from farmers. They keep staff to protect and maintain the Horticulture PV power station. Also, a preliminary agriculture/crop plan is suggested to farmers to help them utilise the land better in case of reduced sunlight.
3) Symbiotic relationship – optimal benefits	Mahagenco can build the Horticulture PV power station and shares a small percentage of energy sale revenue with farmers as maintenance charge. Farmers organise themselves into a local institution (company or cooperative), to which Mahagenco will outsource the maintenance of the Horticulture PV power station. The local institution of farmers will systematically manage the maintenance by devising appropriate by-laws and rules, with the help of Mahagenco. Farmers will utilise the land, clean the part of the Horticulture PV power station in their field through their local institution; the water for cleaning can automatically irrigate their fields.

6.3.3 Qualitative Cost and Benefit Comparison of Institutional Scenarios

Table 40 Qualitative cost and benefit comparison of institutional scenarios.[112]

Cost	Scenario	Mahagenco	KfW	Farmers
		Stakeholder		
Financial	(1)	Increased security & surveillance.	Backfires through loan.	Loss of income and livelihood. Not being able to be competitive bidder.
	(2)	Increased security & surveillance relatively lower than in (1).	Lower to (1).	Adjustments have to be made with their current cropping pattern. Reduced sunlight will impact yield.
	(3)	Sharing the revenue (payment for maintenance services according to industry sector minimum wage) is loss of revenue Loss of revenue from land rent.	None.	Time and labour spent in contributing towards maintaining the kW_p installed in their land.
Social	(1)	High, as farmers may lose income from farming.	Very High, social externality will result in negative publicity for KfW bank in South Asia. Also defeats purpose of development bank.	Loss of livelihood results in extreme poverty.

110 Source: Input by Neha Durga.
111 Source: Input by Neha Durga.
112 Input by Neha Durga.

Cost	Scenario	Mahagenco	KfW	Farmers
	(2)	Lower than (1) but higher than current practice, as the current revenue from farming may reduce due to partial sunlight availability. Negative Social Externality.	Lower than (1) but still high.	Lower than (1) but still high.
	(3)	None.	None.	None.
Political	(1)	High, since the land acquisition and employment issues can be used to earn political mileage by local politicians.	High, association for KfW bank with land acquisition issue may result in bad publicity and defeats purpose of development bank.	Farmer may retreat to social unrest and radical political organisations.
	(2)	Lower than (1).	Lower than (1).	None.
	(3)	None.	None.	None.
General risk	(1)	Social unrest in the village may result in difficulty in construction and operational phases.	Negative branding.	Absolute poverty.
	(2)	Farmers might sabotage plant to maximise sunlight penetration for better yields.	None.	Reduced income due to reduced sunlight from faming.
	(3)	Stakeholder coordination & communication risk.	None.	Social “saboteurs” among community members.
Benefits				
Financial	(1)	Additional income from land rent.	None.	None.
	(2)	Reduced cost of security compared to (1).	None.	Better than (1), worse than current.
	(3)	Reduced cost of security and maintenance.	None.	Increased income from Crop and energy Co-production.
Social	(1)	None.	None.	None.
	(2)	Better than (1).	Better than (1).	Better than (1), worse than current.
	(3)	Mahagenco may lead by example by proofing, that CSR can be integrated effectively in strategic and operational business process.	Optimal support for sustainable social development. Showcasing win-win models.	Reduced vulnerability, climate smart income from energy production.
Difficulty of implementation				
	(1)	Difficult and may not go as planned. Social unrest and protest very likely.		
	(2)	Relatively easier than Model 1 to start but when the crop yield will be lesser subsequently in the future, collective discord may create difficulty in operating and maintaining it		
	(3)	Initial discussions and farmer mobilisation required for organizing farmers into an institution Capacity building of farmer institution		

6.4 Summary

Since in a Horticulture PV system different stakeholders and partners are involved, the success of partnership will depend on how effectively all the stakeholders are being brought together and inclined towards the same objective. An attractive incentive structure for farmers and other stakeholders appears crucial for designing and evaluating different institutional models discussed in this chapter. Additional stakeholders such as government agencies and NGO’s should be involved in order to provide an incentive design that suits the farming community as well as the power generation company.

As a conclusion, we recommend a strategic partnership of shared benefits and costs to hedge multiple risks and to ensure a smoother long-term relationship. Therefore, costs in the short term should be evaluated against long term and strategic benefits of good social relations. Considering the core activities of different partners i.e. energy business for Mahagenco, cropping for farmers, and lending for KfW, cost and benefits for them have been discussed. For Mahagenco a unique chance opens up take the initiative and act as a leader in reconciling and integrating different perspectives that are related to their core business.

Also, if imposing drastic changes in cropping patterns, adequate guidance of experienced agricultural institutions should be considered to provide continuous support to farmers. An organisation should be found that may act as an intermediary, an interface between the farmers and Mahagenco. This organisation must have experiences in agriculture and stakeholder management. It should be of local origin or well-connected in the local area and should enjoy the trust of the farming community. During the results workshop it was proposed to involve Tata Trusts as such.

Recommendations

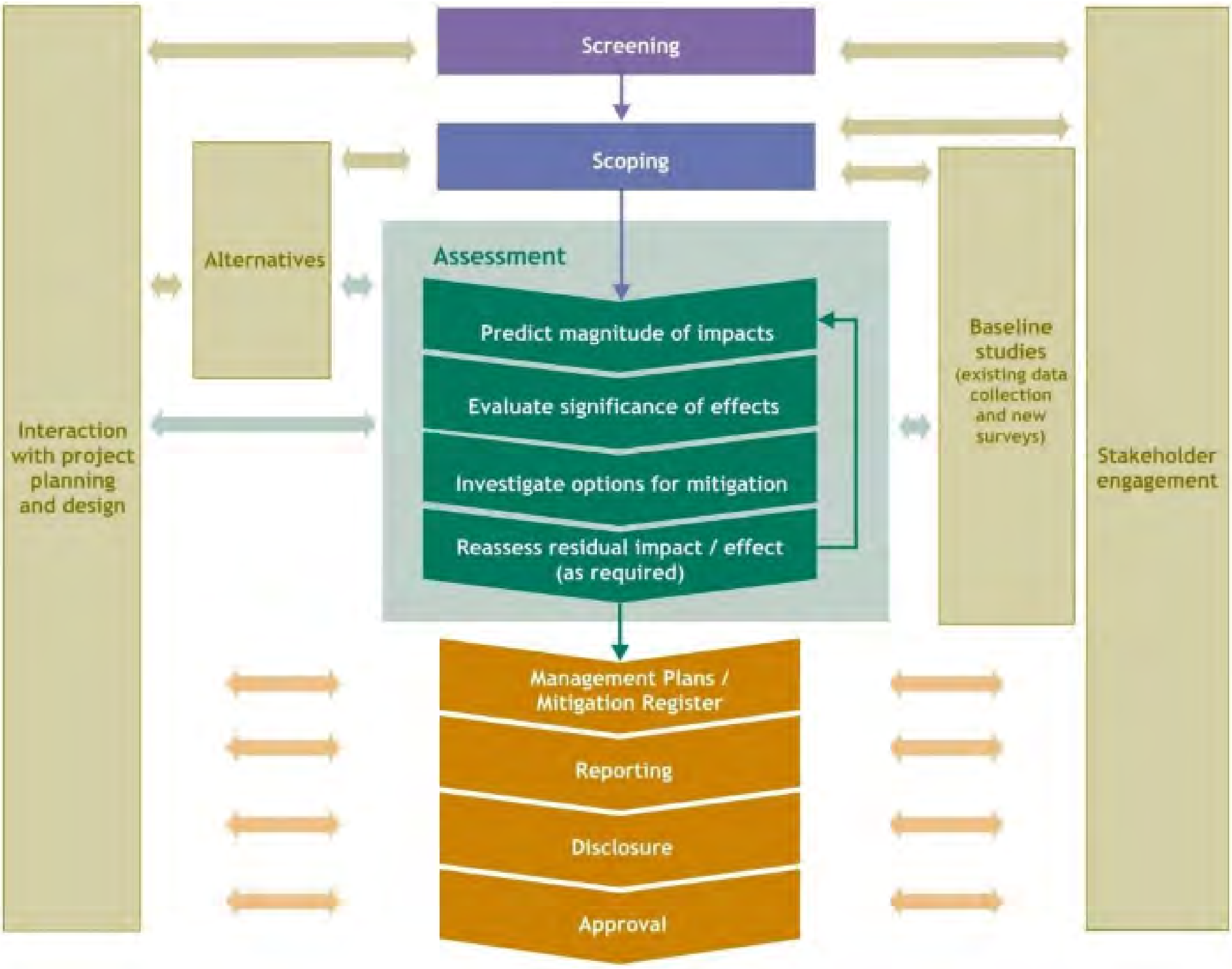
- Identify possible intermediary organisations that can act as an interface between Mahagenco and the farming community and facilitate communication and alignment of the different perspectives.
- Conduct a detailed household survey in order to assess needs, interests and capabilities of the community in greater detail.
- Evaluate the scope of potential economic support for the farming community to develop agriculture at the project site.
- Identify possible organisations like Tata Trusts or GIZ that may provide support for increasing the agricultural productivity at the project site.
- Identify potential areas and farmers willing to participate for a pilot facility that incorporates at least 10 farmers in order to test a meaningful institutional arrangement.

7 ESIA Scoping Report

In this chapter we assess the major environmental and social impacts of the proposed project using ESIA scoping methodology. The Horticulture PV system is generally eligible to an ESIA according to KfW project requirements. However, it is white listed by the Government of India and no EISA is required for government approval. Nevertheless, it is strongly recommended to conduct a full ESIA in order to avoid any adverse impacts and damages, even though the Horticulture PV system represents a mitigation measure by itself. The preparation of the scoping study is an important milestone to identify potential hotspots and give direction to upcoming research for a full ESIA assessment that conforms to international standards. In Section 7.1 we described the applied methodology while in Section 7.2 we summarise and present the outcomes of the scoping exercise. Hence, this chapter does not include a separate summary.

Figure 36 gives overview about a schematic ESIA process. Screening and scoping have been conducted with the pre-feasibility, however major stakeholder involvement and outreach with local Indian organisations that may function as intermediaries between Mahagenco and the farmers community is still to be done.

Figure 36 General ESIA process.[113]



The screening process is already conducted including respective field trips and first stakeholder consultations. However, the scoping process may require further inputs and aspects of discussion during the results workshop. Furthermore, a full scoping exercise may include stakeholder consultation with environmental protection

113 Source: (Chaudhary 2017).

organisations and farmers organisations. Within the scope of this study, no Indian NGO's or Government Agency had been directly consulted by Fraunhofer ISE.

In this study we have considered different scenarios in order to assess different environmental impacts concerning solar energy generation (CO2 reduction), water consumption and employment. In the report the estimated impacts are explained hence this section only references to the respective section in the report. Different scenarios can be found for the PV power station itself, the cleaning system, the water management system and crop choices.

The estimation of environmental impacts is rough, and most figures must still be calculated given specific Horticulture PV system layout plans, construction plans and empiric measurements for instance regarding soiling and crop shadow response. Such detailed studies may be possible when specific requirements for a Horticulture PV system tender process are decided upon.

7.1 Scoping Method

Within the scope of this pre-feasibility study, only mayor impacts, hotspots, and tendencies can be stated. Further research must be conducted to achieve necessary data quality for a full ESIA.

The scoping study has been systematically prepared based on the EU commission document "Guidance on EIA – Scoping"[114] and the provided checklists. Additionally, current frameworks and already conducted ESIA's from other solar power stations in India had been considered for the desktop review such as the Scoping-Matrix used by (Chaudhary 2017) that has been adapted to the Horticulture PV system characteristics. The matrix shows four sorts of cell colourings. The cell colouring indicates in relationship each project activity has to each sustainability resource/ receptor.

Table 41 Scoping-matrix legend. Interactions of project activities and resources/receptors.[115]

=	No interaction of Project Activity with Resource or Receptor is reasonably expected.
=	Interactions reasonably possible with assessment still pending or the same impact than a conventional PV power station or conventional agriculture
=	Interactions reasonably possible with outcomes leading to a significant impact positive way compared to a conventional PV power station or conventional agriculture
=	Interactions reasonably possible with outcomes leading to a significant impact in a negative way compared to a conventional PV power station or conventional agriculture

In ANNEX page 128 the EU Commission checklists can be found. The cell colouring is same as for the scoping matrix, furthermore the EU Commission checklist contains more detailed comment on each aspect. Generally, the environmental impacts are described in each section of the report. Below similar solar power station ESIA's are listed for reference:

Similar Solar Power Station ESIA's:

- Draft ESIA: India: Dahanu Solar Power Project 40 MW_p (ADB 2011)
- Environmental and Social Impact Assessment of 25 MW_p Solar PV Project at Village Bareta, District Mansa, Punjab (ADB 2016)
- (ESIA) of Proposed 100 MW_p Solar PV Power Project: Veltoor, Telangana (Chaudhary 2017)

Environmental and Social Management Frameworks:

- EU commission document "Guidance on EIA – Scoping" (Commission 2011)
- Final Environmental and Social Management Framework for Solar Park in India (World Bank 2018)
- Environmental and Social Management Framework – Solar PV Park (World Bank 2017)

114 (Commission 2011.)
115 Fraunhofer ISE.

7.2 Scoping Summary

7.2.1 Construction Phase

Due to the structure of the Horticulture PV system and the more complex mounting structures, the environmental impacts during the construction phase are generally expected to be more significant especially regarding transport and installations of the mounting structure and the solar module installations. It is expected that heavier trucks and machinery are required to construct the Horticulture PV system. Therefore, traffic will increase, and occupational H&S becomes a hotspot even more than it was with a conventional PV system.

However, besides these issues, the Horticulture PV is expected to have approximately 70-80% higher CO_2 emissions caused by the higher use of mounting equipment compared to a GM-PV. Still, CO_2 emissions are expected to be far below those of goal or gas powered TPP. In order to mitigate possible damages to the soil of the plot, it is proposed to apply the innovative Spinanchor method as described in Section 3.2.3.

Regarding the social relations and stakeholder participation, no mayor outreaches have been conducted by Fraunhofer ISE. However, it seems strongly recommended to integrate the farmers in the design process as early as possible in order to ensure that potential technical synergies of solar power station and agriculture can by realised and are covered by the active community support. The success of the Horticulture PV system strongly depends on a well-planned, integrated and implemented collaboration of solar power station maintenance, solar module cleaning and cropping activities. In the authors view, such a degree of coordination is only possible when the farmer's community that decides to stay, fully and actively supports the project.

7.2.2 Operational Phase

The below overview summarises the scoping exercises conducted with checklists and scoping matrix.

Table 42 ESIA scoping for the operational phase.[116]

Aspect operational phase	Mayor impacts	Comparison to conv. PV or conv. agriculture	Further baseline studies required
Topography and drainage	Flat area, rather small impacts. Agricultural system may need irrigation canals. Potential impacts on rain harvest structure and potential Holiya implementation.	Expected similar regarding the solar power station, however larger influences on the water management system.	Geological assessment full water balance (spot and district).
Land consumption	Land use intensity increases. Dual land use.	More land is required to produce same amount of electricity.	Parameters are derived from other baseline studies.
Ground water	No ground water extractions are yet considered. Any ground water extractions must be coordinated with the water management of the Akola and nearby districts.	Expected to be similar.	Groundwater assessment.
Surface water	Water emissions and withdrawals to Balapur reservoir are likely.	Depends on water management and cleaning system designs.	Full water balance (project site and district).
Air emissions	Dusting during construction and diesel fumes by trucks and tractors.	Expected to be similar.	Soiling testing on modules.
Noise emissions	Less significant impacts to be expected	Expected to be similar.	Noise pollution assessment.
Soil condition & quality	Soil condition could improve. Horticulture PV system may decrease erosion and more organic cropping methods could decrease pressures on soil health.	Soils are preserved in a productive way.	Full laboratory soil testing and crop pattern assessment.
Micro climate for agriculture	Horticulture PV system provides shading which may lead to crop growth increase of decrease depending on crop. Shading also improves protection against heat waves and strong precipitation such as hail.	Overall improvement expected.	Mayor aspects covered by this report. However, more detailed desktop research is necessary.

116 Source: Fraunhofer ISE.

Aspect operational phase	Mayor impacts	Comparison to conv. PV or conv. agriculture	Further baseline studies required
Ecology & biodiversity: terrestrial	The Horticulture PV system requires interrow green stripes, that have shown a slight increase of biodiversity on the land (pilot facility Germany).	Overall improvement expected.	Eco-system impact assessment.
Ecology & biodiversity: aquatic	No significant impacts. Potential water emission to Balapur reservoir are filtrated and in case of filtration system failure, mayor pollutant would be dust only.	Expected to be similar.	Laboratory testing of water emissions and filtration system.
Landscape – visual impact	Steel constructions over large areas. Stakeholder consultations in Germany have indicated a potential aversion of the population against such large structures. However, cultural perception may be different at project site.	More significant.	Stakeholder participation process, full household survey.
Loss of land based livelihoods	Horticulture PV system strongly mitigated this impact.	Significant improvement expected.	Detailed employment and workforce plan.
Employment opportunity	Horticulture PV creates inherently more employment.	Significant improvement expected.	Detailed employment and workforce plan.
Occupational safety	Horticulture PV system is more prone to accidents due to the level of integration of different activities on-power-plant-site.	Additional measures must be taken to ensure minimal risk.	Comprehensive health & safety management plan.
Community health & safety	A risk is given during construction phase and in case community living houses are keep on-site.	Additional measures must be taken to ensure minimal risk.	Comprehensive health & safety assessment & management plan.
Waste generation	Besides agricultural wastes and wastes from power station maintenance no industrial or other wastes are given.	Expected similar.	Waste management plan.

7.2.3 Decommissioning & Dismantling

Currently there are no distinct experiences with dismantling a Horticulture PV system of this size. However, similar to construction, it is expected that further measures must be taken to mitigate environmental impacts by additional efforts to dismantle the ground mounting structure and protect the agricultural lands below.

Current research and experiences with pilot facilities indicate no long-term environmental effects after dismantling. The Horticulture PV system shall be designed to provide an optimal trade-off of solar energy production and agriculture at the same place of land. Hence, full recovery of soil quality after dismantling represents a basic requirement to the system design. Furthermore, the Horticulture PV system developer may investigate opportunities for a modular design. Such a design would allow a constant renewal of the power station. Lifetime could then, theoretically, be extended indefinitely.

In any case, a full Decommissioning Management Plan should be drafted and decided upon.

8 Benchmark Analysis

8.1 Objectives and Method

In this section, we compare the design and research results of the proposed Horticulture PV with experiences and results of the Fraunhofer ISE research pilot system at Lake Constance/Germany and other existing Horticulture PV systems in Europe and the world. Main objectives of this benchmarking analysis are verifying the results of this study and providing ideas on the overall expected performance of the proposed Horticulture PV system in comparison to other systems.

8.2 Technical Design

Installing non-tracked bifacial PV modules, the general approach of the proposed Horticulture PV design resembles to the Fraunhofer ISE research pilot system at Lake Constance/Germany. However, regarding strategies for a uniform light distribution, the Paras design combines the Fraunhofer ISE patent of deviating from a pure south orientation with the principle of the Japanese Solar Sharing approach using smaller PV module rows to increase homogeneity of light conditions on the ground. This allows for a lower deviation from the south and higher electrical yield.

Similarly, with 4 meters the vertical clearance of the Paras approach is closer to typical Solar Sharing designs than the German system at Lake Constance. While the lower vertical clearance limits the employment of large land machines, the distance between pillars is relatively small with a maximum machine width <7m compared to <19m in the Lake Constance design.

Table 43 Comparison Horticulture PV design at Paras and German pilot facility at Lake Constance.[117]

	Unit	Horticulture PV in Paras	Pilot facility in Heggelbach
PV module row width	[m]	1.85	3.40
Row distance	[m]	5.00	9.50
Vertical clearance	[m]	4.00	5.50
Distance between pillars (vertical to rows)	[m]	7.00	19.00
Distance between pillars (horizontal to rows)	[m]	5.00	12.40
Coverage rate	[%]	37.1	35.8

With respect to sheltering of PV modules, the coverage rate is slightly higher in the Paras design than at Lake Constance. Due to the high annual solar irradiation and the dry winter months in Maharashtra, benefits from additional sheltering are expected to be much larger than in Germany where less sunshine and more equal precipitation over the year is given.

Due to the continuing progress of PV technologies, the high efficiency of the considered PV modules together with the higher coverage rate allows for a much higher installed capacity of the Paras design than most existing Horticulture PV systems in Europe.

117 Source: Fraunhofer ISE.

8.3 Proof of Concept Examples Worldwide

This section gives an overview about the most innovative approaches and concepts that combine agriculture and electricity production. Table 45 provides an overview on some Horticulture PV approaches.

Table 45 Examples of Horticulture PV approaches worldwide.[118]

Germany, Hochschule Weihenstephan, 30 kWp, 2013

Italy, R.E.M. Tech Energy, 3 x APV systems since 2011
3,2 MWp, 1,3 MWp, 2,15 MWp Agrovoltaico

France, University of Montpellier, 50 kWp, 2010
2017 – 2019: 45 MWp Agrivoltaic-Tender-Process

Japan, Solar Sharing, Ministry of Agriculture, Forest and Fishery, Akira Nagashima
1.054 Solar Sharing 2013 - 2018, 80 kWp/Project, 85 MWp

Italy, Corditec, Ahlers, 800 kWp, 2012

Egypt, SEKEM, Almaden, Kairo, 90 kWp, 2017

USA, University of Arizona, approx. 50 kWp, 2017

Taiwan, Green Source Technology, 400 kWp, 2016

Beside Germany's Horticulture PV R&D activities there are mainly three important global players that shaped the recent developments of Horticulture PV technologies: As the first country promoting Horticulture PV systems on a larger scale, the Japanese Ministry of Agriculture and Fishery decided on a supporting scheme in 2013 to allow solar sharing for good agricultural land. This initiative was significantly pushed and shaped by the local Horticulture PV pioneer Akira Nagashima. Since then, more than 1000 Horticulture PV systems have been installed in Japan on rice and other crops. As foreseen in the supporting scheme, rather small-scale systems can be found with an installed capacity of less than 2MWp.

In Europe, France is the leading Horticulture PV marked having a promotion scheme in place since 2017. The scheme is organised in annual tenders with a volume of 15 MWp each and a maximal size eligible for receiving feed-in tariffs of

118 Source: Fraunhofer ISE.

3 MWp. A typical technology approach in France is followed by the French National Institute for Agricultural Research (INRA) in Montpellier that employs tracked PV modules to optimise the tilt angle for increasing both agricultural and electrical yields. Regarding crop selection, vineyards are in the focus of INRA research activities as benefits appear to be relatively high.

Since 2015 also China discovered benefits and opportunities of a dual land use for agriculture and PV power generation. Since then large areas have been covered not only to promote renewable energies but also to fight the ongoing desertification in some areas. Today, the largest share of Horticulture PV capacity can be found in China with estimated 1.7 GWp. Rice and berries are among the reported crops growing in the installed systems.

8.4 Agricultural Cultivation and Performance

Despite a higher installed capacity and module coverage rate and a respective lower relative PAR over the year, the absolute available PAR for cultivated crops is still almost 60% above the level at Lake Constance as to be seen in Table 46. This is because of the higher overall solar irradiation. Accordingly, considering the absolute PAR as a benchmark, at the Paras location even a low light transmission rate of 40% would still produce the same level of solar irradiation than the Lake Constance design does with a transmission rate of approximately 65%.

Surely, for some crops typically cultivated in the Akola region this level might be not sufficient to grow with acceptable yield. This comparison shows that in sunny areas a capacity close to GM-PV systems appears feasible if crop varieties from less sunny regions are chosen.

Table 44 Comparison of available PAR and LER at Horticulture PV and German pilot facility.[119]

	Unit	Location Paras/India	Location Heggelbach/Germany
Global Horizontal Irradiation (GHI)	[kWh/m²/a]	1,939	1,202
Transmission rate Horticulture PV system	[%]	62	65
Available PAR	[kWh/m²/a]	1,202	757
LER	[-]	1.95	1.73

Regarding the land use efficiency at the project site measured by the LER, the expected agricultural and electrical yield almost doubles (+94%) the overall productivity of land while the results of the first two years at Lake Constance indicated an average rise of 73%.[120] According to land use efficiency reported in the literature, the proposed Horticulture PV design for Paras is expected to perform better than most other reported results of dual land use systems.

8.5 Summary

Regarding strategies towards uniform light distribution, the proposed Horticulture PV design for Paras combines the Fraunhofer ISE patent of deviating from a pure south orientation with the principle of the Japanese Solar Sharing approach using smaller PV module rows to increase homogeneity of light conditions on the ground. This allows for a lower deviation from the south and higher electrical yield at lower cost on mounting equipment. With an expected rise of land use efficiency of about 94% the proposed design is expected to perform better than most other reported results of dual land use systems.

While the results of the benchmarking analysis suggest a relatively well performing and economic competitive system, though, it should be noted that the conditions with respect to project size, climate, region, farming practices, and business case differ to such an extent that in some regards a comparison may only be of limited informative value.

119 Source: Fraunhofer ISE.
120 The LER of the pilot facility at Lake Constance is likely to be overestimated due to the very dry and sunny summer 2018.

ANNEX

8.6 ESIA Scoping Checklist

8.6.1 Information on the Project

Information for scoping	Section in report	Remarks / further study required
Contact details of the developer		
Name of the company.	Maharashtra State Power Generation Company Limited (refered to as Mahagenco)	
Main postal address, telephone, fax and e-mail details for the company.	Prakashgad, D Block BKC, Naupada, Bandra East, Mumbai, Maharashtra 400051, India	
Name of the main contact person and direct postal address, telephone, fax and e-mail details.	tba	
Characteristics of the project		
Brief description of the proposed project.	See Section 1 Introduction	
Reasons for proposing the project.	See Section 1 Introduction	
A plan showing the boundary of the development including any land required temporarily during construction.	See Section 2.1 Geographical Location and Site Map	Detailed map of current or traditional crop pattern and previous plot ownerships is required. Map for land required temporarily is required.
The physical form of the development (layout, buildings, other structures, construction materials, etc).	See Section 3 Technical Design	Detailed Horticulture PV system layout and construction plan is required.
Description of the main processes including size, capacity, throughput, input and output.	See Section 3 Technical Design and 4 Agricultural Analysis and Concept	Detailed material balances and life cycle assessment is required.
Any new access arrangements or changes to existing road layout.	Has not been considered in this study. Potential requirements defined for cleaning and water management system.	Detailed traffic and road layout plan required. Integration into traffic and infrastructure strategy of Akola District required.
A work programme for construction, operation and commissioning phases, and restoration and after-use where appropriate.	Not considered in this study.	Detailed work programme required.
Construction methods.	See Section 3.2.3 Mounting Structure and Foundation. Innovative Spinanchor technique so preserve soil quality. See Section 3.3 Proposition of the Horticulture PV System Design construction plans for the German pilot facilities could support as orientation for further development.	Full assessment of necessary and optional construction methods for a Horticulture PV system required.
Resources used in construction and operation (materials, waster, energy, etc.)	Not considered in this study. Main impact expected through additional steel and larger construction equipment.	Assessment of resources to be utilised for construction. Subtask of material balances and life cycle assessment, required.
The relationship with other existing/ planned projects.	The soiling from nearby Paras TPP has been considered in Section 2.3.1. Considerations should also be taken given possible impacts during decommissioning of the coal power station end of the 2020s. Potential interrelations are also given regarding water management.	Detailed assessment required.

Information for scoping	Section in report	Remarks / further study required
Information about alternatives are being considered.	This report considers different system scenarios for the PV system, the cleaning system, the water management system and the agricultural system. The alternative of coal power station extension has not been considered in this study.	Further parameter and details shall be added to the sensitivity scenario analyses.
Information about mitigating measures which are being considered	The goal of the Horticulture PV design approach was to mitigate the negative effects by a potential conventional PV system. Minimal environmental impacts had been the orientation.	Assessing mitigation measures based on specific construction plans required.
Other activities which may be required as a consequence of the project (*e.g.* new roads, extraction of aggregate, provision of new water supply, generation or transmission of power, increased housing and sewage disposal).	Such activities have only partly been considered as possible connection points to more intensive study.	Detailed construction plan required to assess infrastructural requirements.
Details of any other permits required for the project.	Has not been considered in this study.	The developer has legal overview on such detail. Legal concept necessary to implement project is required.
Location of the project		
Maps and photographs showing the location of the project relative to surrounding physical, natural and man-made features	See Section 2.1 Geographical Location and Site Map and Section 1.3 Societal Background of the Proposed Horticulture PV Project	More and better pictures must be taken to cover all aspects of the project site.
Existing land-uses on and adjacent to the site and any future planned land uses	Land use was central point of consideration and can be found in most sections.	Detailed map of current or traditional
Zoning or land-use policies	Have partly been considered.	Comprehensive policy review required.
Protected areas or features	Has not been considered.	Assessment of protected areas required.
Sensitive areas	Has not been considered.	Assessment of sensitive areas required.
Details of any alternative locations which have been considered	Has not been considered.	Assessment of alternative locations required. Fraunhofer ISE currently works on GIS supported tools to identify potential land for Horticulture PV systems for Germany.
Characteristics of the potential impact		
A brief description of the likely impacts of the project considering the following factors:	See Section 4.2 Impacts of Horticulture PV on Agriculture	
Impacts on people, human health, fauna and flora, soils, land use, material assets, water quality and hydrology, air quality, climate, noise and vibration, the landscape and visual environment, historic and cultural heritage resources, and the interactions between them.	See Scoping Matrix and Environmental Impact Checklist. Main point of consideration in this study: Good conditions for agriculture and water consumption impacts as well as integration of solar power station and agricultural processes.	Detailed ecological assessment is required. Health & safety assessment and management plan is required. Comprehensive household survey and stakeholder participation process is required. Health Impact Assessment (HIA) required.
Nature of the impacts (*i.e.* direct, indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative).	Mitigating and reducing general environmental impacts, avoidance of long-term or permanent impacts were goal of the Horticulture PV system design approach.	Detailed material balance and life cycle assessment required.
Extent of the impact (geographical area, size of the affected population/habitat/ species).	Potentially, through extensive and inefficient water use, the ground water balance of the district will be affected.	Detailed water balance required. Water consumption to be coordinated with government agencies.
Magnitude and complexity of the impact.	Depends on decisions on crop pattern and cleaning system operations.	Detailed water balance required
Probability of the impact.	High, since water would need to be extracted and directly impacts ground water levels.	Detailed water balance required

Information for scoping	Section in report	Remarks / further study required
Duration, frequency and reversibility of the impact.	Groundwater resources in this region are generally under pressure. Precipitation becomes more and more unsteady. There is a risk of the region drying out in the long-term.	Detailed water balance required
Mitigation incorporated into the project design to reduce, avoid or offset significant adverse impacts.	See system design scenarios.	
Transfrontier nature of the impact.	Not considered in this study.	Assessment of and coordination with potentially impacted frontier federal states required with focus on Madhya Pradesh, Chhattisgarh and Telangana.

8.6.2 Checklist for Scoping Consultees

The checklist may be filled in for the results workshop.

Checklist of Consultees for Scoping

- Environmental Authorities
- regional and local authorities
- authorities responsible for pollution control including water, waste, soil, noise and air pollution
- authorities responsible for protection of nature, cultural heritage and the landscape
- health and safety authorities
- land use control, spatial planning and zoning authorities
- authorities in neighbouring countries where transfrontier impacts may be an issue

Other Interested Parties

- local, national and international environmental and social interest groups
- sectoral government departments responsible for agriculture, energy, forestry, fisheries, etc whose interests may be affected
- international and transfrontier agencies whose interests may be affected eg cross-border river basin commissions
- local employers' and business associations such as Chambers of Commerce, trade associations, etc
- employees' organisations such as trades unions
- groups representing users of the environment, eg farmers, fishermen, walkers, anglers, tourists, local wildlife groups
- research institutes, universities and other centres of expertise
- the general public

The General Public

- landowners and residents
- general members of the local and wider public
- elected representatives and community figures such as religious leaders or teachers;
- local community groups, residents' groups, etc;

8.6.3 Checklist of Potential Environmental and Social Impacts

=	No interaction of Project Activity with Resource or Receptor is reasonably expected.
=	Interactions reasonably possible with assessment still pending or the same impact than a conventional PV power station or conventional agriculture
=	Interactions reasonably possible with outcomes leading to a significant impact positive way compared to a conventional PV power station or conventional agriculture
=	Interactions reasonably possible with outcomes leading to a significant impact in a negative way compared to a conventional PV power station or conventional agriculture

Will construction, operation or decommissioning of the project involve actions which will cause physical changes in the locality (topography, land use, changes in waterbodies, etc.)?					
	Questions to be considered in scoping	**Yes/ No/?**	**Which characteristics of the project environment could be affected and how?**	**Is the effect likely to be significant? Why?**	**Assessments (conducted or required)**
1.1	Permanent or temporary change in land use, landcover or topography including increases in intensity of land use?	Yes	Dual land use: agriculture and solar energy generation.	Agricultural practises and solar power plant structure must be integrated.	Full land use assessment pending.
1.2	Clearance of existing land, vegetation and buildings?	Yes	Horticulture PV site preparations.	Plot must be restructured to allow integration.	Specific plant layout plan pending.
1.3	Creation of new land uses?	Yes	Party different crop pattern, installations of solar modules, building constructions.	Entire plot is affected.	Specific crop pattern proposal pending.
1.4	Pre-construction investigations e.g. boreholes, soil testing?	Yes	Crop pattern and Horticulture PV system installation.	Rock formations may hinder the ground mounting installations and well digging activities. Soil quality influences crop choices.	Soil quality for agriculture, geological assessments are pending.
1.5	Construction works?	Yes	Power station construction, several equipment housing places etc. water canals.	Soil preservation for agriculture, influence on micro water balance.	Impact assessment of construction works on plot soil quality pending. Fully micro and macro water balance is pending.
1.6	Demolition works?	Yes	Current structures on the plot.	Potential soil and water contamination. Housing and equipment storage of farmers.	Construction impact assessment pending.
1.7	Temporary sites used for construction works or housing of construction workers?	Yes	Not considered in this study.		
1.8	Above ground buildings, structures or earthworks including linear structures, cut and fill or excavations?	Yes	See Section 3.3 Proposition of the Horticulture PV System Design.		

1.9	Underground works including mining or tunnelling?	Potential	Possible underground water canals or electrical lines.	Not considered in this study.	
1.10	Reclamation works?	No			
1.11	Dredging?	Potential	Well digging.	Water balance and water storage. Geological stability.	Geological assessment pending.
1.12	Coastal structures e.g. seawalls, piers?	No			
1.13	Offshore structures?	No			
1.14	Production and manufacturing processes?	Potential	Potential agro-food light industry attached to the farm.		Business model for concept farm pending.
1.15	Facilities for storage of goods or materials?	Yes	Agricultural goods.		Business model for concept farm pending.
1.16	Facilities for treatment or disposal of solid wastes or liquid effluents?	Yes	Biological agricultural wastes and storage for fertilisers etc.	Depends on crop pattern and degree of organic farming methods among others.	Business model for concept farm pending.
1.17	Facilities for long term housing of operational workers?	Yes	Farmers community and cleaning system staff.	Partly addressed in 6 Social Assessment	Comprehensive household survey pending.
1.18	New road, rail or sea traffic during construction or operation?	Yes	Pathways through the plot.		Road and pathway grid concept pending.
1.19	New road, rail, air, waterborne or other transport infrastructure including new or altered routes and stations, ports, airports etc.?	Potential	New road for installation equipment.		Road grid concept pending.
1.20	Closure or diversion of existing transport routes or infrastructure leading to changes in traffic movements?	Potential	Depends on the degree of which the Horticulture PV system is open to “external” vehicles.		Security and H&S concept of Horticulture PV system pending.
1.21	New or diverted transmission lines or pipelines?	Yes	Mayor changes due to transmission lines and water management.	See sections on PV system and water management.	Specific power station layout pending.
1.22	Impoundment, damming, culverting, realignment or other changes to the hydrology of watercourses or aquifers?	Yes	Changes according to design of water management system.	See sections for water management, cleaning system and irrigation.	Specific power station layout pending. Detailed water balance pending.
1.23	Stream crossings?	Potential	Depends on natural drainage system.		Assessment of natural drainage system.
1.24	Abstraction or transfers of water from ground or surface waters?	Potential	Ground water extraction or water withdrawals from Balapur dam are likely.	Depends on water management, irrigation and other consumption parameters.	Detailed water balance pending.
1.25	Changes in waterbodies or the land surface affecting drainage or run-off?	Potential	Potential irrigation canals, wells or water storage sheds.	Depends on water management approach.	Specific water management design pending.

1.26	Transport of personnel or materials for construction, operation or decommissioning?	Yes	Transport issues have not yet been assessed.	Depends on power station construction plan.	Assessment on power station construction impacts & logistics pending.
1.27	Long term dismantling or decommissioning or restoration works?	Potential	Possible deconstruction works of the Paras Thermal Power Station during mid to end of 2020's should be considered in Horticulture PV system design.	Not yet considered in study.	Prepare scoping of this issue.
1.28	Ongoing activity during decommissioning which could have an impact on the environment?	Potential	No current research on dismantling or replacing Horticulture PV systems. Impacts on agriculture are immanent.		Prepared LCA of Horticulture PV system and conceptualise potential dismantling / replacing, decommissioning strategies.
1.29	Influx of people to an area in either temporarily or permanently?	No	No mayor population shift is expected. Decrease of population rather expected.		Determine overall employment generation of project site.
1.30	Introduction of alien species?	No	Only crops and plants that are locally known are considered in this study.		
1.31	Loss of native species or genetic diversity?	No	Slight increases of biodiversity can be expected.	Depends on crop pattern and vegetation between plots and rows.	Specific biodiversity impact assessment pending.
1.32	Any other actions?				

Till construction or operation of the Project use natural resources such as land, water, materials or energy, especially any resources which are non-renewable or in short supply?					
2.1	Land especially undeveloped or agricultural land?	Yes	Currently not under cultivation due to land use conflict and economic uncertainties for the farmer's community.	No agricultural activities.	
2.2	Water?	Yes	Seasonal precipitation with partly no groundwater availability during dry season.	Refer to water management and irrigation section of the report.	Detailed assessment of water balance pending.
2.3	Minerals?	Potential			Geological assessment pending.
2.4	Aggregates?	No			
2.5	Forests and timber?	No			
2.6	Energy including electricity and fuels?	Yes	Solar energy to be harvested with Horticulture PV system.	See irradiation and electrical yield assessment section.	Detailed energy payback time calculation of proposed Horticulture PV system pending.
2.7	Any other resources?	Yes	The fertile soil of the spot shall be preserved. Land is still available as agricultural resource.	See 3.2.3 Mounting Structure and Foundation	Local assessment of Horticulture PV system site preparation and installation on soil quality pending.

Will the Project involve use, storage, transport, handling or production of substances or materials which could be harmful to human health or the environment or raise concerns about actual or perceived risks to human health?					
3.1	Will the project involve use of substances or materials which are hazardous or toxic to human health or the environment (flora, fauna, water supplies)?	Yes	Electrical components and equipment.	See section on Horticulture PV system design.	Detailed Bill-of-Materials (BoM) pending.
3.2	Will the project result in changes in occurrence of disease or affect disease vectors (e.g. insect or water borne diseases)?	Potential	New crop pattern could bring occurrences of local crop diseases.		Crop pattern disease vulnerability assessment pending
3.3	Will the project affect the welfare of people e.g. by changing living conditions?	Yes	See 6 Social Assessment		Employment impact assessment pending.
3.4	Are there especially vulnerable groups of people who could be affected by the project e.g. hospital patients, the elderly?	Yes	Families of the affected farmers.		Detailed household survey of farmer's community pending.
3.5	Any other causes?	Yes	Health & Safety on site		Health & Safety concept pending
Will the Project produce solid wastes during construction or operation or decommissioning?					
4.1	Spoil, overburden or mine wastes?	No			
4.2	Municipal waste (household and or commercial wastes)?	Yes	Several wastes from facility and equipment maintenance as well as agricultural wastes.		Waste generation assessment pending.
4.3	Hazardous or toxic wastes (including radioactive wastes)?	Yes	Electrical components and equipment.		Dismantling concept pending.
4.4	Other industrial process wastes?	Potential			
4.5	Surplus product?	Potential			
4.6	Sewage sludge or other sludges from effluent treatment?	Potential	Dust filtered by the water management system.	See section on the soiling effect.	Design of the filtration component of the water management system pending.
4.7	Construction or demolition wastes?	Yes	Demolition wastes of buildings.		Horticulture PV system construction plan pending.
Will the Project release pollutants or any hazardous, toxic or noxious substances to air?					
5.1	Emissions from combustion of fossil fuels from stationary or mobile sources?	Yes	Diesel emissions to air from tractors, land machinery or water pumps.		Detailed life cycle energy assessment of entire Horticulture PV system pending.
5.2	Emissions from production processes?	Potential	In case of agro-food light industry attached to concept farm.	Generally expected to be low.	Detailed farm concept pending.
5.3	Emissions from materials handling including storage or transport?	Yes	Transport trucks etc.	Generally expected to be low.	Horticulture PV system construction plan pending.
5.4	Emissions from construction activities including power station and equipment?	Yes	Machinery, trucks etc. Dust emissions when works are conducted during dry periods.	Generally expected to be standard. Impacts on soil quality must be assessed.	Horticulture PV system construction plan pending.

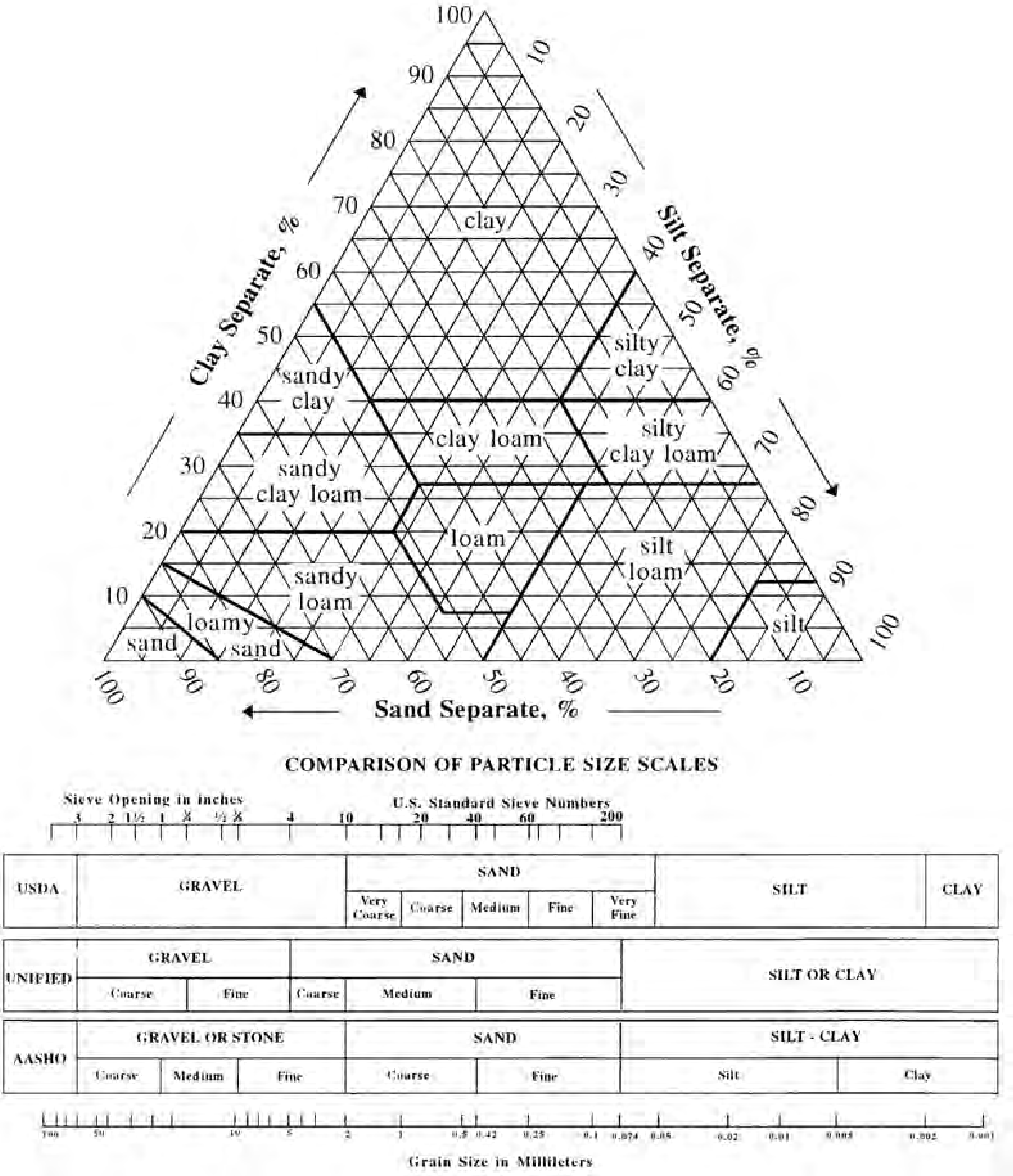
5.5	Dust or odours from handling of materials including construction materials, sewage and waste?	Yes	Dust emissions during construction and agricultural activities.	Impacts on soil quality and soiling of down sides of bifacial modules.	Detailed laboratory soil & soiling testing pending.
5.6	Emissions from incineration of waste?	No			
5.7	Emissions from burning of waste in open air (e.g. slash material, construction debris)?	Potential	Burning of agricultural wastes against best practice.		Farm policy on agricultural waste treatment pending
5.8	Emissions from any other sources?	No			
Will the Project cause noise and vibration or release of light, heat energy or electromagnetic radiation?					
6.1	From operation of equipment e.g. engines, ventilation power station, crushers?	Yes	Transformers, inverters and electrical equipment.	Not covered in this report. Impacts however, likely.	Noise assessment pending.
6.2	From industrial or similar processes?	Yes	Transformers, inverters and electrical equipment.	Not covered in this report. Impacts however, likely.	Noise assessment pending.
6.3	From construction or demolition?	Yes	Transformers, inverters and electrical equipment.	Not covered in this report. Impacts however, likely.	Noise assessment pending.
6.4	From blasting or piling?	No			
6.5	From construction or operational traffic?	Yes	Transformers, inverters and electrical equipment.	Not covered in this report. Impacts however, likely.	Noise assessment pending.
6.6	From lighting or cooling systems?	Potential	Not considered in this study		
6.7	From sources of electromagnetic radiation (consider effects on nearby sensitive equipment as well as people)?	No			
6.8	From any other sources?	No			
Will the Project lead to risks of contamination of land or water from releases of pollutants onto the ground or into sewers, surface waters, groundwater, coastal waters or the sea?					
7.1	From handling, storage, use or spillage of hazardous or toxic materials?	Potential	Electrical components		
7.2	From discharge of sewage or other effluents (whether treated or untreated) to water or the land?	Yes	Discharge of filtrated rain water harvest.		Determine parameters for filtration system design.
7.3	By deposition of pollutants emitted to air, onto the land or into water?	No			
7.4	From any other sources?	No			
7.5	Is there a risk of long-term build-up of pollutants in the environment from these sources?	No			

Will there be any risk of accidents during construction or operation of the Project which could affect human health or the environment?					
8.1	From explosions, spillages, fires etc. from storage, handling, use or production of hazardous or toxic substances?	Yes	Electrical overloads and shocks.		Health & Safety concept pending
8.2	From events beyond the limits of normal environmental protection e.g. failure of pollution control systems?	Yes	heat related failures, water filtration system failures.		Comprehensive risk assessment pending.
8.3	From any other causes?	Potential	Interference of cleaning system, Horticulture PV mounting structure and agricultural activities must be avoided by power station design.	See 3.2.3 Mounting Structure and Foundation.	Detailed power station layout pending.
8.4	Could the project be affected by natural disasters causing environmental damage (e.g. floods, earthquakes, landslip, etc.)?	Yes	Hailstorms. Horticulture PV system mounting structure protects crops.	See 2.5 Environmental Risk Assessment.	Disaster risk and security plan pending.
Will the Project result in social changes, for example, in demography, traditional lifestyles, employment?					
9.1	Changes in population size, age, structure, social groups *etc*?	Yes	Project decision will determine further land use and employment for over 100 marginal farmer households.	See 6 Social Assessment.	Detailed household survey and participation process must be conducted.
9.2	By resettlement of people or demolition of homes or communities or community facilities e.g. schools, hospitals, social facilities?	Potential	Current situation of housing issue and farmers still living onsite are not known. However, land was already acquired by Mahagenco years ago.		
9.3	Through in-migration of new residents or creation of new communities?	Potential	Depends on the housing and community plan for the farmers that stay and the staff for cleaning system maintenance.		Detailed employment plan pending
9.4	By placing increased demands on local facilities or services e.g. housing, education, health?	Potential	It is recommendable to improve overall health and educational facilities in the surrounding villages.		Corporate Social Responsibility (CSR) concept pending.
9.5	By creating jobs during construction or operation or causing the loss of jobs with effects on unemployment and the economy?	Yes	Conservative estimations by the authors expects not more than 60 - 70 full time equivalent (FTE) positions to be created. However, Horticulture PV will increase employment in any case, compared to a conventional PV facility.	It must be part of the participation process to elaborate which farmers would like to stay and be open to new labour activities.	Detailed employment plan pending.
9.6	Any other causes?	Potential			
Question - Are there any other factors which should be considered such as consequential development which could lead to environmental effects or the potential for cumulative impacts with other existing or planned activities in the locality?					
10.1	Will the project lead to pressure for consequential development which could have significant impact on the environment e.g. more housing, new roads, new supporting industries or utilities, etc?	Yes	However, similar alternatives like conventional PV or coal power stations seem to induce higher impacts.		Construction plan pending.

10.2	Will the project lead to development of supporting facilities, ancillary development or development stimulated by the project which could have impact on the environment e.g.: • supporting infrastructure (roads, power supply, waste or waste water treatment, etc) • housing development • extractive industries • supply industries other?	Yes	Water filtration and irrigation systems, potential improvements of roads and pathway grid, potential improvements in agricultural yield storage, machinery equipment and transport as well as possible attachment of agro-food light industries. Development of agricultural and allied sectors towards higher mechanisation degree possible. Furthermore, potentials for training and educational centres for farming communities given.	Depending on the scale of financial support being provided to a potential agricultural cooperative and the service rates for cleaning and maintenance.	Assess potentials of additional support via KfW supplement programmes to foster sustainable and organic agriculture as well as opportunities provided by other banks such as NABARD.
10.3	Will the project lead to after-use of the site which could have an impact on the environment?	No	Without having a detailed dismantling concept yet, it is expected that the Horticulture PV system can be deinstalled without any long term environmental aftermath impact.		
10.4	Will the project set a precedent for later developments?	Yes	The proposed Horticulture PV system has not yet been built on such a power station scale. The experiences that will be made and the data that will be collected may provide the empirical foundation for effective and large scale Horticulture PV systems application potentially for whole India.		
10.5	Will the project have cumulative effects due to proximity to other existing or planned projects with similar effects?	Yes	The Horticulture PV systems water consumption and possible irrigation schedules must be integrated in the water balance planning of the respective district.	CO_2 savings tending to be lower as conventional PV.	

Soil Information

Figure 37 Soil classification scheme

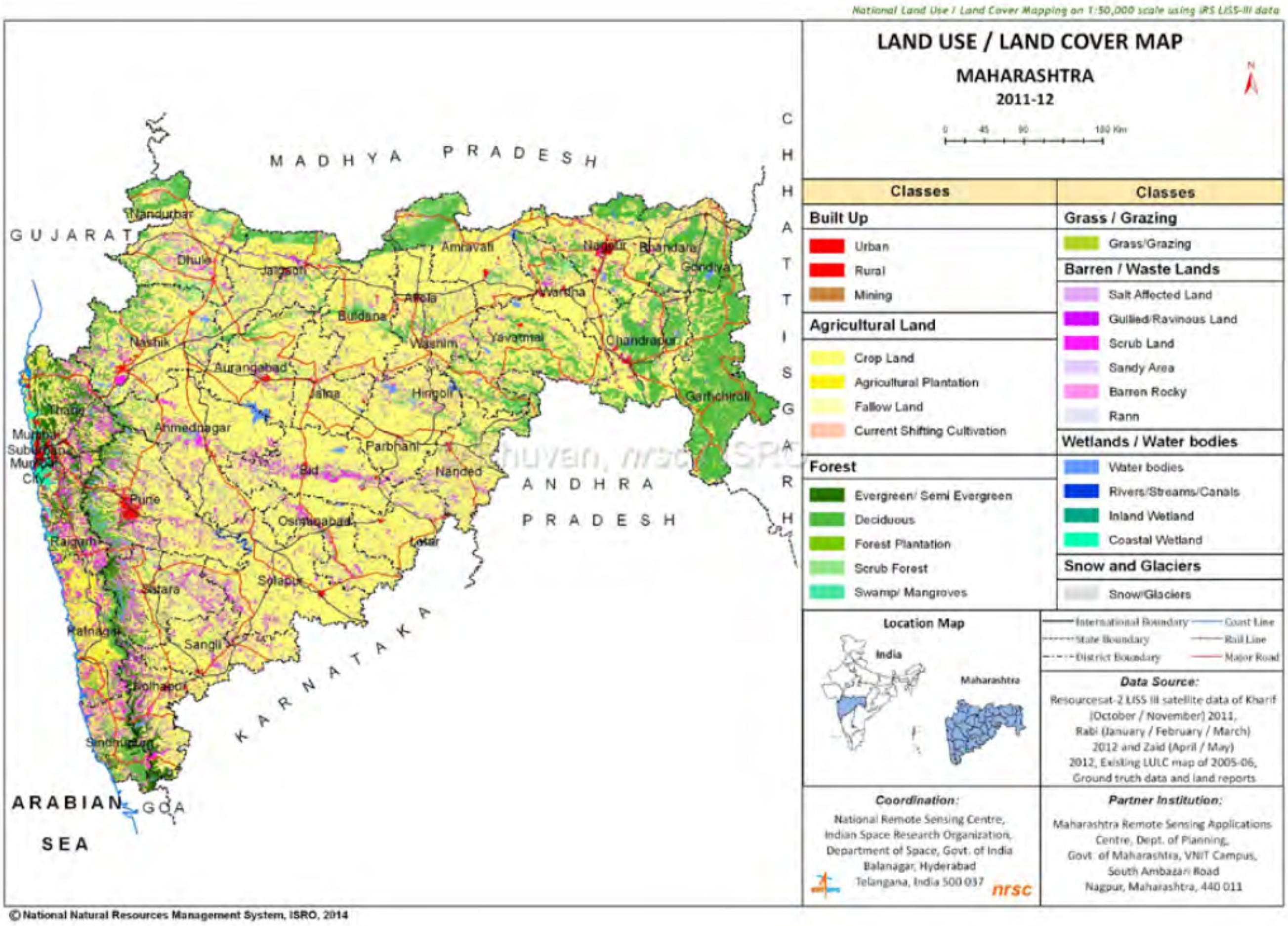


The yellow frame highlights the soil to be found at the project site.

Land Use at Project Site

The Indian Renewable Energy Development Agency (IREDA) provides the following land use map for Maharashtra.

Figure 38 Land use map of Maharashtra.[121]



The Akola district shows comparatively large volumes of agricultural land, especially in the north and the south of the project site there are plenty of agricultural lands.

121 Source: IREDA 2014.

Figure 39 Land use by district, Maharashtra.[122]

District and category wise distribution of Land Use / Land Cover in Maharashtra (2011-12)

(Area in sq. km.)

L 1	L 2	Ahmednagar	Akola	Amravati	Aurangabad	Bhandara	Bid	Buldana	Chandrapur
Agriculture	Crop land	13140.39	4452.03	6984.39	7285.22	2235.23	7725.16	7784.04	5389.23
	Current Shifting cultivation								
	Fallow	320.76	145.73	861.79	916.51	119.60	1105.29	70.33	48.83
	Plantation	9.51	4.24	281.06	8.09	8.91	15.35	0.16	0.63
Barren/unculturable/ Wastelands	Barren Rocky	253.30		0.58	17.28	2.15	2.05		2.65
	Gullied / Ravinous Land	7.44	53.70	56.20	0.34	0.07	0.44	35.91	1.42
	Rann								
	Salt Affected Land								
	Sandy Area								
	Scrub Land	1460.76	154.14	249.80	458.13	191.51	1184.78	368.41	377.88
Builtup	Mining	10.56	6.00	6.51	5.67	5.79	4.41	6.30	52.52
	Rural	113.46	58.52	78.18	92.80	61.24	94.06	84.48	69.23
	Urban	104.93	54.26	85.84	120.54	31.81	76.35	51.68	151.49
Forest	Deciduous	398.50	335.85	2496.32	587.45	1011.37	76.32	682.22	3425.49
	Evergreen/Semi evergreen	28.33	0.00	0.35	0.00	0.00	0.00	0.00	0.00
	Forest Plantation			2.17		40.27			130.64
	Scrub Forest	590.00	57.27	843.59	319.24	39.40	139.37	395.20	457.05
	Swamp / Mangroves								
Grass / Grazing	Grass / Grazing					1.53			
Snow and Glacier	Snow and Glacier								
Wet lands / Water bodies	Coastal Wetland								
	Inland Wetland					0.39			
	River/Stream/Canals	209.09	81.60	116.04	71.01	103.10	92.47	51.66	166.23
	Water bodies	400.97	52.66	149.17	330.71	98.61	243.96	130.61	216.71

(Above statistics are provisional)

Environmental Risk Assessment for the Paras Project Site

The aim of this task is to estimate the risk level from natural hazards at the site of Paras in Maharashtra, India. The source data was obtained from the Global Risk Data Platform[123] and from web-based tool "*ThinkHazards!*" with detailed regional data developed by Global Facility for Disaster Reduction and Recovery (GFDRR). Obtained data were analysed and visualised in QGIS computing program. For better visualisation a 100 km buffer line was created around the test site Paras, called "Paras area" for the risk assessment analysis.

Assessed natural hazards include river flood, wildfire, extreme heat, earthquake, drought, cyclone, coastal flood, and landslide within the project area. This information is valuable for the project planning and design.

Extreme Heat

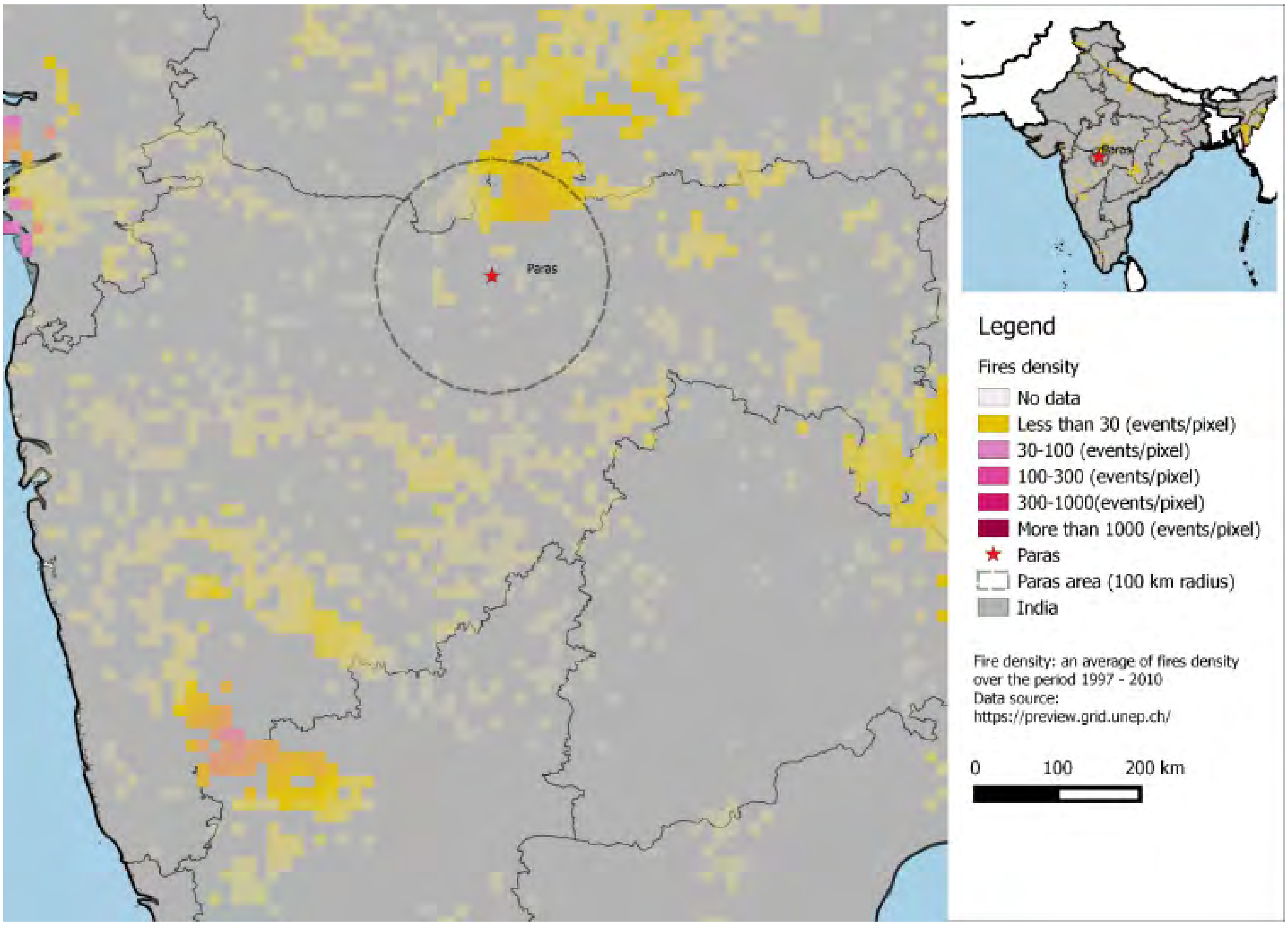
Unfortunately, there were no spatial data available at Global Risk Data Platform regarding extreme heat risk for the Paras area. However, according the "*ThinkHazards!*"[124] the risk of extreme heat was classified as **high**. The prolonged exposure to extreme heat is expected to occur at least once in the next five years and must be taken into account in the project planning decisions, project design and construction methods.

122 Source: IREDA 2013.
123 https://preview.grid.unep.ch/index.php?preview=data&lang=eng
124 http://thinkhazard.org/en/report/115-india/

Wildfire

In the Paras area the wildfire hazard is classified as **high** according the report from *ThinkHazards!.* Thus the chance of encountering weather that could support a significant wildfire resulting in both life and property loss in any given year is greater than 50%. Also the fire density which summarises the numbers of fires that occurred per year in the time period 1999 and 2007 was about 30 events per pixel in significant parts of the Paras area. Therefore the impact of wildfire must be considered in all phases of the Agrophotovoltaics project at Paras, in particular during design and construction.

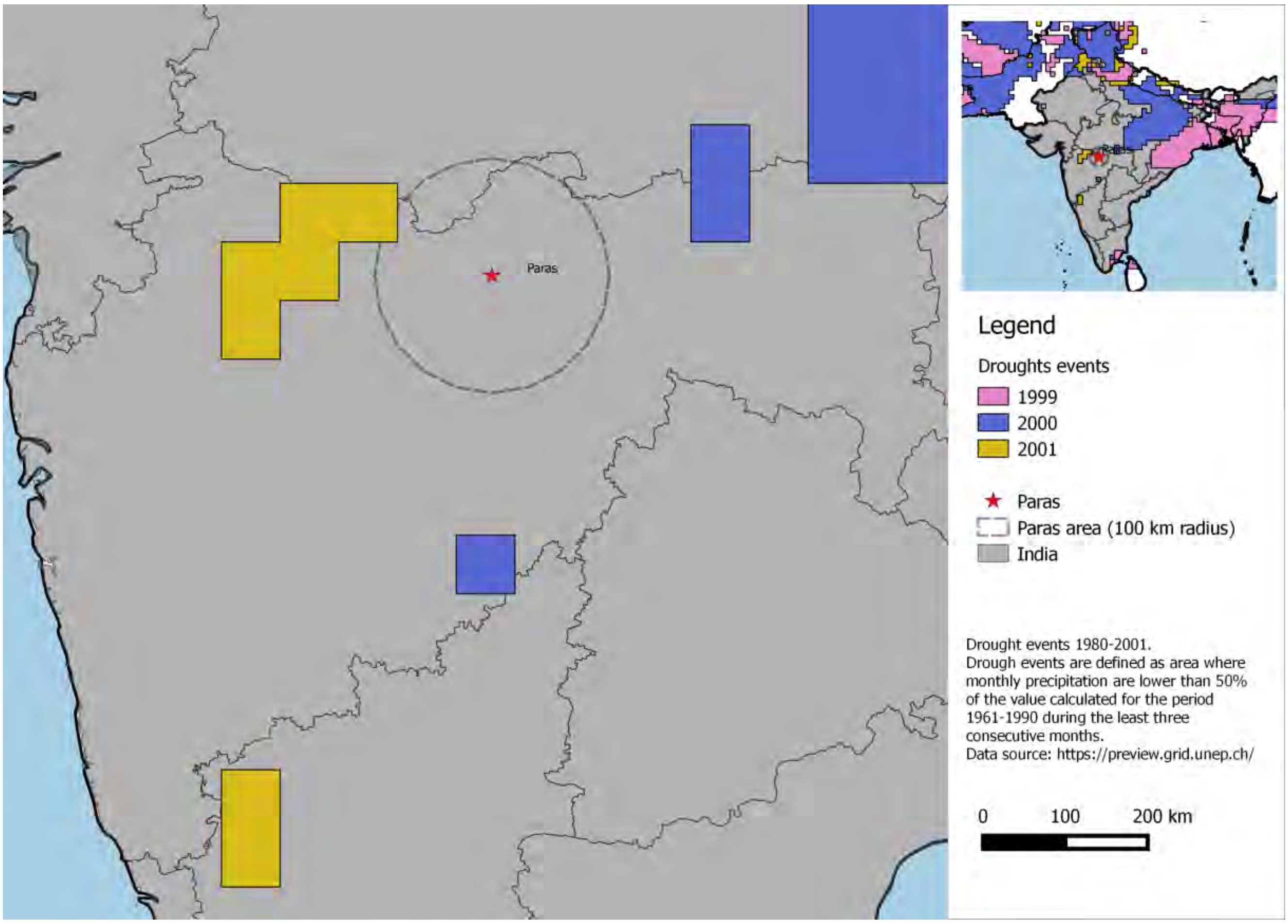
Figure 40: Map of fires density in Maharashtra region.



Droughts Events and Water Scarcity

According our data analysis the Paras area wasn't directly affected by drought events, but in Maharashtra region there were severe drought events in the time periods between 1980 and 2001. Also the *"ThinkHazard!"* platform classified the water scarcity hazard (directly influenced by droughts) for the project area as **medium**. Medium hazard level means 20% chance droughts of occurrence in the coming 10 years. Based on this information, the impact of drought must be considered in all phases of the Horticulture PV project in Paras.

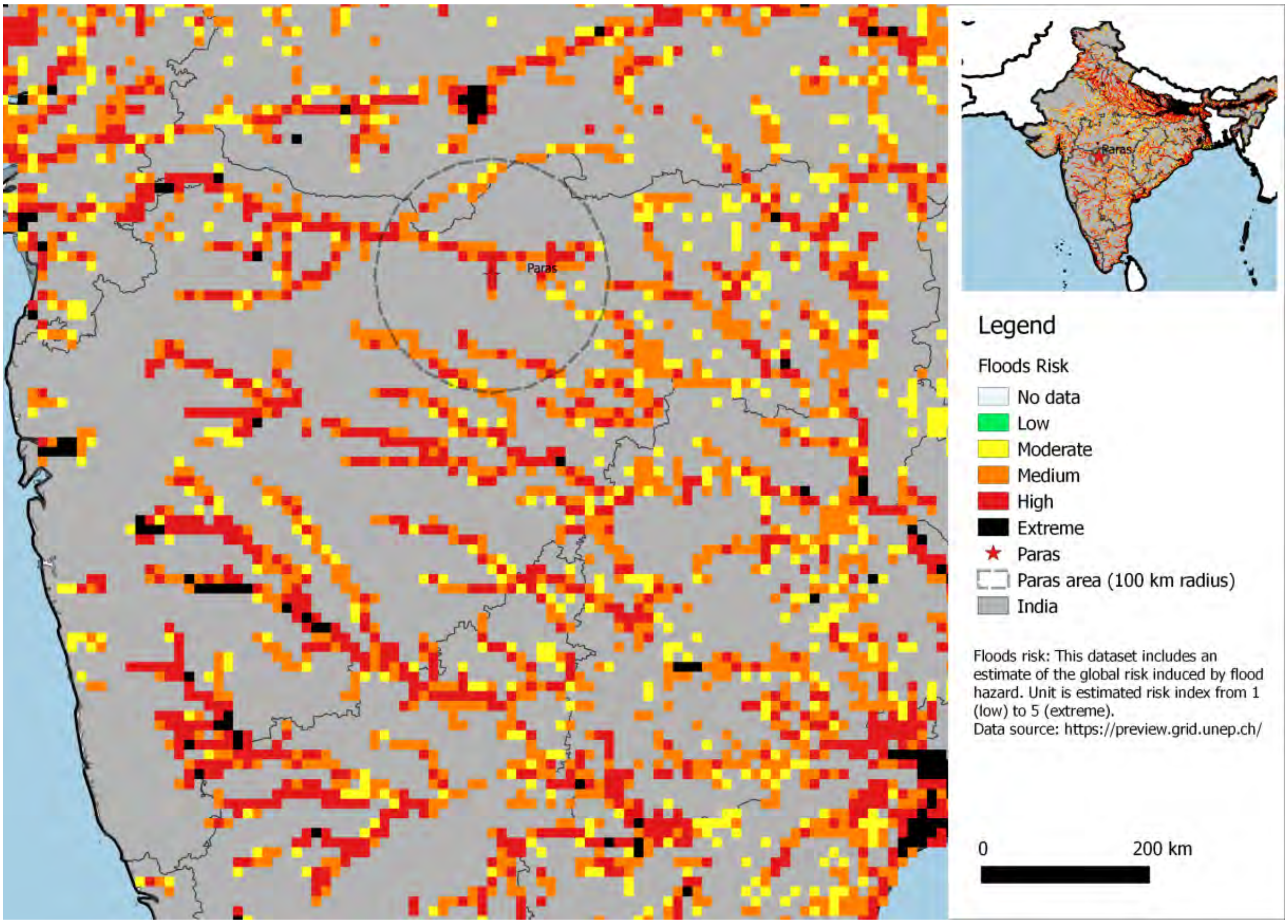
Figure 41: Map of droughts events in Maharashtra region.



Floods Risk

The below figure shows the floods risks of the main rivers in the Maharashtra region with focus on Paras area. The different colours are representing the risk level of floods. Compared to the global flooding level, the risk of flooding is moderate to high in the Paras area. According to *"ThinkHazard!"* the level of river and urban flood are both **medium** for Paras area and should therefore be considered in the project planning decisions, project design and construction methods.

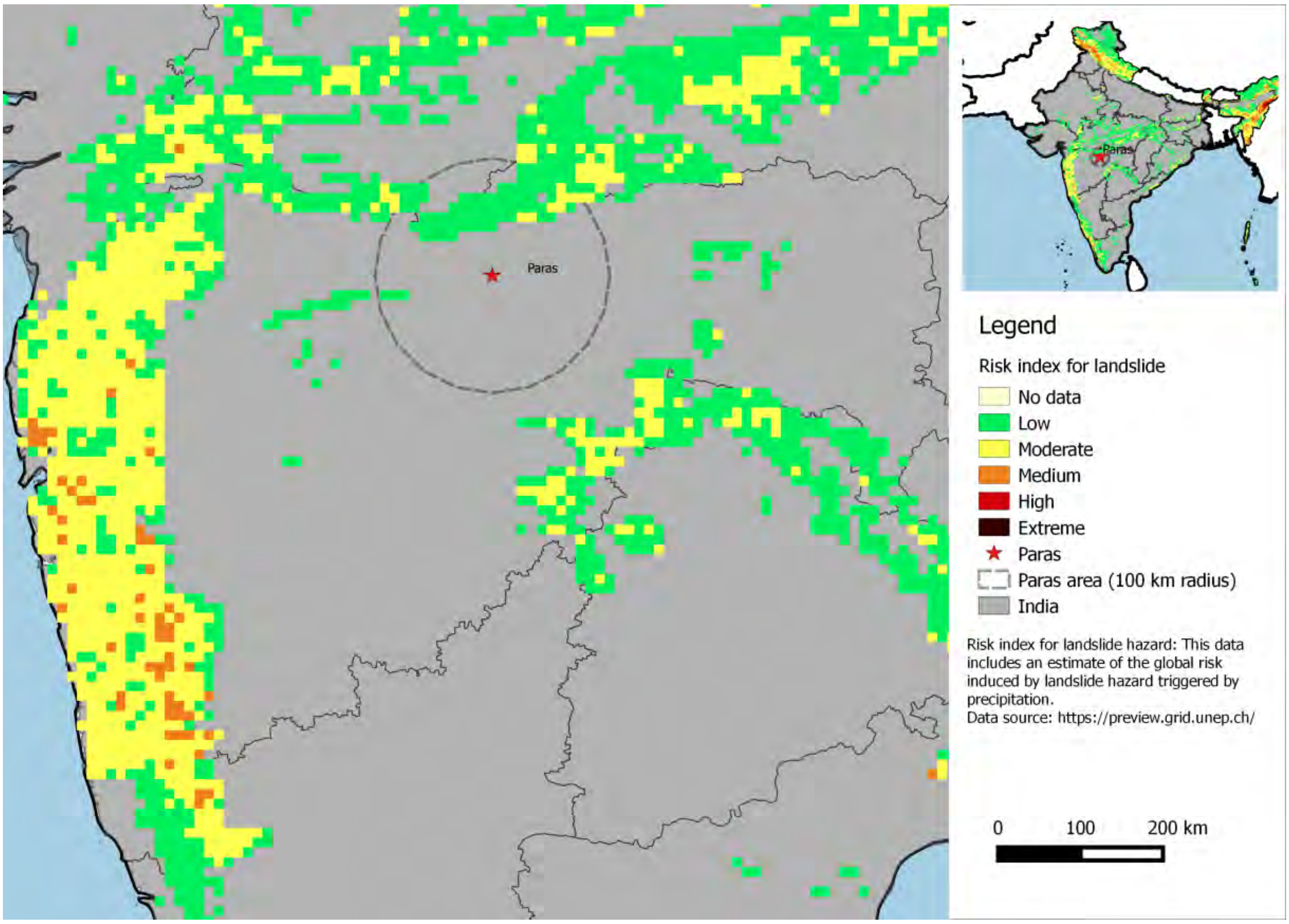
Figure 42: Map of floods risk in Maharashtra region.



Landslide

Landslide susceptibility has high level of hazard in India. This means that India has rainfall patterns, terrain slope, geology, soil, land cover and (potentially) earthquakes that make localised landslides a frequent hazard phenomenon. However in the Paras region the risk for landslide was classified with **low** or **moderate** index. It is difficult to determine future locations and timing of large rock avalanches and therefore it is questionable, if the potential of landslide should be better considered in the project planning decisions.

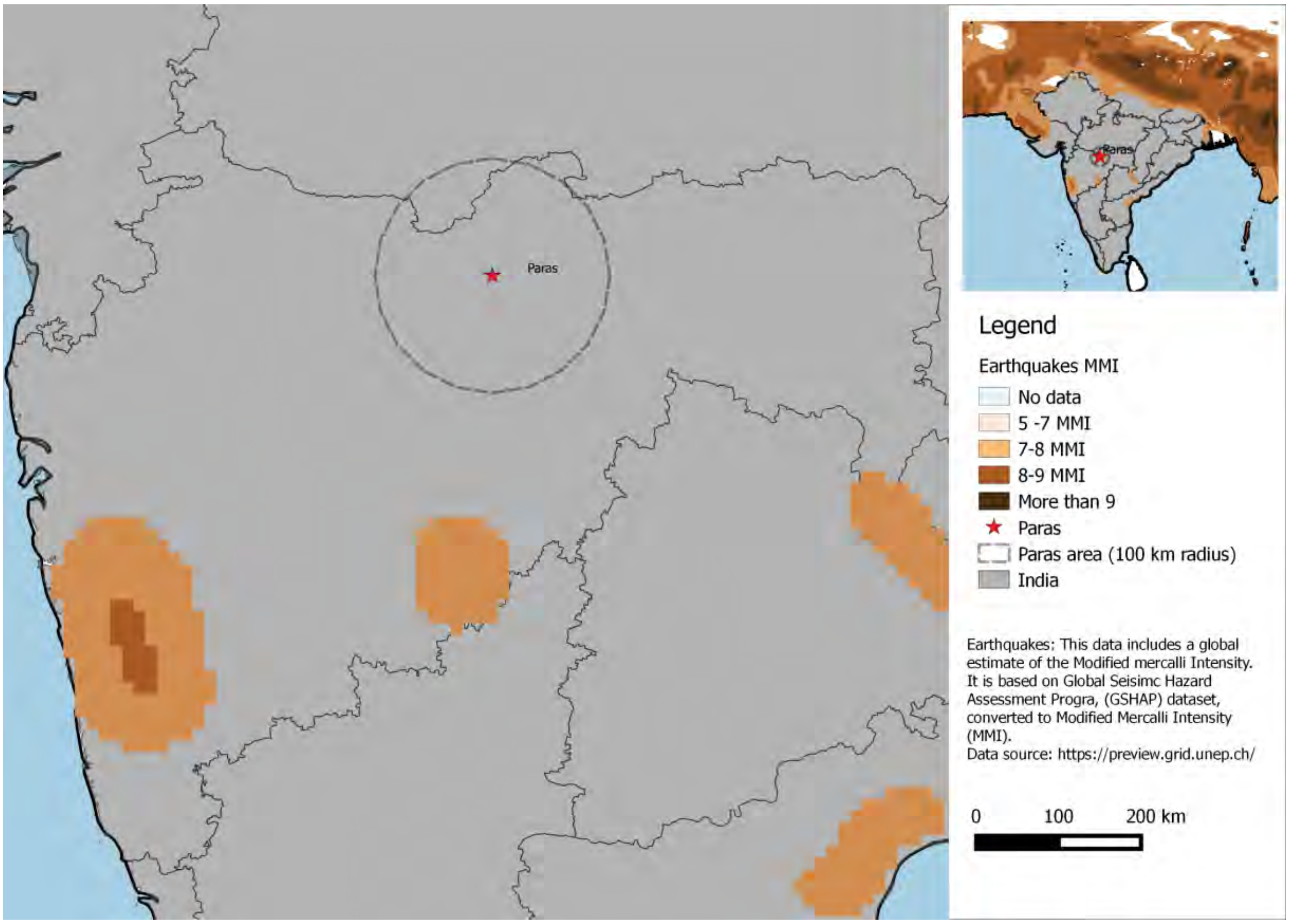
Figure 43: Map of landslides risk in Maharashtra region.



Earthquakes

The earthquake impact is measured in Modified Mercalli Intensity (MMI). The MMI levels range from 1 to 12 (lowest to highest). The Maharashtra region mostly shows values from 7-8 (strong to very strong shaking, felt by all, damage to buildings and other structures) and small parts are the class 8-9 (very strong to severe, even heavy furniture overturned). The Paras area is not affected, however. According to *"ThinkHazard!"*, the project area has **medium** risk level of earthquake and the chance of potentially-damaging earthquake shaking in the area in the next 50 years is about 10%.

Figure 44 Map of earthquakes events in Maharashtra region.



Low Natural Hazards

Coastal flood and cyclone risk are both classified as **very low** risk according the information from *ThinkHazard!* Platform and therefore there is no need to be considered in the project.

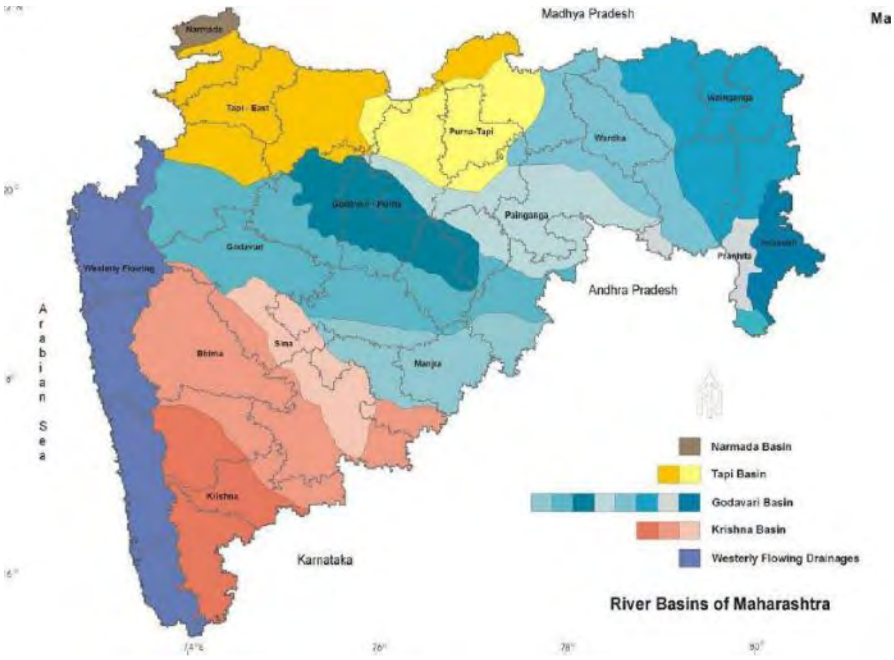
Further Water Related Considerations

Most information are extracts from the “Report On The Dynamic Ground Water Resources Of Maharashtra (2008-2009)” (CGWB 2011) and their successor reports from later years (CGWB 2017).

Other baseline information ca be found in the “Ground Water Information Akola District, Maharashtra“ report. (Ministry of Water Resources 2013).

River Basins

Figure 45 River basins of Maharashtra source[125]



Paras village in Balapur block falls under the alluvial plain of Tapi Purna river valley or Tapi river basin. The information present here is for Balapur block, as that is the unit for analysis for groundwater state department.

Rain Distribution

125 Source: CGWB 2017

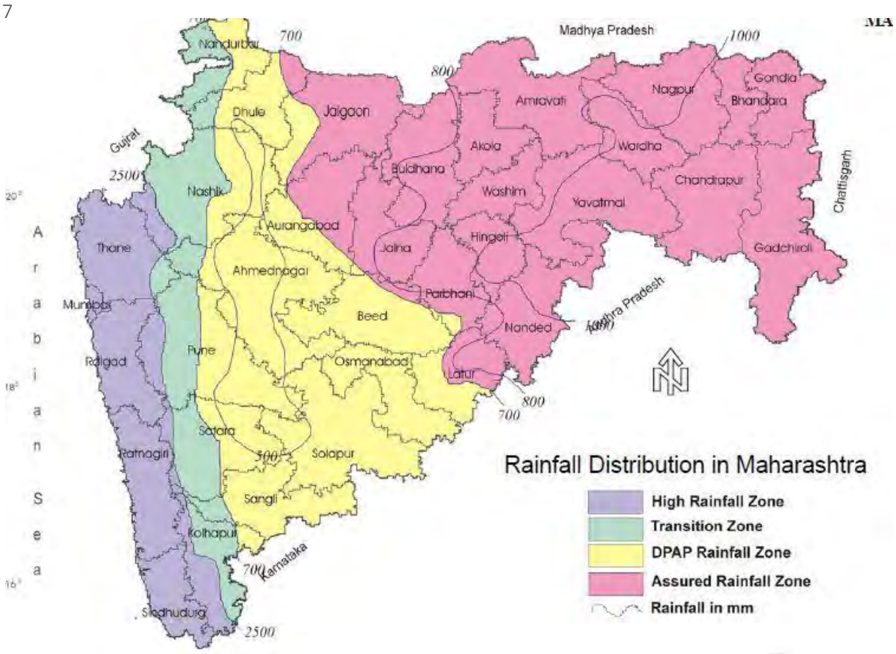
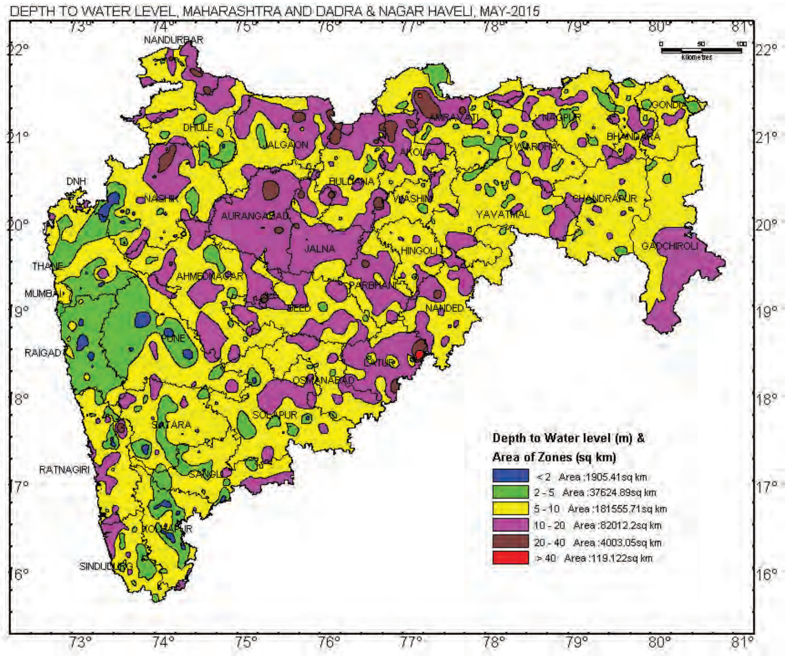


Figure 46 Rainfall distribution in Maharashtra.

During the water year (2015-16), the groundwater observation wells monitored by central groundwater board (CGWB) were monitored four times, i.e. May 2015, August 2015, November 2015, and January 2016. At all the four instances the deepest water levels (of the order of 20 meters below ground level (MBGL)) were found in wells in Tapi and Purna alluvium basin. Balapur falls under this region. Information was not available for the number of wells in Balapur region showing decline in groundwater depth. Figure below shows the depth of groundwater as on May 2015 across Maharashtra.

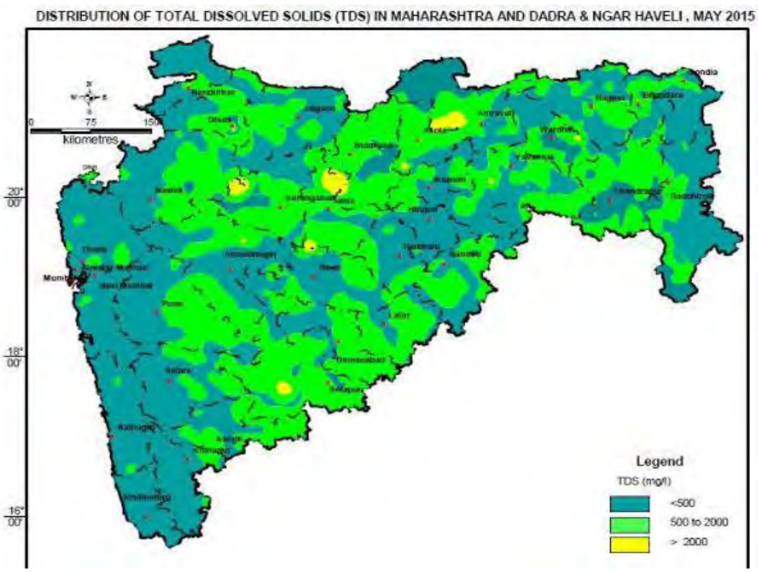
Groundwater Impact & Quality

Figure 47 Depth of water level, May 2015.[126]



The TDS found in the groundwater around Balapur region is close to 500mg/l. The other regions have higher TDS and therefore the hardness of groundwater is more in other regions (CGWB 2017).[127]

Figure 48 Distribution of total dissolved solids (TDS) in Maharashtra.[128]



126 Source: CGWB 2017.
127 http://cgwb.gov.in/Regions/GW-year-Books/GWYB-2015-16/GWYB CR 2015-16.pdf
128 Ibid.

Drainage & Mounting Structure

For rainwater harvesting, the recommended slope of the PV module row is 7/5,000 mm to 15/5,000mm (according to standards in greenhouse buildings where rainwater has to be drained over large distances). Regarding the assumed maximum row length of the proposed system of 150 meters, the vertical difference between the ends of the row ranges between 0.21m and 0.45m.

Table 45 Calculation of water flows for drainage..[129]

Water Management at Rows

Trapeze - Hail Volume, Full Panel

	Unit	Value
Width (above), bo	[m]	0.13
Width (below, left), bu	[m]	0.25
Height, h	[m]	0.70
Width (below, right), x	[m]	1.50
Row length	[m]	130.00
Cross section	[m²]	0.13
	[dm²]	
Wetted perimeter	[m]	3.23
Speed	[m per sec]	2.10
Water outflow	[Litre per sec]	279.00
	[m³ per min]	16.74
Acceptable hail volume per row	[m³]	16.9
Max. precipitation	[m³ per ha]	3,935
20% at one day	[m³ per ha]	787
40% at one hour	[m³ per ha]	315
	[m³ per m²]	0.03
Per row	[m²]	227.50
Total hail volume per row	[m³]	7.16

Trapeze - Rain Outflow, Drainage

	Unit	Value
Width (above), bo	[m]	0.25
Width (below, left), bu	[m]	0.13
Height, h	[m]	0.18
Width (below, right), x	[m]	0.03
Row length	[m]	130.00
Cross section	[m²]	0.03
	[dm²]	3.38
Benetzter Umfang	[m]	0.51
Speed	[m per sec]	2.90
	[Litre per sec]	99.30
Water outflow	[m³ per Min]	5.96
Max. precipitation	[m³ per ha]	3,935
30% at one day	[m³ per ha]	1,181

129 Source: Fraunhofer ISE.

50% at one hour	[m^3 per ha]	590
	[m^3 per m^2]	0.06
at one minute multiplied with factor 5 storm condition	[m^3 per m^2]	0.005
Per row	[m^2]	227.50
Total maximum water outflow due to rain	[m^3]	1.12

It both cases it can be stated that it seems feasible to construct drainage lines of acceptable size and stability to cope with heavy rain falls and hail volumes. No significant shadowing impact is expected.

However, special care must be taken regarding quality, since hail may accumulate quickly and often does not unfreeze for hours.

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