MSc Program
Renewable Energy in Central and Eastern Europe

The relevance of PV as an electricity source for the hotel industry in developing countries

The case of India
Illustrated by the example of
Somatheeram Ayurvedic Health Resort

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Univ. Prof. Dr. Dipl.-Ing. Reinhard Haas

Mag. (FH) Elisabeth M. Reinthaler

ID 1127411

Vienna, November 2013

Affidavit

I, **Mag. (FH) Elisabeth Maria Reinthaler,** hereby declare

1. that I am the sole author of the present Master Thesis, **“The relevance of PV as an electricity source for the hotel industry in developing countries, The case of India, Illustrated by the example of Somatheeram Ayurvedic Health Resort”**, 109 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, _______________ ____________________________

Date Signature

Abstract

The core objective of the thesis is to reveal the relevance of PV as an electricity source for the hotel industry in developing countries.
The electricity problem, combating daily power cuts as well as the special load profile of hotels is analyzed, clarifying whether PV is a relevant solution.
The topic is illustrated by a feasibility study for a South Indian Ayurvedic Resort. A field study is conducted to be able to understand the situation and to design the plant. In order to calculate the key ratios a dynamic investment approach is applied.
The results unfold that even a quite small PV plant with a battery back-up system creates a major positive impact which is of high energetic, ecologic and economic relevance.
In every case and country, the local circumstances need to be considered and the load profile has to be compared with the supply profile of the sun, being the fuel for PV.

Isn't it time to talk not only about weather, but also about climate?
Nicholas D. Kristof, New York Times, October 2012

Table of content

List of Tables

List of Figures

List of Abbreviations

A	Area
AC	Air condition
Ah	Ampere hours
ANERT	Agency for non-conventional energy and rural technology
BOS	Balance of system
CO2	Carbon dioxide
CO2eq	Carbon dioxide equivalent
CRF	Capital recovery factor
c-Si	Crystalline silicon
DCR	Domestic content requirement
Eele	Electric energy yield
EPBT	Energy pay back time
EPC	Engineering, Procurement, Construction
EPIA	European photovoltaic industry association
FIT	Feed-in-tariff
FLA	Flooded lead-acid battery
GDP	Gross domestic product
GHG	Green house gas emissions
GHI	Global horizontal irradiation
GW	Gigawatt
JNNSM	Jawaharlal nehru national solar mission
ISMA	Indian Solar Manufacturers Association
kVA	Kilo volt ampere
kW	Kilowatt
kWh	Kilowatthours
kWp	Kilowatt peak
LCR	Local content regulation
LED	Light emitting diode
LEED	Leadership in energy and environmental design
LRGC	Long run generation costs
MNRE	Ministry of new and renewable energy
MW	Mega watt
NAPCC	National action plan on climate change

NPV	Net present value
NSM	National solar mission
O&M	Operation and maintenance
PR	Performance ratio
PV	Photovoltaic
QSol	Solar irradiation
r	Solar panel efficiency
RAB	Reverse auction bidding
RAP	Reverse auction process
REC	Renewable energy certificate
RES	Renewable energy sources
RPO	Renewable purchase obligations
Rs	Indian Rupees
SF	Solar fraction
V	Volt
VRLA	Valve-regulated lead-acid battery
Wh	Watthour

1 Introduction

Tourism plays a major role in many developing countries which enforces economic development and poverty reduction. Globally it contributes 5% to the GDP[1]. At the same extent it is responsible for the world's GHG[2].

To activate tourism and to satisfy its involved parties energy is essential. Renewable energy might be the smartest solution, when it comes to security of energy supply.

India, the country on which the thesis is focused on, is coping with a major electricity problem. The land is lacking electricity and the energy providers are shutting off the supply on a regular basis.

In addition the grid instability is causing energy insecurity. Rural electrification is not fully developed. Many areas don't have a grid and as a matter of fact don't have access to power. The share of renewable energy sources is still very little, although the preconditions and potential for the implementation of photovoltaic are fabulous.

In this master thesis emphasis will be put on the relevance of PV as an electricity source, spotlighting the hotel industry in developing countries, taking India as an example. The topic will be illustrated by a feasibility study for a medium sized PV power plant at "Somatheeram Ayurvedic Health Resort", a health tourism resort close to Trivandrum in southern Kerala.

Being aware about the power problems in the area the author was suggesting the management of the resort the option of installing a PV system in order to secure electricity, save costs and to save CO2 emitted by the diesel generator. The results of the feasibility study will be a profound decision making tool for the management whether to realize the project.

In addition to the hands on project, details are shared about the Intersolar-award-nominated-project in northern Kerala, called "Spice Village", which was inspected.

The focus will be put on India because of several reasons. India is a huge and emerging country and therefore of great interest for the author. Due to the size and

---

[1] UNWTO (2013), UN World Tourism Organization, http://www2.unwto.org/en/content/why-tourism

[2] UNEP (2011), Tourism, Investing in energy and resource efficiency , p 414, http://www.unep.org/resourceefficiency/Portals/24147/scp/business/tourism/greeneconomy_tourism.pdf

the economic upraise, the power problems and the need for energy, a successful integration of renewables can have a vast impact. In terms of volume and in terms of a potential role model which can be copied and multiplied to the rest of the world.
Besides that the author used to work in India some years ago and is personally attached to the country.

1.1 The core objective of the thesis

The core objective of this work is to assess the relevance of PV as an electricity source in tourism in developing countries. More precisely, it is investigated whether PV can contribute significantly to a change towards a more sustainable tourism.

Besides assessing the relevance of PV, which will be explained more in depth, the thesis intends to raise the awareness concerning renewable energy in developing countries. The idea of compiling a feasibility study is aiming at the realization of the project and thus also being a showcase for the region.
As a showcase, the project could demonstrate the advantages of renewable energy. It should raise awareness not only in the hotel industry sector, but should also stimulate smaller case tourism projects and even the application of RES in households.

Regarding the energetic aspect of PV the thesis should reveal, whether PV can combat the lack of power by investigating about the sun irradiation and the demand. Supply and demand have to be matched. Solutions for power storage need to be discussed, in order to get most out of it.
It should show whether PV can boost the tourism business. The economic viability will be answered. For start-up companies in un-electrified areas, using PV as their main power supply, it might create jobs and income, as it offers the opportunity to open up a business in first place. For existing tourism businesses it could save on running expenses and have economic advantages.
For companies switching from fossil fueled applications to PV, it might improve the health conditions and protect the environment, as emissions are avoided, which are either inhaled by humans or absorbed by nature.

Summarizing the core questions, the thesis should answer whether PV will improve the living standard in developing countries, by disseminating electricity, saving money and protecting health and nature.

In a nutshell, the main objective of this thesis is being a medium for knowledge transfer for the tourism business. In a broader sense this is applies also for any potential electricity consumer.

1.1.1 Definition of relevance

Searching for a definition of the word relevance leads to quite a philosophic excursion. Hjørland and Sejer Christensen have summarized the meaning of relevance as following: "Something (A) is relevant to a task (T) if it increases the likelihood of accomplishing the goal (G), which is implied by T." [3]

In this case, the question is how relevant PV (A) is as an electricity source (T), to provide energy services to hotel operators and it clients in developing countries (G). The more something matters the higher is the relevance. The higher the relevance the more difference it makes for the decision maker.
The feasibility study of this master thesis will be a profound decision making tool for the management at Somatheeram.

In this specific case the question is how relevant is PV as an electricity source in the hotel business in developing countries. The relevance is split up into four aspects.
The question concerning the energetic relevance will prove whether it can cover a substantial part of the electricity demand as well as the forecasted degree of autonomy.
By analyzing the economic aspect, it will be answered whether PV can cut down the running electricity costs perceivably, when the investment will pay back and how the long run electricity costs sourced from PV look like.
The question about the ecologic relevance will check whether PV can cut down emissions tremendously. It should explain how much CO_2 can be avoided and how much diesel can be substituted by PV.

[3] Hjørland, B., Sejer Christensen, F. (2002). Work tasks and socio-cognitive relevance: a specific example. Journal of the American Society for Information Science and Technology, 53(11), p. 964

As a fourth aspect, all the advantages will be summed up and evaluated whether they play a positive role for the image of a hotel, which helps to market the resort easier.

These four aspects are covered separately in detail. They are backed up with the results of the executed calculations.

1.1.2 External factors influencing the relevance of PV systems

The relevance of PV as an electricity source can be major influenced by the following factors:

The size of the PV installation matters. The more space is available the more energy can be produced and even saved in batteries.

The support scheme of RES, and PV in specific can be the decisive point whether to make a PV installation feasible.

The sun irradiation of the location plays a key role in the relevance of PV. The more sun, the more production and the sooner the investment is paid back.

The demand profile of the hotel is important to know in detail in order to check when energy is needed. The more energy is consumed at the same time when energy is produced by the sun, the higher is the overlap of supply and demand.

1.1.3 Internal factors boosting the relevance of PV systems

Even if space is limited the output of the PV plant can be scaled up, if first an energy audit is executed, which leads to energy saving. Having a reduced power demand, the impact of PV as a RES makes a larger impact.

Support schemes are planned on in a long run and can't be influenced by an individual that easy. Better is to look for alternative funding from international development agencies, or sponsoring partner, which can use the plant as a successful reference project.

The sun irradiation of the location cannot be influenced. What one can do is to choose the ideal inclination and orientation towards the sunlight, in order to maximize the yield.

A supervision system makes it easy to control the production of the PV system and helps to identify problems and act quickly in order to avoid losses.

If the current demand profile of the hotel doesn't overlap with the supply of the sun in a sufficient extent, it is possible to try to change the behavior of the electricity usage.

1.2 Method of approach

In order to structure the elaboration of the thesis it was divided into two parts.
The hermeneutical section is dealing with the core topic of the thesis. General research was conducted to learn about the existing studies and activities in the field of sustainable tourism and the use of PV and RES in general in developing countries. A showcase is included to get an idea of how PV can be successfully integrated into the existing power supply.
This theoretical framework serves as the base for the thesis.

The second part of the thesis is the empirical component. Here, the method of how to assess the relevance of PV as an electricity source was determined. As a first step the local solar irradiation data had to be sourced and converted into the electricity yield. In the scope of this work it is referred to as supply, or supply of sun. Then the demand of the specific consumer had to be identified. In order to obtain the result, both the supply and demand have to be matched.

The elaboration of a feasibility study for a tourism resort in southern India should serve as an example how to apply the method of assessing the relevance of PV.
By researching about the demand of the resort, the supply of the sun in Trivandrum and the available space for the plant it was possible to get a first idea, whether PV could play a notable role as an electricity supply at Somatheeram.
After considering several possibilities for a suitable PV plant at Somatheeram, the calculations were conducted for two options. The economic key ratios were determined by a dynamic investment calculation.
After assessing those two options, finally one recommendation was given.

After explaining the results of the empirical study, conclusions of the thesis were drawn.

1.2.1 Citation of main literature

Several institutions and associations are already dealing with the core topic of this thesis and constitute a relevant source of information for the author.
The UNWTO, World tourism organization, is the United Nations agency responsible for the promotion of sustainable and universally accessible tourism. It gave some insights in the current green activities in tourism business.
The UNEP, another sub-organization of the United Nations, which is dedicated to sustainable development of the global environment, is also engaged in eco-friendly tourism in developing countries. They are publishing scientific articles on that topic and are cooperating closely with the local tourism businesses in order to push a healthy development.
National and international hotel associations as well as hotel chains have started a so called green hospitality movement. The author could gain an overview on the obstacles they faced in the past, their success and their most decisive initiatives.

The literature sources mentioned below delivered information specifically on PV in India.
The homepage as well as the Indian solar handbook of Bridge to India, a strategic solar consultancy company, supporting international clients to enter the Indian market, was of major importance.
Mercom Capital Group, a research-, market intelligence- and effective communication company delivered facts and figures.
The Ministry of new and renewable energy (MNRE), by the Government of India, gave exact information about support schemes and status quo of PV in India. Their homepage and a hardcopy of the annual report 2012-2013, which was received during the personal Interview in Delhi was of high importance.
Updates and trends were found in the PV Magazine, a magazine and newsletter service for experts.
The calculations of the PV electricity yield in Trivandrum, are based on the weather data of the US Energy Department. The figures about the demand of the resort were supplied by the staff of Somatheeram.
A complete list of the sources used is to be found at the end of this document.

1.2.2 Structure of work

The thesis is divided in five chapters. Chapter one is serving as an introduction to the topic, giving a general overview of the correlation of the main components. It also explains the heart of the thesis, meaning the core objective, why the thesis is written and which questions are going to be answered.
In this section also the method of approaching the task of elaborating a master thesis is outlined. It mentions the main literature sources, the process how to obtain results, how to calculate and specifies on which data the calculations and as a matter of fact the results are based on.

The theory, describing the core topic, is found in chapter two. The status quo including current challenges and potential solutions for the future is analyzed. It includes a best practice example as well as an excursus, which is added in order to fully understand the current status.

Chapter three and four are tackling the feasibility study. Whereas in chapter three the current situation is the core topic, in chapter four the results are presented, including a final recommendation.

The last chapter, the conclusion of the thesis, is summing up the main aspects, results and points to be considered. It gives an insight what has been learnt while dealing with the topic. Here also future outlooks and possible consequences of the work are discussed.

2 The use of PV in tourism in developing countries

In this chapter the relation between the general situation of electricity and the tourism business in developing countries taking India as an example will be discussed.

Tourism is a driving force for economic development and poverty reduction in developing countries, which contributes 5% to the global GDP.[4] Nevertheless it is also responsible for about 5% of the world's GHG[5].

To activate tourism and to satisfy its involved parties it needs energy. Many parts in the developing world are lacking power. In rural areas it is common not to have any electrification, there is simply not enough power, or the grid is instable. Struggling with that problem, many hotels are combating it with a diesel generator, which is relatively inefficient, costly, loud and polluting the surroundings. A sunny country like India and many other developing countries along the sunbelt, have a high solar irradiation almost double as much as in Europe. The solar irradiation also referred to as global horizontal irradiation (GHI) is about 1000 kWh/m² in Europe and about 2000 kWh/m² in India[6].

PV as a decentralized power supply, fueled by the sun, which shines for free, emitting neither noise nor CO2 might be a relevant electricity source supporting the tourism and in specific the hotel business. Going green also interrupts the destruction of landscape and eco-systems, which are in many cases the very precious base for tourism.

2.1 The electricity situation in Kerala, India

India is an emerging country and its economy is growing rapidly. As a matter of fact the industrial sector is booming, jobs are created, the people are becoming wealthier

[4] UNWTO (2013), UN World Tourism Organization, http://www2.unwto.org/en/content/why-tourism
[5] UNEP (2011), Tourism, Investing in energy and resource efficiency , p 414, http://www.unep.org/resourceefficiency/Portals/24147/scp/business/tourism/greeneconomy_tourism.pdf
[6] SolarGIS (2013), Maps, http://solargis.info/doc/71

and are consuming more energy than in the past. According to the Economist, India's energy demand is expected to almost double within the next 10 years[7]. It is a challenge to meet the rising demand.

2.1.1 Electricity mix

The special situation in Kerala although is, that it generates 90% of its electricity from hydro power. The remaining 10% are made up from thermal power plants and some small wind parks[8].

2.1.2 Lack of power

Kerala, like the whole country of India in general, is suffering from a severe lack of power. The main reasons for that are the growing power consumption, insufficient power generation capacity, lack of its optimum utilization and outdated or non-existing transmission and distribution lines[9]. Moreover many of the hydro power plants are already 50 years old and need to be refurbished and new ones would need to be built additionally. But hydro power business and the construction of dams are stagnating. Barely any new projects are under development due to an increasing number of opponents, who are against re-settlement of people and are favoring the protection of eco-systems.[10] Therefore if monsoon is weak in Kerala it has a great impact on the power generation. The reservoirs won't last until the next year's monsoon. In peak times the south is registering a power shortage of about 26% in 2013[11]. All across India, in 2012, hydropower supply was reduced by 15% compared to 2011, due to weak rainfall[12].

[7] The Economist (2012), An area of darkness, http://www.economist.com/node/21559977
[8] KSEB (2012), Kerala State Electricity Board, Electricity Generation, http://www.kseb.in/~ksebuser/index.php?option=com_content&view=article&id=69&Itemid=70
[9] India Core (2013), Power, Unbalanced growth and shortages, http://www.indiacore.com/power.html
[10] Ranjan, V. (2013), Manager at Team Sustain, Personal Interview, June 2013
[11] The New Indian Express (2013), South to see maximum power shortage this fiscal, p.13, Edition: Kochi, June 8, 2013
[12] Tiwari, R. (2012), Hydropower supply falls 15% as reservoirs dry up, in The Economic Times, http://articles.economictimes.indiatimes.com/2012-07-18/news/32730680_1_temperatures-and-trade-winds-surface-temperatures-and-trade-tonne

2.1.3 Power cuts

As the gap between demand and supply is quite large, the options to overcome it are very restricted and are mostly resolved by simple power cuts. Depending on the situation, in average the power is cut twice a day, in the morning and in the evening. Especially during Kerala's peak demand which is between 6 and 10 pm. In comparison to the major part of the rest of the world, Kerala has very little industry, so the demand in the evening hours is higher than during the day, as the residential demand exceeds the industry's demand[13].

2.1.4 Avoiding consumption in peak-time

Trying to avoid consumption at peak-times, has several positive consequences.
Electricity costs at peak times are more expensive and are a larger financial burden.
Consuming at peak times means also that less attractive forms of generation need to be used, within a country and like the diesel generator in the case of Somatheeram. It causes dirty and noisy emissions.
A further growth of the demand in peak times means also more investment into the public grid system, including transmission and distribution lines. This would be again reflected in a higher electricity price.
Besides energy saving and energy efficiency, the redistribution of demand meaning shifting the consumption from peak to off-peak times can be part of a solution.

2.1.5 The need for alternative sources

Kerala being unable to produce enough energy at the moment, it has to purchase from neighboring states. But also the neighboring states are expecting power shortages in the future. Paying a high price for the electricity from the dirty and noisy diesel generator and being dependent on imports is unsatisfactory and shows the need for alternative sources. The power problem can be seen as beneficial for non-conventional energy sources.[14] According to Mr Prasad from ANERT[15] the focus in

[13] ANERT (2013), Agency for Non-Conventional Energy and Rural Technology, www.anert.gov.in
[14] Prasad, A., (2013), Joint technical director at ANERT, Agency for non-conventional energy and rural technology, Trivandrum, Kerala Personal Interview; June 2013
[15] ANERT (2013), Agency for Non-Conventional Energy and Rural Technology, www.anert.gov.in

Kerala will be put on PV, as for example for wind it is very hard to get building permissions due to land restrictions.

2.2 Energy consumption in tourism

Globally, transport is the most energy intensive tourism sub-sector causing 72% of all tourism related CO2 emissions. Still, saving energy or using RES in the accommodation field can make a difference as it accounts for 21% of all CO2 emissions[16]. The more luxurious the hotel is, the more energy will be used. The CO2 emissions go up to 100 kg/guest/night.[17]

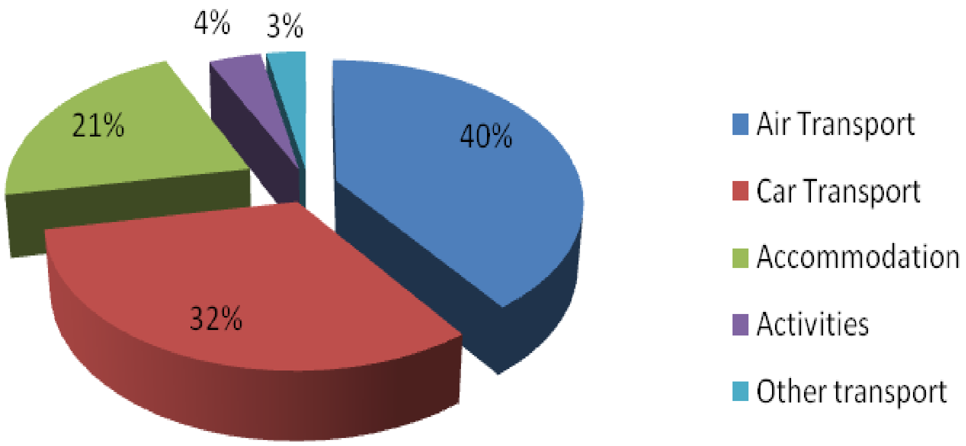


Figure 1: Contribution of various tourism sub-sectors to CO2-emissions in %, modified according to UNEP[18]

2.2.1 The energy consumption of hotels

Depending on the country and its climate the main consumers in a hotel are different.

The figure below is taken from the government of Canada, as an adequate illustration of hotels in South India couldn't be found. It has to be considered that it is

[16] UNEP (2011), Tourism, Investing in energy and resource efficiency , p 414, http://www.unep.org/resourceefficiency/Portals/24147/scp/business/tourism/greeneconomy_tourism.pdf

[17] Allcot (2013), The first hotel reservation "application" that systematically offsets the carbon footprint for all reservations, http://www.allcot.com/2013/02/18/hot-co-uk-the-first-hotel-reservation-application-that-systematically-offsets-the-carbon-footprint-for-all-reservations/

[18] Compare: UNWTO (2008), Climate change and tourism, p. 34, http://sdt.unwto.org/sites/all/files/docpdf/climate2008.pdf

having four seasons including a long heating period in winter time. Heating therefore makes up for a larger part than it would in a tropical area like South India. For developing countries in a similar climatic zone, like eg. the Himalaya area, North India or Eastern Europe, the figures are representative.
In Kerala and in other sunbelt areas of the world heating up the room temperature is not the issue, people are rather concerned about cooling it down. Therefore the two positions in the figure below can more or less be exchanged.

Figure 2 shows that heating and lighting needs most of the energy, accounting for almost 70%, followed by hot water production and cooking facilities.

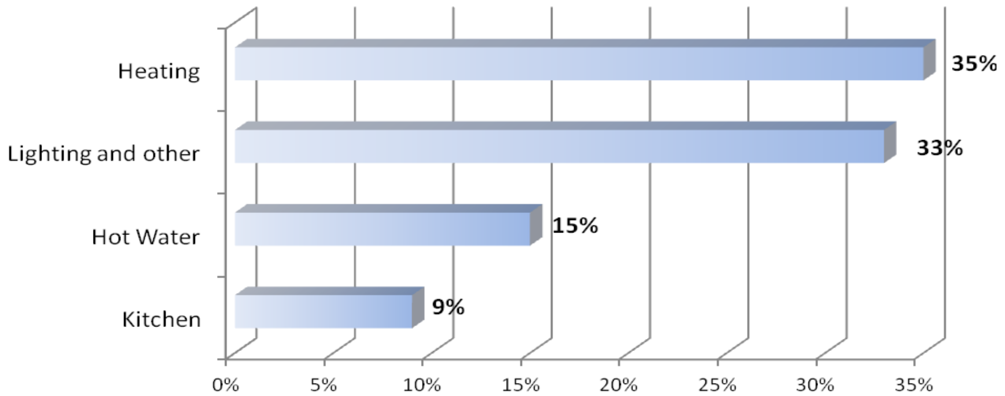


Figure 2: Energy use in hotels, modified according to Natural Resources Canada[19]

Having researched other sources, the common result is that the largest energy consumers in the hospitality sector are AC and heating systems, lighting, cooking and cleaning facilities.[20]

2.2.2 The share of electricity in hotels

The share of electricity of the total energy demand may vary a lot. Depending on the energy systems in the hotel, the hotel could be heated with electricity, which is common in countries like Norway, as they have plenty of electricity from hydro power[21]. Whereas in Austria it is common to use biomass[22], gas or oil. Hot water for

[19] Natural Resources Canada (2009), Office of energy efficiency, determine where you use energy, http://oee.nrcan.gc.ca/publications/commercial/m144-10-2003e/2803
[20] UNTWO (2008), Climate change and tourism, p. 34, http://sdt.unwto.org/sites/all/files/docpdf/climate2008.pdf
[21] Markusson, N., Monsen, K., Russell, S. (2009), Promotion of efficient heat pumps for heating, http://www.geos.ed.ac.uk/homes/nmarkuss/HPNorway.pdf

showering can be supplied by heating it up with fossil fuels, electricity or as it is very common already in Austria by using solar thermal equipment. Air condition in comparison is mainly run with electricity, which increases the share of electricity in countries where it needs to be cooled instead of heated. Assuming an average hotel, mostly using conventional sources of energy in a warm place like Kerala, the electricity share would amount up to 80%. The rest might be gas used for cooking and diesel for miscellaneous generation. Compared to Europe, approximately 70% of the total energy is used for heating up the room temperature and hot water. The remaining 30% is the electricity share.[23]

2.2.2.1 The role of Air-Condition in the load profile

The figure below is the result of an analysis of electricity use in 16 hotels in Hongkong. The climate in Hongkong is sub-tropical and comparable with South India. According to the study the share of electricity is 73% of the total energy demand. As the figure shows the A/C heavily dominates the electricity use with almost 50%.

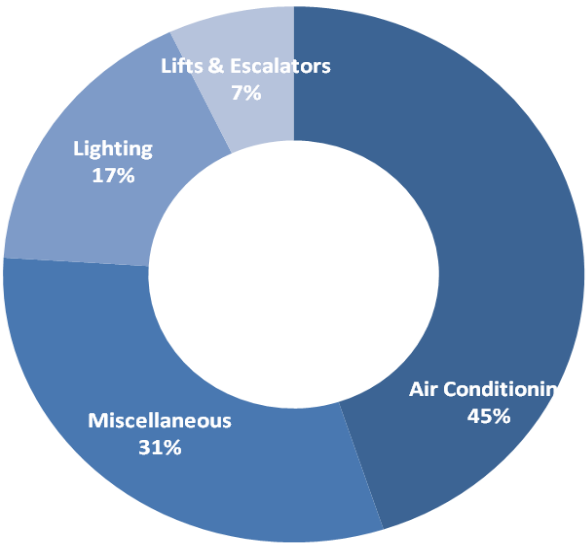


Figure 3: Average percentage breakdown of total electricity use, modified according to Hotelverband[24]

[22] Ökoenergie Cluster (no date), Biomass heating in Upper Austria, http://www.oec.at/fileadmin/redakteure/ESV/Englisch/Publikationen/Biomass_heating_Upper_Austria_engl_US_Letter_216x279_2013_Sicht.pdf

[23] Hotelverband (2013), Energieeffizienz, http://www.hotelverband.at/Energieeffizienz_Folder.pdf

[24] Shiming, D., Burnett, J. (2002), Energy use and management in hotels in Hong Kong, http://jyjs.gzhu.edu.cn/jzsb/upload_file/201052176464785.pdf

The A/C is a high energy consuming appliance. At Somatheeram the power of an AC per room is 2000W, compared to a fan per room with only 80W.
The use of A/C is linked to the outside temperature. In hot season in average hotel like to run it for up to 16 hours a day, in normal season up to 10 hours and in winter only 1-2 hours or not at all.[25]

2.3 Green hospitality movement

Sustainable tourism is an increasing trend that can be observed worldwide.[26] Eco-friendly measurements are taken throughout the touristic fields like gastronomy, hospitality and transport. A TripAdvisor survey highlights a transition to green hospitality.[27] The green hospitality movement had to combat skeptical guests, hotel owners and operators in the past who were thinking measurements for sustainability would impact guest satisfaction negatively.
Meanwhile the major hotel chains are convinced and have implemented strategies to support hospitality sustainability. Not only to gain a competitive advantage, offering a guest enhancement but also to save money and resources.[28]

2.3.1 Top five global eco-friendly practices[29]

The latest biannual global TripAdvisor survey[30] searched for the main sustainable measurements in hotels. 25.000 responses from hoteliers added up to the following top five global eco friendly practices.

The most popular practice, leading with 79% is changing to energy efficient light bulbs, eg like LED bulbs. 62% of the hoteliers are opting for towel and linen reuse,

---

25 Somatheeram (2013), Emails and Interview, May - August 2013
26 Blackburne, A. (2012): Sustainable tourism labelled a "key trend" by luxury travel network, http://blueandgreentomorrow.com/2012/08/23/sustainable-tourism-labelled-a-key-trend-by-luxury-travel-network/
27 Hasek, G. (2012): TripAdvisor survey unveils hospitality industry's top eco trends, in: Green Lodging News, http://www.greenlodgingnews.com/tripadvisor-survey-unveils-hospitality-industrys-top
28 Parisi, S. (2013): Sustainability hospitality reporting showing positive trends, in: EcoGreenHotel News, https://www.ecogreenhotel.com/Sustainability_Hospitality_Reporting_Showing_Positive_Trends.php
29 Hasek, G. (2012): TripAdvisor survey unveils hospitality industry's top eco trends, in: Green Lodging News, http://www.greenlodgingnews.com/tripadvisor-survey-unveils-hospitality-industrys-top
30 TripAdvisor (2012): TripAdvisor survey insights, http://www.tripadvisor.com/PressCenter-c7-Survey_Insights.html

followed by 56% of the respondents who are applying an overall energy efficiency plan for their hotel. Equally 52% of the interviewees implement a green cleaning program and are investing in water efficient toilets and showerheads.

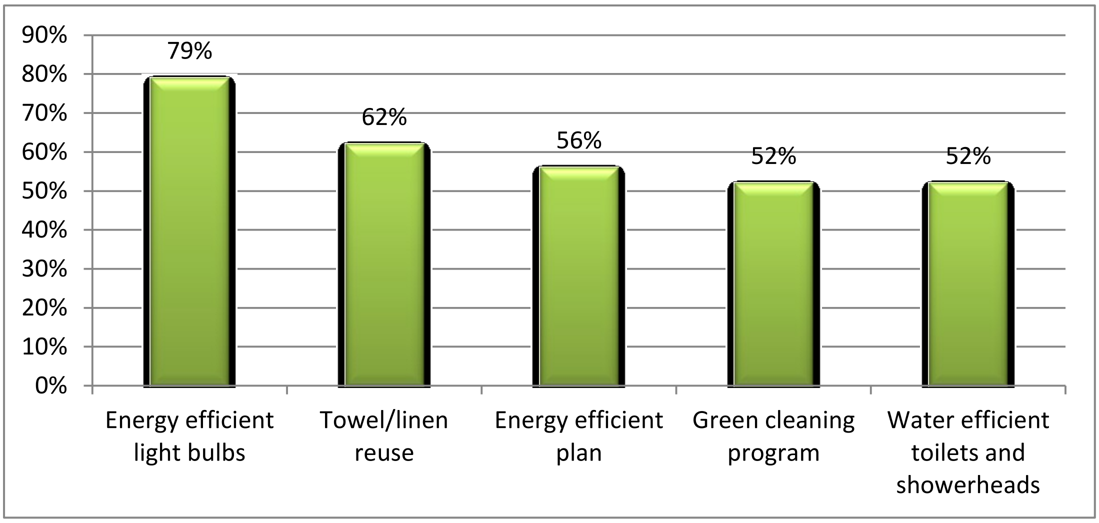


Figure 4: Top five global eco-friendly practices[31]

2.3.1.1 Four important benefits of green hotels[32]

Going green isn't only a trend to be followed; it rewards the hotel management with several benefits. The four most important ones are listed below.

Increased profitability

Going green probably needs higher upfront investment, but it quickly pays off, as it saves costs in the long run. As energy costs are predicted to rise, this leads to higher profitability. In addition a green image allows the hoteliers to ask for a premium price, which guests might be willing to pay for.

Education, community involvement, enhanced brand image reputation

Operating a hotel in a sustainable way or even being part of green certification programs the hotel management has to provide education about protecting the environment to employees and guests. A classic example is the towel-linen re-use

[31] Own graph, based on data from Hasek, G. (2012): TripAdvisor survey unveils hospitality industry's top eco trends, in: Green Lodging News, http://www.greenlodgingnews.com/tripadvisor-survey-unveils-hospitality-industrys-top

[32] Millar, M. (2013): Five important benefits of green certification, http://hotelexecutive.com/business_review/2857/five-important-benefits-of-green-certification

policy, which educates to save water. Often hotels are asked to involve in local charities. All these activities create a favorable perception and reputation.

Differentiation from other hotels

Being active in the green front helps the hotel to stand out of the crowd. This leads already to the next point.

Expanded marketing opportunities

Standing out of the crowd offers new opportunities to position the hotel in a different way and to address a specific target group. New segments can be attracted and new marketing strategies developed.

2.4 Showcase Spice Village, Thekkady, India[33]

This chapter is dealing with a showcase of energy efficiency and the application of RES in the hotel industry. It can be an inspiring role model for the hotel business in India and other developing countries.

The eco-resort Spice Village[34] in Thekkady; Kerala, owned by CGH Earth, Hotel and Resorts was nominated in 2012 for the Intersolar Award India[35] in Mumbai. The resort is a successful example for green hospitality movement.

After undergoing an energy audit, the resort reduced its former total connected load tremendously from 310kW to 65kW. The greatest impacts had the reduction of A/C, the exchange of ordinary light bulbs into LED bulbs, the exchange of desk-top computers into lap tops and upgrading electrical appliances to more efficient models. In order to go green the company added a 65 kW PV power plant in June 2012, as it is shown in the picture below. As there was lack of space on the ground and trees were not allowed to be cut, a solution was needed. A special construction was applied offering multiple benefits. A kind of open hall was built up high, to avoid being overshadowed from the trees. At the same time the hall gives shadow to the underneath basketball and tennis court. Another add-on is that that it was constructed the way that it collects rain water.

---

[33] Prasanth, J., (2013), Engineer at Spice Village, Personal Interview, June 2013
[34] Spice Village (2013), http://www.cghearth.com/spice-village
[35] Intersolar Award Ceremony (2012), http://www.intersolar.in/fileadmin/Intersolar_India_2012/INTERSOLAR_AWARD_INVITATION.pdf

Figure 5: PV plant at Spice Village[36]

The PV plant includes a 45 kW battery system which consists of 72 batteries with a total capacity of 8.254 AH, equaling a storage of 400 kWh.[37] The power plant can cover approximately 60-70% of the daily electricity consumption. Being able to cover that much, the demand of diesel was shrinking from 4.500 l/month to only 1.200 l/month. The total costs including the battery back-up and the energy audit amounted to 18 Mio Rs (approx 3.500 EUR/kW). A 30% investment subsidy was granted by the government of India. The anticipated pay back time of the of PV plant was originally calculated 5,5 years. As the diesel and electricity prices are rising faster than assumed, the pay back time will probably be reduced to 4,5 years.

2.5 Excursus: The Indian PV market

Lack of power, grid instability and pollution is calling for alternative generation of power. The preconditions for photovoltaic as a source of electricity are fabulous.
Like no other sustainable power supply, it is predestinated for electrification of rural off-grid areas. Decentralized PV systems on the individual homes and small

[36] Own photo (2013)
[37] Middleton (2013): Spice Village Resort, India, in: EQ International, http://issuu.com/gouravgarg/docs/april_2013

communal power plants connecting the villagers via mini-grids can improve their daily life.

2.5.1 India's PV resource potential

The potential for PV in India is very high. As the figure below shows the solar irradiation is very high. It varies from approximately 1.800-2.400 kWh/m², which is almost double the irradiation in Germany, where it ranges from 900-1.400 kWh/m².

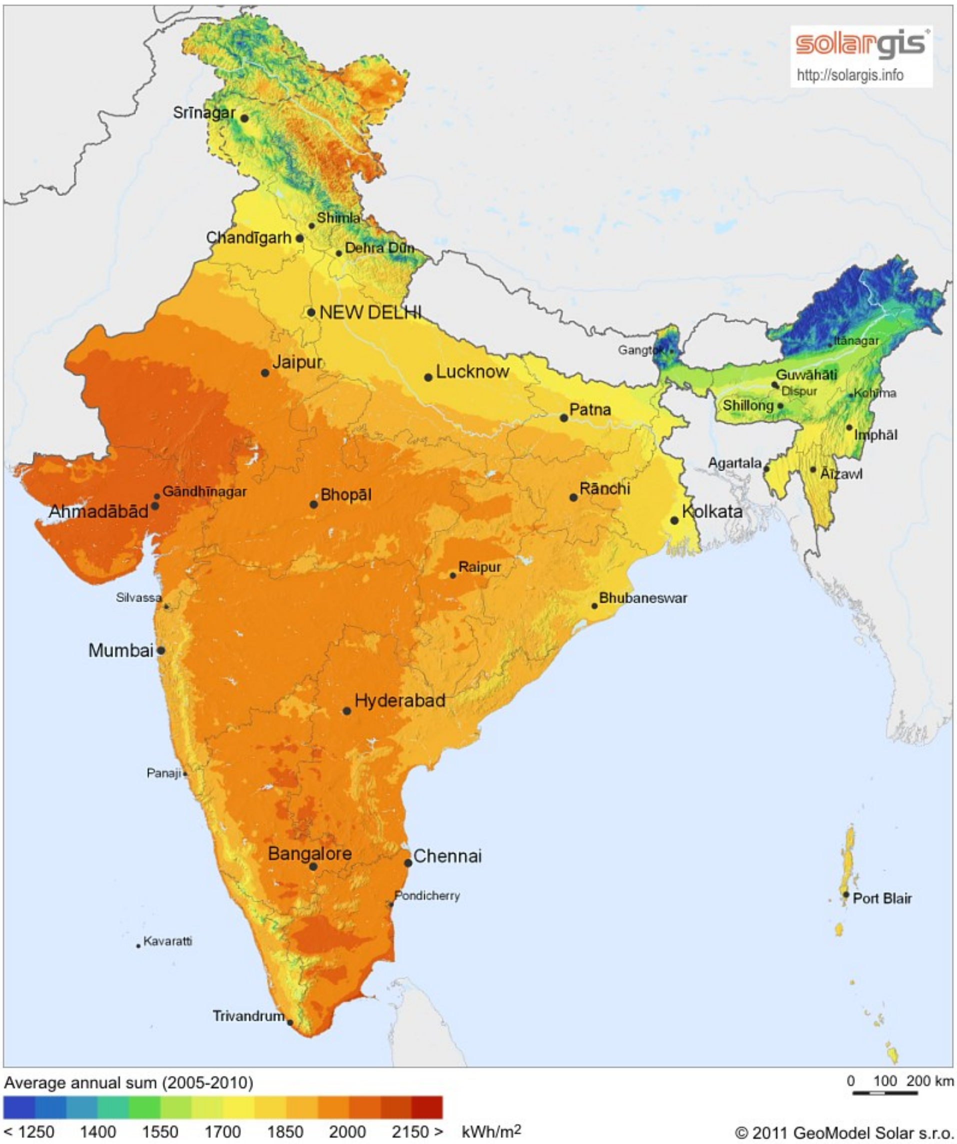


Figure 6: India's global horizontal solar irradiation[38]

[38] Solargis (2013),Solar Map India, http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-India-en.png

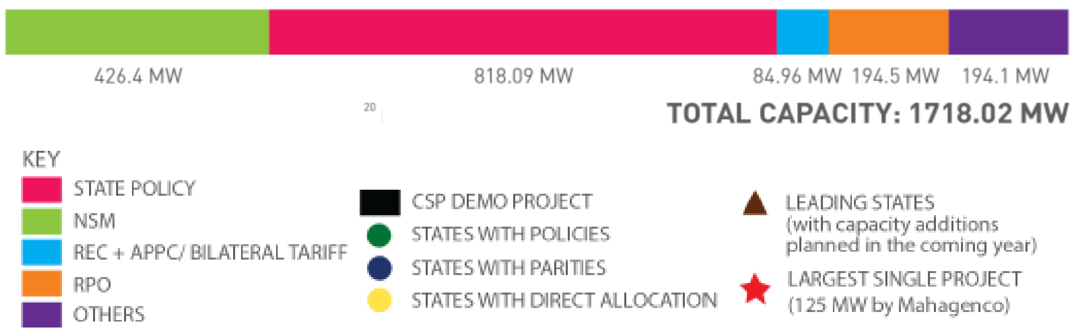
India is huge country but very densely populated, therefore land availability is low. The realization of ground mounted PV power plants is causing conflicting interests. Considering that, the rooftop mounted systems are the more suitable versions.[39]

2.5.2 Total installed capacity

Despite India's huge potential for PV, the total cumulated installed capacity is relatively small. As the next figure below shows it amounts to only 1,7 GW, as on May 2013.

Besides the total cumulated installed capacity, the figure gives an overview of how the PV installations are distributed. On the one hand it reveals the capacity per state. Gujarat (824,1 MW), Rajasthan (549 MW) and Maharashtra (162,7 MW) are the leading states having installed approximately 90% of the country's total capacity.[40] On the other hand it gives an idea about the many support schemes in India. The capacities are classified into the kind of support scheme, again nationwide, and also in addition per state. This way the figure points out the respective share per kind of support scheme nationwide as well as per state. The upper bar on top of the illustration shows the sum of installations per kind of support scheme. The names of the support schemes can be found in the legend below.

India has several support schemes, which will be described later in detail. The most important support schemes are the green colored one which represents the NSM scheme and the pink one which stands for state policies. The major triggers for the 1,7 GW in India were the Gujarat Solar Policy, a state policy, and phase one of the National Solar Mission (NSM). 70% of all installed projects are benefitting from those two support policies.



[39] Wikipedia (2013), Solar Power in India, http://en.wikipedia.org/wiki/Solar_power_in_India
[40] Bridge to India (2013), The India Solar Handbook, June 2013 edition, p. 6

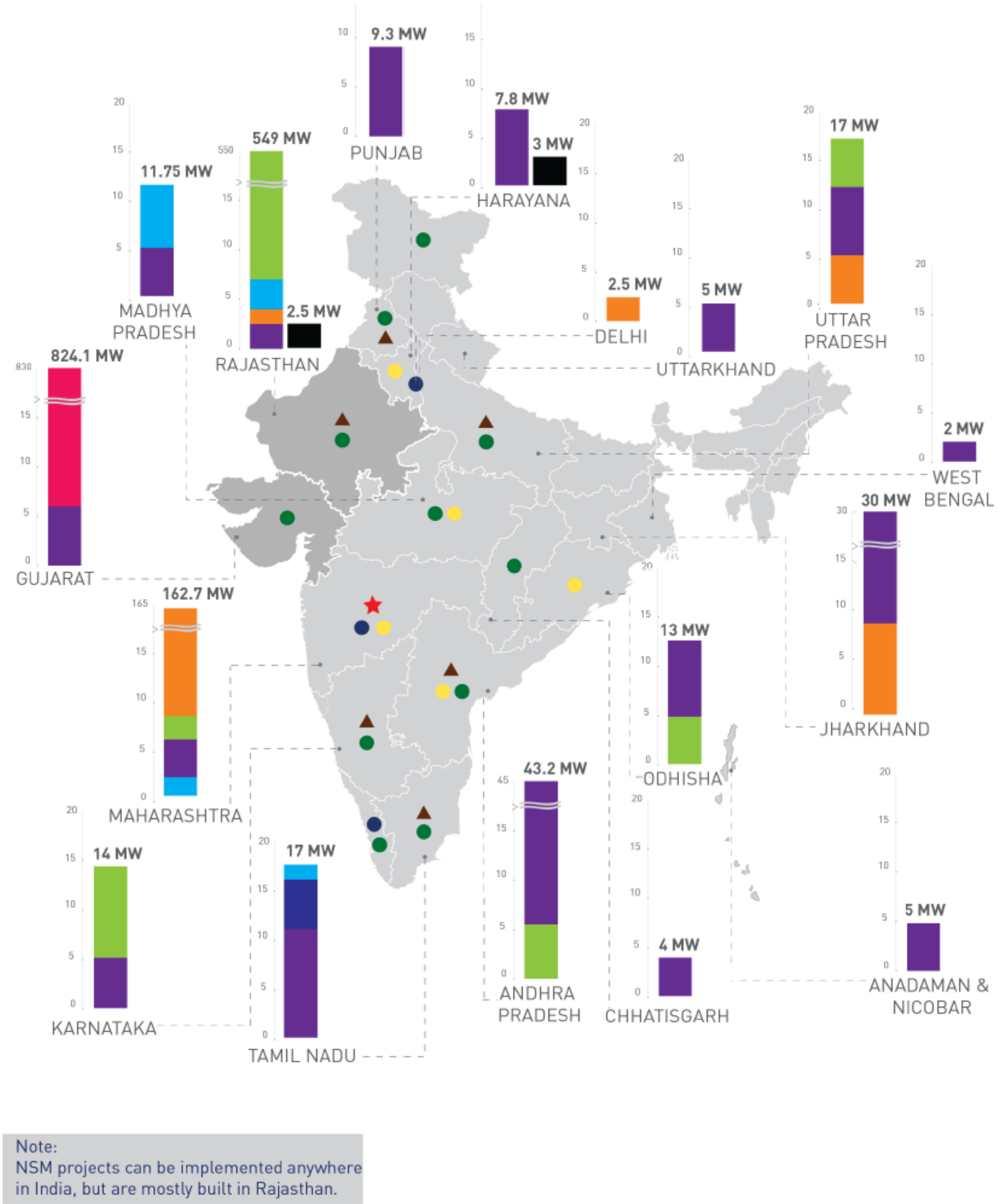


Figure 7: Grid connected Solar PV in India[41]

Compared to the European market, solely in Germany 1,7 GW of PV was added within only one month, which happened in June 2012[42]. Germany's cumulative installed capacity reached 32,6 GW in March 2013[43].

[41] Bridge to India (2013), The India Solar Handbook, June 2013 edition, p. 3
[42] Ehrenstein, C., (2013), Photovoltaik-Bau kollabiert nach Förderkürzung, In: Die Welt, http://www.welt.de/politik/deutschland/article117830961/Photovoltaik-Bau-kollabiert-nach-Foerderkuerzung.html
[43] Enkhardt, S., (2013), Germany hits 32,6 cumulative PV capacity, In: PV-Magazine, http://www.pv-magazine.com/news/details/beitrag/germany-hits-326-gw-cumulative-pv-capacity_100010394/#axzz2YeTneIDT

Even though the European market it rapidly decreasing, in 2012 still 55% of the new global capacity was installed in Germany[44]. In 2013 it is expected that Asia takes over from Europe as the leading sales market[45].

A historic event happened in 2012 when the global cumulative installed capacity hit the 100 GW mark[46].

2.5.3 Installation capacity forecast

According to the figure below, it is expected that 12,8 GW of PV will be installed by 2016 in India. Currently we can observe a rather policy driven PV industry. Within the next three years it will shift to a grid parity driven one.

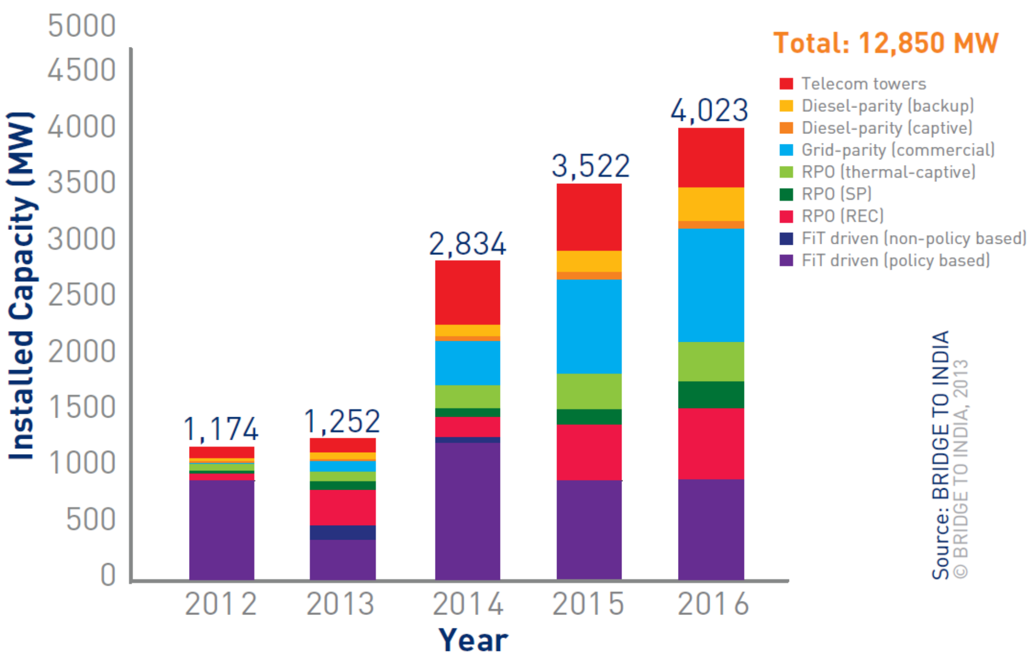


Figure 8: Expected installed solar capacity till 2016[47]

[44] EPIA (2013), European Photovoltaic Industry Association, Global market outlook for photovoltaics 2013-2017, p 5, http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiapublications/GMO_2013_-_Final_PDF_01.pdf&t=1373554465&hash=4f0bec7eca4c422af168d1dbab2a0e35023db0f0

[45] Trendforce (2013), PV market to flourish in Asia in 2013, http://pv.energytrend.com/research/20130107-4841.html

[46] EPIA (2013), European Photovoltaic Industry Association, Global market outlook for photovoltaics 2013-2017, p 5, http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiapublications/GMO_2013_-_Final_PDF_01.pdf&t=1373554465&hash=4f0bec7eca4c422af168d1dbab2a0e35023db0f0

[47] Bridge to India (2013), The India Solar Handbook, June 2013 edition, p.11

2.5.4 India's PV support schemes

India has several strategies to promote PV, which will be shortly explained in this chapter. The figure below highlights once more the PV installations per policy type as already addressed in figure 7.

In 2010, the Prime Minister of India launched the Jawaharlal Nehru National Solar Mission[48] (JNNSM or NSM), as part of the national action plan on climate change (NAPCC). The target of the NSM is to install 20 GW of grid connected and 6 GW of off-grid solar PV by 2022. [49] Among other support schemes, the NSM includes the capital subsidy of 30% of the total investment costs.

A part of the NSM funds are sanctioned through a reverse auction process (RAP)[50]. RAP is a reverse bidding process, where sellers bid online at a competitive low price. All bids will be published, then a certain period will be given afterwards in order to adapt the bids which allows to go even lower. The auction then will be closed and the lowest bidder will win.

Besides this national support under NSM there are various state policies, which are very successfully applied in Gujarat and Maharashtra, as can be seen in the graph below. State policies often opt for FITs.

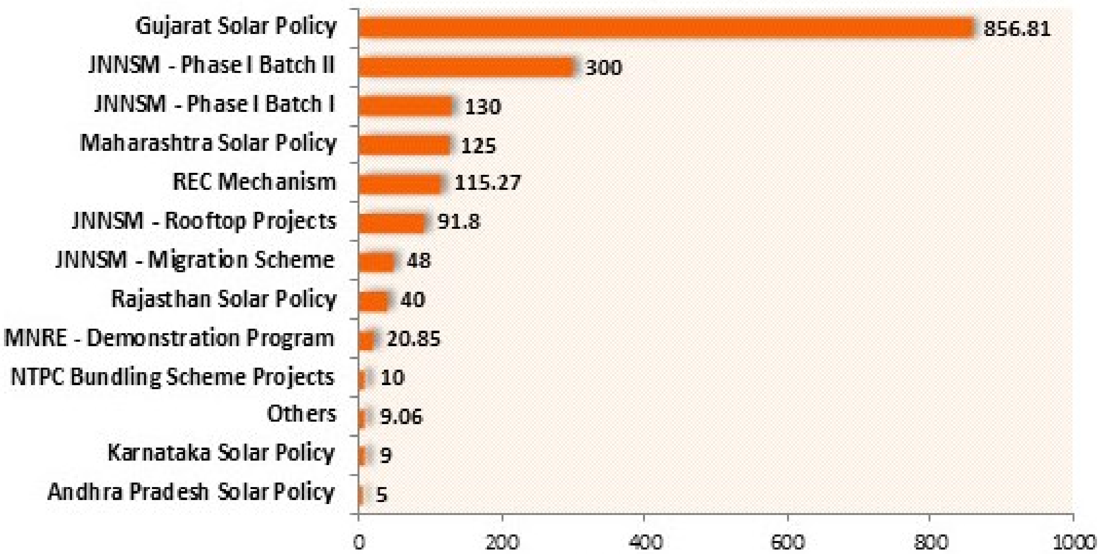


Figure 9: All India solar PV installation by policy type, May 2013 (MW)[51]

[48] Ministry of New and Renewable Energy (2013), Scheme Documents, Jawaharlal Nehru National Solar Mission, http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/

[49] Ministry of new and renewable energy (2012), Annual Report 2012-2013

[50] FWHT (2013), Professional association, Reverse auction bidding, http://www.fwhlaw.com/articles/reverse_auction_bidding.cfm

[51] Mercom Capital Group (2013), Indian solar market update, 2nd quarter 2013, http://mercomcapital.com/indian-solar-market-update-2nd-quarter-2013

Another segment of the policies are the renewable energy certificates (REC), which is driven by the renewable purchase obligations (RPO) of states. RECs can be earned when electricity is sold. Still this mechanism didn't yet take off due to the little demand of RECs.

Currently 1,7 GW of PV are installed across the country. The lion's share was driven by central and state policies offering FITs.
Now as grid-parity has been reached already in some states, and will be reached by 46% of the states by 2016, the projects will more and more be parity driven[52].

2.5.4.1 Capital subsidy under NSM

The focus will be put on the 30% capital subsidy[53] under the NSM, as it is the most suitable option for Somatheeram's circumstances.

In order to get the 30% capital subsidy, under NSM, the MNRE has set certain preconditions which have to be fulfilled.
A list of accredited channel partners was issued by MNRE, which includes solar photovoltaic system integrator, taking care for the design, procurement, installation and if desired maintenance of a turn-key PV power plant.
These channel partners are obliged to source products according to the local content regulation (LCR) [54].

The use of an imported turn-key PV system is not permitted under the support scheme, although single components can be imported. Indian crystalline silicon modules are mandatory, although solar cells and modules based on another technology, eg thin-film, can be imported[55]. BOS balance of system also has to comply with the latest edition of IEC/BIS standards as specified by NMS.
The controversy LCR might be adapted in the future.

---

[52] Bridge to India (2013), The India Solar Handbook, June 2013 edition, p. 13 ff
[53] Ministry of New and Renewable Energy (2010), Jawaharlal Nehru National Solar Mission, Guidelines for off-grid and decentralized solar application, issued June 16, 2010
[54] Green Clean Guide (2013), MNRE capital subsidy scheme for off-grid solar systems, http://greencleanguide.com/2013/07/17/mnre-capital-subsidy-scheme-for-off-grid-solar-system/
[55] Ministry of new and renewable energy (2012), Annual Report 2012-2013

2.5.5 India's suffering PV manufacturing industry

According to the Indian Solar Manufacturers Association (ISMA) for 2013 1 GW of PV installation is projected. In average only 10-15% domestically produced cells and modules will be installed, although the industry would have the capacity to serve 100%.[56]

In 2010, when the Jawaharlal Nehru National Solar Mission[57] (JNNSM or NMS) was announced, solar manufacturing started to boom. Although today a large share of producers is running their plants below capacity, planned expansion activities are postponed and many manufacturers even have temporarily shut down their facilities. The scapegoat for this economic turmoil, according to the Indian producers, is called China. China's module manufacturing capacity exploded from less than 6 GW in 2007 to approximately 55 GW in 2012. Already by 2013 80% of the worldwide PV output has its origin in China, in 2008 it was only 32%.

Indian manufacturers aren't competitive any more. The average Indian plant capacity is less than 100MW/year compared to the standard sized plants in China with around 500-1000MW/year. As a matter of fact India cannot enjoy economies of scale in production, and they have a weaker position when it comes to the purchase of raw materials. Besides the advantage in size, China's PV industry is suspected of dumping its products. As labor in India is very cheap, many factories still didn't opt for automation and robotics due to economical reasons. Manual actions in the production processes are error-prone and can influence the quality negatively.

According to S. Venkataramani, General Secretary of the Solar Manufacturers Association (ISMA), currently in India, cell producers use 5-8% of their installed capacity, respectively for module producers it is about 20-25%.

Summing up all these factors, the cost of production in India is currently higher than the market prices. This is the reason for the numerous bankruptcies and closings of production facilities, not only in India but also in other countries around the globe.[58]

---

[56] Special Correspondent (2013): Solar units seek anti-dumping duty on imports from China, in: The Hindu, http://www.thehindu.com/todays-paper/tp-business/solar-units-seek-antidumping-duty-on-imports-from-china/article4635385.ece

[57] Ministry of New and Renewable Energy (2013), Scheme Documents, Jawaharlal Nehru National Solar Mission, http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/

[58] Singh, S. (2013): Swamped by a flood of imports. In: PV Magazine, Solarpraxis AG, June 2013, pp 54-59

2.5.5.1 Call for anti-dumping duty and governmental support

To push the business of national manufacturers, the Indian government supported right from the beginning of the NSM the use of c-Si (crystalline silicon) cells and modules from Indian producers under the first phase and set up a domestic content requirement (DCR).

The DCR was not applicable for thin-film products. This created a perverse behavior in the market, said Mr Ajay K. Goel, CEO from Tata Power Solar. Most experts agree, that thin-film is not suitable for India, nevertheless it was the preferred technology, its share amounted to 75% of all NSM projects, compare to the global utilization average of 15%.

The National Solar Mission (NSM) program was rolled out in two phases. Phase one again is divided into two batches.

The conditions for the second phase are not yet published. According to interviewed officials of the MNRE it is considered to include thin film modules as well in the DCR.

Under batch one, during the last three years in 70% of the projects imported solar cells or modules were used, despite the DCR[59].

In order to further protect the Indian PV industry (ISMA) has called for imposition of anti-dumping duty on cheap imported solar equipment from China[60], US, Taiwan and Malaysia and ask for a stronger support from the government as eg investment subsidies for manufacturing plants.

After the first investigations in the mentioned Asian countries and the US, now India is trying to expand the anti-dumping probe even to EU and Japan[61].

[59] Singh, S. (2013): Swamped by a flood of imports. In: PV Magazine, Solarpraxis AG, June 2013, pp 54-59

[60] Special Correspondent (2013): Solar units seek anti-dumping duty on imports from China, in: The Hindu, http://www.thehindu.com/todays-paper/tp-business/solar-units-seek-antidumping-duty-on-imports-from-china/article4635385.ece

[61] Obiko Pearson, N. (2013) India may expand solar anti dumping probe to EU and Japan, in: Bloomberg, http://www.bloomberg.com/news/2013-07-19/india-may-expand-solar-anti-dumping-probe-to-eu-japan.html

3 Description of feasibility study for "Somatheeram Ayurvedic Health Resort"

The Somatheeram Ayurvedic Health Resort is located at the coast, in the very south of India, close to Trivandrum, the capital of Kerala state. It has won 9 times the award for the best ayurvedic centre in Kerala.

Having known that India has a power problem, it was experienced by the author heavily, when for example reading at night in the cottage. Within one hour the electricity was gone for about 5-8 times in average for either a few seconds or approximately half a minute. Due to this lack of energy the management of the hotel is interested in filling the gap and installing a PV system. Within the frame of this master thesis a feasibility study for the installation of a PV plant will be elaborated. In addition a recommendation for an overall new energy concept will be given.

Figure 10: Entrance of Somatheeram Ayurvedic Health Resort[62]

[62] Own photo (2013)

3.1 The resort

As the map of Somatheeram below illustrates, the resort has 66 cottages, among them standard and special bungalow as well as deluxe suites, which are scattered all over a beautiful garden with many Ayurvedic plants and palm trees, facing the Arabian sea.

When the resort is fully booked it offers space for approximately 130 guests. Besides the cottages it features an Ayurvedic hospital, a yoga hall, a swimming pool and some small gift- and Ayurvedic shops. [63]

Figure 11: Map of Somatheeram Resort[64]

[63] Somatheeram (2013), Ayurveda in India,
http://www.somatheeram.org/de/?gclid=COGPtYmaj7gCFYGz3godeVYAaQ
[64] Own photo of map (2013)

The picture below shows a standard cottage. It gives a quite a good impression of the setting within the resort, how the buildings are embedded in the jungle garden.

Figure 12: Standard cottage[65]

Huge palm trees are predominating the surroundings, surmounting the bungalows and dropping shadow. The roofs are made of palm tree leafs, which have to be renewed every year.

[65] Own photo (2013)

Figure 13: Roof-tops of bungalows[66]

3.2 Framework and problems[67]

All collected facts and figures are summarized and analyzed in this chapter. This includes the demand of the resort and describes the specific power problems. To render the whole situation at the resort, also current sustainable projects will be mentioned.

3.2.1 Total connected load

Adding up all consumers in the resort is delivering a clear result. The electricity appliances with the highest share of the total load are the water heater with 48% (162kW), followed by the A/C with 18% (60kW), the laundry with 15% (50kW) and the plugs with 12% (41kW).

Still, the connected load must not be mixed up with the demand. The total load is the sum of the connected appliances with their potential nominal power rate per hour.

[66] Own photo (2013)
[67] Somatheeram (2013), Emails and Interview, May - August 2013

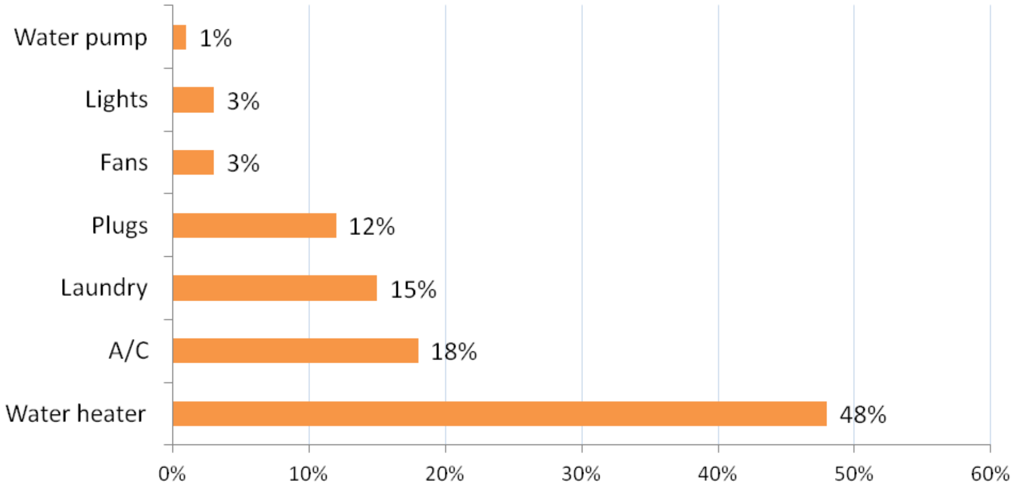


Figure 14: Total connected load 336 kW[68]

3.2.2 Current electricity demand

The total connected load is 336 kW. Depending on the season and the amount of guests, the resort has a demand of approximately 20.000 kWh/month, excluding the power generated from the diesel generator. It is suggested that this back-up system covers 10% of the total electricity needed. Therefore the yearly electricity demand sums up to about 260.000 kWh.

3.2.3 Current electricity supply

Currently 90% of the energy demand is supplied by the public grid. As mentioned before 10% are taken from the diesel generator backup system, when there is a lack of supply from the grid which happens mostly in the peak time between 6 pm and 10 pm.

3.2.3.1 Diesel generator

The diesel generator has a power of 160 kVA, with a capacity of 250 l. Depending whether the generator is connected at full or low load, the average electricity

[68] Own calculation based on distribution of total connected load

production per liter diesel is about 2-2,5 kW. The costs for one liter diesel are currently 54,31 rs.

The costs per kWh produced with the own diesel generator are therefore equaling around 27 rs. 60% of the time, the generator is working at full load, the remaining 40% in low load. At full load the connected load is about 50kW, but it can go up to 92kW. Per hour around 32,5 liters of diesel are needed, it can then last around 7-8 hours. When operating in low load, approximately 12,5 liters per hour are burned, which can last for about 20 hours, without being refilled.

It is critical to avoid low load if possible as the efficiency curve goes down, operating not fully loaded[69].

The average monthly diesel demand is about 1.100 l.

The diesel generator is mostly used during the peak time from 6 – 10 pm, when insufficient electricity is provided from the grid due to power cuts and also during the day whenever the supply is interrupted due to grid instability. Daily, in total this means around 60 – 100 kWh are produced by the diesel generator.

Figure 15: Diesel generator[70]

The picture above shows the 160 kVA diesel generator of the resort.

[69] Wikipedia (2013), Diesel generator, http://en.wikipedia.org/wiki/Diesel_generator
[70] Own photo (2013)

3.2.4 Current electricity problems

The resort has about two power cuts daily, in average lasting about two hours, sometimes short cuts of a few minutes, sometimes up to several hours. Besides the power shortage a power cut can also be caused if the grid's voltage fluctuation is too low.

3.2.5 Existing sustainable projects

The PV project isn't the first sustainable project which the resort is considering. Somatheeram has already started to implement two sustainable projects, which will be shortly touched on.

A rain water collection system already exists, as it can be seen in the pictures below. Along the walkways in the resort, the water can flow into the ground, where it is collected in a large tank. The collected rain water is mostly used for watering the plants in the garden.

Figure 16: Rain water collection system[71]

Currently a waste water treatment plant is under construction. The plant will filter the waste water of the resort, in order to reuse water and to avoid waste being exposed to the sea nearby. At the point of writing the thesis no additional information was given.

[71] Own photo (2013)

4 Results of the case study analysis

Based on the current situation in the resort and considering the given circumstances, energetic, ecologic and economic analyses have been conducted to answer the core objective of the thesis. After unfolding the analysis results regarding the compliance of supply and demand, the suitable design of a PV system will be specified, including an assessment of the need of a battery back-up system. Bearing in mind the relevance of various possibilities, two options will be suggested, for which the detailed calculations are executed. The results are then presented and compared, followed by a suggestion for Somatheeram.

4.1 The match of supply and demand

In this chapter it will be elaborated if and to what extent the electricity produced from the sun, is able to meet the demand of the resort. The question needs to be answered at what time of the day and how much electricity is produced, compared to at what time of the day and how much electricity is needed.
To finally answer this question, for both the supply and the demand a profile has to be compiled, showing the situation throughout the day, which are then being matched. The match reveals information whether electricity is supplied exactly then when it is needed, how much is produced compared to the need and whether there is a surplus of supply.

4.1.1 Electricity demand profile of Somatheeram

Unfortunately no exact load profile of the energy provider for Somatheeram was received. Nevertheless an estimation from the maintenance department was compiled, which is resulting in the following load profile.

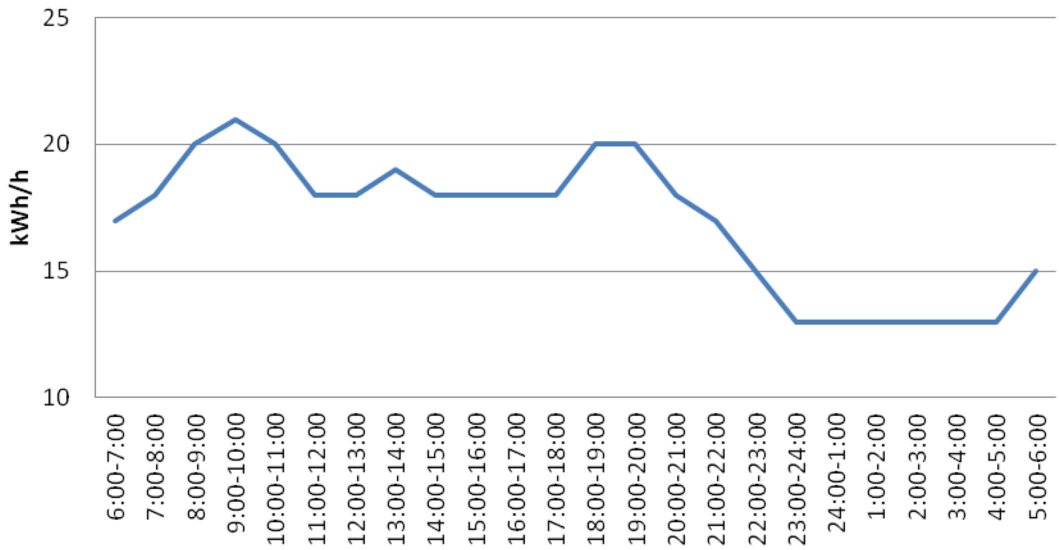


Figure 17: Load profile estimation for Somatheeram[72]

In average, across the year, 50% of the electricity is needed from 6 am to 6 pm in the Keralian "normal-time", 17% in the "peak-time" from 6 pm to 10 pm, and 33% during the night in the "off-peak time" from 10 pm to 6 am. Having only the rough information of the electricity demand as shown below, I am using the real example of a hotel in Austria. The graph shows the real load profile of a comparable hotel in Vienna of its energy provider.

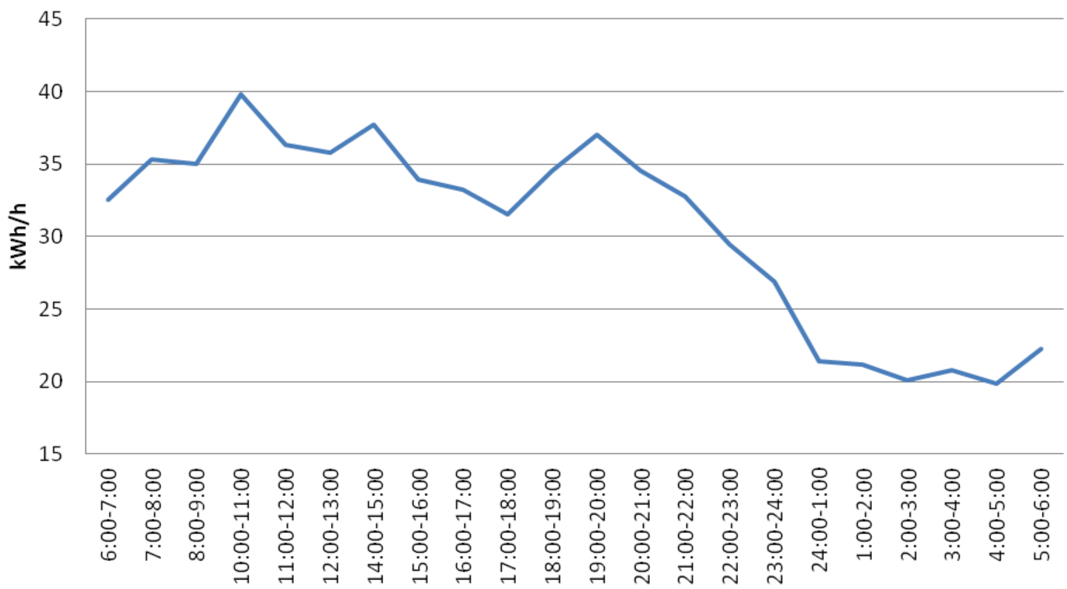


Figure 18: Load profile of comparable hotel[73]

[72] Own graph, compiled according to the estimation for the month of August 2013 by maintenance dept of Somatheeram, exact values may vary

[73] Own graph, compiled according to the supplied data from Verbund (2013): Load profile of a comparable hotel, email conversation, August 2013

Having similar preconditions the load profile of the hotel in Austria can be used as a representative example also for Somatheeram. As it is a hotel with a similar size and a restaurant, it has more or less the same distribution of demand. It shows that in the early morning between 6 and 9 am the demand raises quickly when people wake up and start the day. Around noon the demand is at its peak, most probably due to the power demand in the kitchen and restaurant. In the afternoon the consumption is reduced, while at 6 pm it raises again. Starting around 8 pm the demand is going down, showing a significant power drop around 10 pm. After 10 pm until 6 am the consumption is at its lowest point. A difference to Austria is that at Somatheeram the electricity demand of the ACs has to be added.

4.1.2 Solar irradiation in Trivandrum

In order to find out how demand and supply matches, the supply, meaning the solar irradiation of the specific location has to be identified. Below, the daily distribution of the global horizontal irradiation is shown. It reflects when the sun shines, which is the fuel for the PV plant.

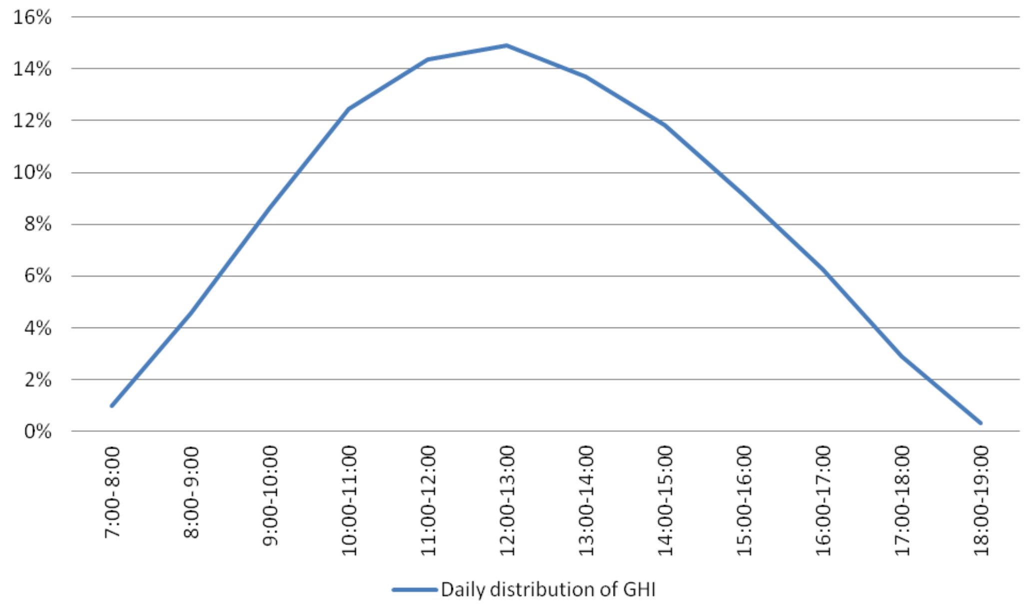


Figure 19: Daily distribution of Global Horizontal Irradiation in Trivandrum[74]

[74] Own graph, compiled according to data from US Department of Energy (2013): EnergyPlus Energy Simulation Software, weather data, India, Trivandrum, http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

The calculation is based on a yearly average. As in India the sun rise and sun set, are more or less at the same time of the day, there is only a slight change of the distribution of the sun hours during the year.

The two lines below show the average daily production of electricity throughout the year. The brown one is representing the production of the 16 kWp plant, the orange one the production of the 32 kWp plant.

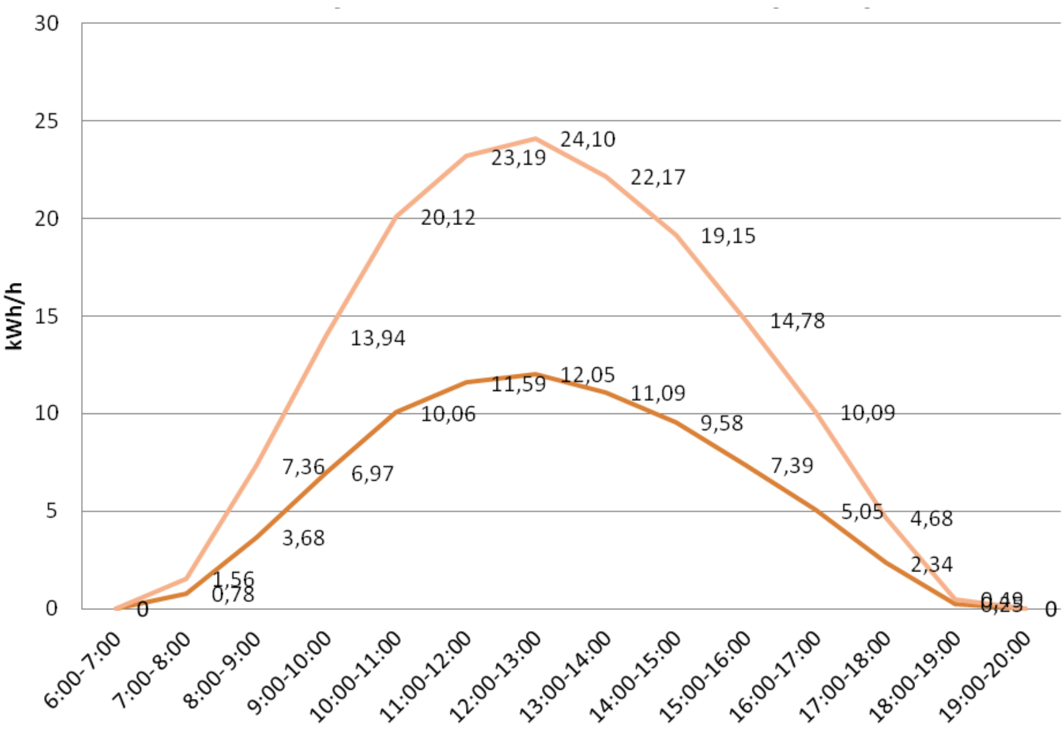


Figure 20: Electricity Production 16 and 32 kWp PV plant[75]

4.1.3 The match of supply and demand

The next graph is summarizing the comparison between the demand of the resort and the potential supply of PV. The overlap of both is indicating of how much electricity is produced and consumed at the same time.

The two lines at the top are reflecting the demand of the resort depending on the season. The purple line at the very top is showing the demand during the touristic peak time like in January and February, when the resort is fully booked. The blue line below indicates the demand during the low season, like in July and August.

[75] Own graph, complied according to own calculations

The two lines at the bottom show the average daily production of electricity throughout the year. The red line represents the production of the 16 kWp PV plant, the green one reflects the production of the 32kWp PV plant.

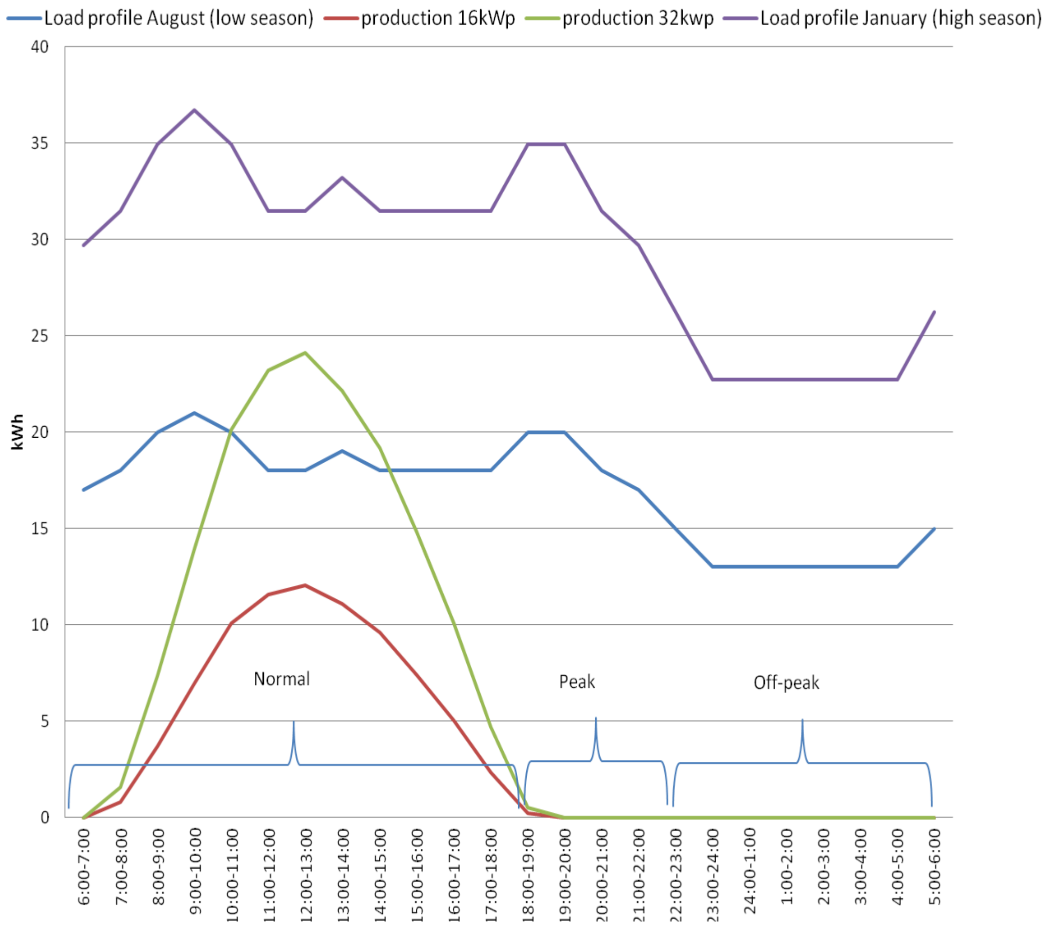


Figure 21: The match of supply and demand in low and high season[76]

Comparing the load profiles with the supply curves shows that there is almost always demand at the moment of time when electricity is supplied. Nearly all the produced electricity from the PV plant can be used.

Talking about surplus, it can be observed that there is no excess electricity generated from the 16 kWp plant. However, the curve of the 32 kWp plant, shows a tiny overlap during noon, but only during two months a year, which is in the low season, when the demand is at its bottom.

[76] Own graph, compiled according to own calculations

4.2 The potential PV plant for the case study

In this chapter all the details and circumstances of the PV plant will be mentioned. Subsequently based on the given facts, a project recommendation will be given, followed by the presentations of the calculation results.

4.2.1 Location for the PV installation

Once arriving at the resort plans about covering all the single bungalows with PV had to be dismissed.

The bungalows' roofs as shown earlier are covered with palm tree leaves, and are newly made each or every other year. This would have meant that the modules would have been de-mounted and re-mounted at the same intervals.

Another argument against PV on the bungalows is that they are settled within a lush garden with high palm trees, shading the roof during many hours of the day.

Finally, the identified space for the PV plant is the flat roof-top of the staff building.

Figure 22: Potential site for PV installation facing north[77]

[77] Own photo (2013)

Figure 23: Potential site for PV installation, facing south[78]

In addition to the identified space, there is the possibility that in 2014 a building with the same size will be available. This would be double the available size for the PV installation. It will be considered as an option in the calculations.

4.2.2 Calculation of the dimension of the PV plant for the given space

The collected data, which concerns the specification of the location as well as the system design is the base for planning the PV plant and calculate its size.

4.2.2.1 Specifications of the location

Available space:	Building 1 (existing): 30 m x 5 m = 150m² Building 2, to be confirmed, (maybe ready by 2014): 30 m x 5 m = 150m² Total 300m²
Obstacles:	no external obstacles, which could cause shading Palm trees can be cut if needed
Latitude:	Trivandrum 8°29'N 76°59E[79]
Roof-type	flat

[78] Own photo (2013)
[79] Maps of Kerala (2011), Latitude and Longitude, http://www.mapsofindia.com/lat_long/kerala/

4.2.2.2 Design of the system

Knowing about the local circumstances, like the limited space, the roof character and considering the geographical information the PV system can be designed as following:

Optimum angle:	7°[80]
Orientation:	south
Mounting method	triangular support mounting system
Positioning:	29 modules vertically in a row 2 rows, with space in between
Size	58 modules x 290W each = 16,8 kWp (A) Including the second building the capacity would be double as big: 32 kWp (B)

For the state-of-the-art PV systems, a rule of thumb says approximately 10 m² are needed for 1 kWp. Having made the arrangement of the modules according their size, the inclination and the given space, the rule matches well with the result.
Regarding the degree of inclination, a point of reference is the latitude. The inclination of a PV module should be similar to the latitude of the location. Depending on the circumstances like strong wind, leaves covering the modules or limitation of space, the inclination can be adapted.
With a low inclination of 7° the self-purification effect is weakening and the modules should be check regularly.

To optimize or avoid the shadowing from one array facing the sun onto the array behind, some space should be left in between. The base for the drawing below, resulting in a shading angle of 58,5°, is the very low solar altitude at noon on 21st of December and 21st of June.

[80] George, A. (2012), Analytical and experimental analysis of optimal tilt angle of solar photovoltaic systems, in: IEE Explore, http://ieeexplore.ieee.org/xpl/login.jsp?reload=true&tp=&arnumber=6477978&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6477978

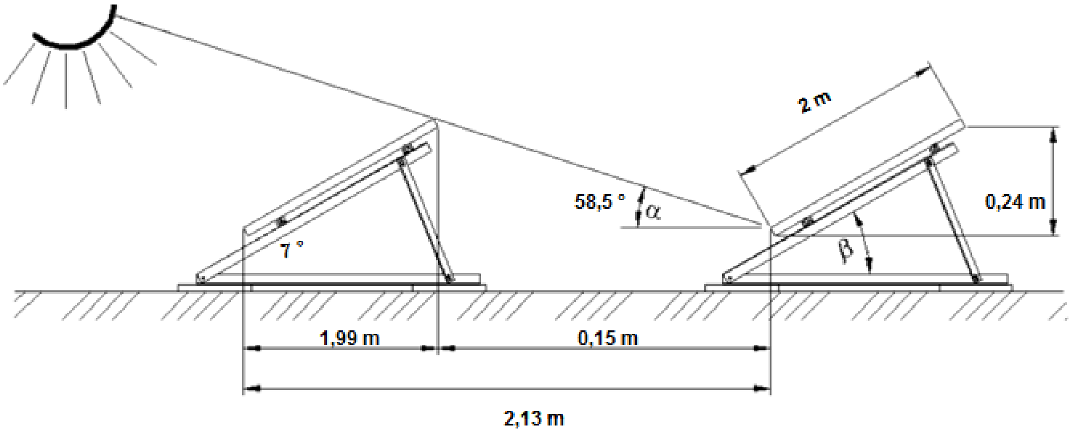


Figure 24: Tilt and shading of PV module arrays[81]

The lifetime of the PV system is estimated to about 30-35 years. In most cases the module producers, just like EMMVEE, guarantee 90% of the performance in the first ten years and 80% of the performance for 25 years. If the modules don't perform accordingly they will be exchanged.

4.2.3 Battery back-up system

Basically a PV plant can work without a battery back-up system. With the option of a battery back-up system, the power produced by the PV system can be stored and discharged when needed, even during night time when no sun is shining. Depending on the specific situation one can think about including one.

4.2.3.1 Assessment of need

There are two approaches to assess whether a battery back-up system is necessary:

The first approach is based on 100% own consumption and saving the surplus of PV production compared to consumption. Having calculated this, the result shows that a 16 kWp plant doesn't deliver in any hour during the year more electricity than consumed. The situation is similar to the double sized plant of 32 kWp. Here only during two months of the year, there is a tiny surplus of about 10-15kWh per day,

[81] Schletter GmbH (2013), Verschattungsrechner

which could be discharged during power cuts. This would result in only about half an hour supply of electricity from the battery which could be used in case of power cut. Summarizing this, a battery for storing excess electricity for a 16 or 32 kWp PV plant isn't reasonable.

The second approach is to rely on the electricity supply out of the grid, and only save approximately as much of the PV production in the battery to be able to discharge it during power cuts or grid instability.
The 16 kWp plant produces about 80 kWh per day, the 32 kWp plant up to 160 kWh. As about 60 to 100 kWh per day are taken from the diesel generator it is a possible option for both the 16 and 32 kWp PV plant, as both sizes would produce enough electricity.

An alternative possibility, which is not considered in the calculations is not to serve all appliances during a power cut, but only the most important, like lights and plugs for example, but not the A/C, as it is a huge electricity consumer. This way the size of the battery could be reduced.

It is recommended to choose a battery size that covers approximately the two to four hours during lack of electricity from the grid.

4.2.3.2 Sizing the battery[82]

Calculating the capacity of a battery depends on the technology. Due to economic reasons a lead battery is recommended, which is very common among PV systems[83]. The triggering point for the battery size is the targeted hours of autonomy, meaning how many hours should the resort be supplied independently from electricity produced by PV and saved in the batteries. It is about two to four hours, as recommended.

The table below shows the link between the targeted hours of autonomy and the average consumption per hour. As mostly the power cuts are happening in the peak time from 6 – 10 pm, the demand per hour needs to be checked. The demand in

[82] Simple Solar Set-up (2013), Battery http://www.simplesolarsetup.com/battery4.html
[83] Solaranlagenportal (2013), Marktübersicht Photovoltaik-Speicher, http://www.solaranlagen-portal.com/photovoltaik/stromspeicher/photovoltaik-speicher

each hour in January and August as an example for peak and off-peak months, is shown in the middle of the table. It varies from about 17 kWh in the off-peak season to 35 kWh in the peak season. The red colored part highlights the peak time zone of demand, categorized by the electricity providers, when electricity is most expensive.

As power cuts last in average two to four hours a day, the demand per hour is added and equals about 80-100kWh depending on the season. The production of the PV plant can be observed in the right part of the table. It shows the kWh produced per hour for the 16kWp plant and for the 32kWp plant separately. The distribution in the last column indicates when most of the electricity is produced. The red colored part shows the lion's share, which is around noon.

Table 1: Hourly demand and production per hour[84]

Time	Category	demand (kWh)			production (kWh)			
		distr. %	January (peak)	August (off-peak)	kWh/kWp	16 kWp	32 kWp	distr. %
6:00-7:00	Normal	4%	30	17	0	0	0	0
7:00-8:00	Normal	4%	31	18	0,05	0,78	1,56	0,97%
8:00-9:00	Normal	5%	35	20	0,23	3,68	7,36	4,55%
9:00-10:00	Normal	5%	37	21	0,44	6,97	13,94	8,63%
10:00-11:00	Normal	5%	35	20	0,63	10,06	20,12	12,45%
11:00-12:00	Normal	4%	31	18	0,72	11,59	23,19	14,35%
12:00-13:00	Normal	4%	31	18	0,75	12,05	24,10	14,91%
13:00-14:00	Normal	5%	33	19	0,69	11,09	22,17	13,72%
14:00-15:00	Normal	4%	31	18	0,60	9,58	19,15	11,85%
15:00-16:00	Normal	4%	31	18	0,46	7,39	14,78	9,14%
16:00-17:00	Normal	4%	31	18	0,32	5,05	10,09	6,24%
17:00-18:00	Normal	4%	31	18	0,15	2,34	4,68	2,90%
18:00-19:00	Peak	5%	35	20	0,02	0,25	0,49	0,30%
19:00-20:00	Peak	5%	35	20	0	0	0	0
20:00-21:00	Peak	4%	31	18	0	0	0	0
21:00-22:00	Peak	4%	30	17	0	0	0	0
22:00-23:00	Off-Peak	4%	26	15	0	0	0	0
23:00-24:00	Off-Peak	3%	23	13	0	0	0	0
24:00-1:00	Off-Peak	3%	23	13	0	0	0	0
1:00-2:00	Off-Peak	3%	23	13	0	0	0	0
2:00-3:00	Off-Peak	3%	23	13	0	0	0	0
3:00-4:00	Off-Peak	3%	23	13	0	0	0	0
4:00-5:00	Off-Peak	3%	23	13	0	0	0	0
5:00-6:00	Off-Peak	4%	26	15	0	0	0	0
Sum per day		**100%**	**710**	**406**	**5**	**81**	**162**	**100%**

[84] Own calculation based on researched demand and production values

Considering a lead acid battery, the battery discharge limit needs to be taken into account. As the discharge depth of lead batteries is 50%, it has to be dimensioned double as big. Therefore for 80 kWh net a battery system, as illustrated below, with a capacity of 160 kWh gross is needed.

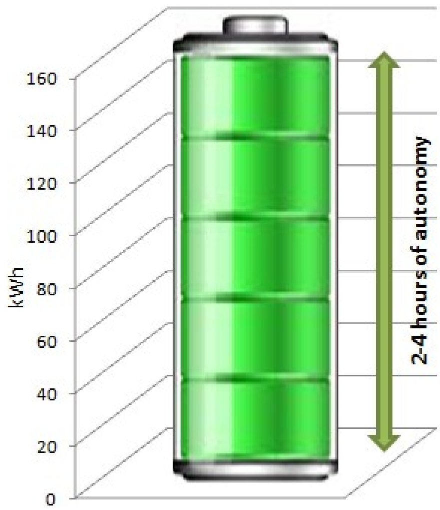


Figure 25: Gross battery size in kWh[85]

A battery with a voltage of 48 V is the most commonly used according to the PV industry[86].

The formula for calculating the battery capacity Q is:

$$Q = U * I * t$$

Q = Capacity (Wh)
U = Voltage (V)
I = Current (A)
t = time (h)

The formula can be applied as following in order to calculate the dimension of the battery:

$$It = \frac{Q}{U}$$

Given parameters:

Capacity needed: 160 000 Wh
Battery voltage: 48 V

[85] Own figure based on own calculation
[86] Mavisis (2013), http://www.mavisis.com/uploads/y-inverter.pdf

When applying the formula the calculation looks as following:

$$It = \frac{160\,000\,Wh}{48\,V}$$

$$It = 3\,333\,Ah$$

A battery with the capacity of 3.333 Ah, equaling 160kWh gross, is needed.

4.2.3.3 Battery technologies for PV systems

As already mentioned the lead acid battery technology is the most commonly used at the moment[87].

One advantage of the lead acid battery is that it exists already more than a century. Due to the long experience it is confirmed that it is a mature, reliable and well-understood technology. Lead batteries are inexpensive and easily available worldwide. Moreover the self-discharge rate is one of the lowest among rechargeable battery systems. [88]

The peculiarity about lead acid batteries is the discharge depth of about 50%. If the battery is discharged lower than 50% it causes harm and shortens the lifetime.

Lead batteries can be divided into flooded lead-acid batteries (FLA) and valve-regulated lead-acid batteries (VRLA). The main difference is that VRLA batteries don't need water to be refilled. That is why they are almost maintenance-free, although they are more expensive and have a shorter lifetime.[89]

The O&M effort of lead acid batteries is low. Besides cleaning, the electrolyte level and cell voltage of the FLA batteries need to be checked every 6 months. [90]

In comparison, the discharge depth of the lithium-Ion battery is much lower, with about 80-90%. Their lifetime is expected to last up to 20 years and there is no O&M to be done. Still the costs for those batteries are very high[91].

---

[87] Solaranlagenportal (2013), Marktübersicht Photovoltaik-Speicher, http://www.solaranlagen-portal.com/photovoltaik/stromspeicher/photovoltaik-speicher

[88] Battery University (2013), The best battery, http://batteryuniversity.com/learn/article/whats_the_best_battery

[89] Trojan Batteries (2013), products, http://www.trojanbatteryre.com/Tech_Support/ComparingFlood2VRLA.html

[90] Fechner, H., (2012), MSc Program, Renewable Energy in CEE, Module 3, Solar Energy, p. 11

[91] Stromspeicher (2013), Stromspeicher, http://www.strom-speicher.org/photovoltaik-stromspeicher/

4.2.4 Selected PV system for the case study

Having considered the all the above mentioned circumstances, a PV system, suggesting the module and battery type is recommended. Still, one has not full autonomy in selecting the components. A MNRE accredited channel partner has to be chosen to realize the project which is eligible for the 30% investment subsidy. A list of the channel partner is published on the homepage of the MNRE.

4.2.4.1 Selection of PV modules

Concerning modules the author is opting for poly crystalline modules, manufactured by the Indian company EMMVEE photovoltaics[92]. The modules are roof top mounted, supported with a triangular under construction.

Module type:	poly crystalline, 72 pcs of 6' cells ES 275-295 P72
Dimension:	990mm x 2007mm x50mm, 1,98m²
Nominal Power:	290Wp
Efficiency:	14,4 %

The mono-crystalline technology is slightly more efficient than poly crystalline, although the gap is shrinking. Still poly crystalline cells are working better in hot climate, as their temperature coefficient is better than that of mono crystalline products.[93] BOS like inverter, cables and mounting system, need to be chosen according to subsidy conditions and channel partner.

4.2.4.2 Selection of the battery back-up system

Having assessed the need of a battery system, while bearing in mind the power cut problem, it is reasonable to add a 160kWh gross lead battery back-up system. A 160kWh battery back-up system can cover about two to four hours of power cut or

[92] EMMVEE photovoltaics (2013), polycrystalline modules
http://emmveepv.com/pdf/EMMVEE_ES_275-295_P72_SEpt2012.pdf
[93] Renewable energy world (2013), mono crystalline or poly crystalline,
http://www.renewableenergyworld.com/rea/blog/post/2012/07/monocrystalline-or-polycrystalline

grid instability every day. In other words it would create two to four hours of autonomy.

4.2.5 The costs of the turn-key PV system

According to Bridge of India, the benchmark prices as of March 2013 for installations ranging size wise from 10-100kWp, without a battery back-up system are currently as following[94]:
100 rs/Wp = 100.000 rs/kWp = approx 1,100 EUR/kWp
Calculating conservatively, a turn-key price of 1,500 EUR/kWp is assumed.
The total costs for a 16kWp PV plant are 24,000 EUR
The average price for lead battery per kWh capacity is about 200 EUR.
To cover daily approximately 3-6 hours of the demand with a discharge rate of 17-30kW, a system with a gross capacity of 160kWh is needed.
The total costs for the battery back-up system are then approx. 32,000 EUR. This price is the average result out of three sources, two among them being rough verbal offers and one a written offer[95]. As the batteries have a life time of 8-10 years, it needs to be assumed, from today's point of view, that the same costs for the replacement of the batteries have to be included in year 10.

The initial costs for a 16 kWp PV plant including a 160kWh battery back-up system amount to 56,000 EUR. Deducting the 30% investment subsidy, the final costs would be 39,000 EUR.

4.3 Incentives and Financing Opportunities

In this section potential incentives and ways of financing will be discussed.
In general PV is not an expensive technology, although it needs a high upfront investment. Once it is installed, there are only minor maintenance expenses but basically running costs are quite low and the investment pays back soon. After that electricity is almost for free.

94 Green Clean Guide (2013), Benchmark prices, http://greencleanguide.com/2013/07/17/mnre-capital-subsidy-scheme-for-off-grid-solar-system/
95 Solarkonzept (2013), Offer per Email September 3, 2013

In order to counteract the high upfront investment, an investment subsidy program was set up by MNRE. In India a capital subsidy of 30% is granted. By the time of writing the thesis the subsidy was still available.

A feed-in-tariff was not considered. Feeding in the produced electricity into the grid and being supplied by the grid was not the target as it wouldn't solve the power cut problem.

4.4 Two recommended options for Somatheeram

Having considered five different options, two of them are recommended for which the calculations are based on. For both options the 30% capital subsidy is taken into account.

Option 1: 16 kWp PV, without battery back-up system
Option 2: 16 kWp PV, with 160 kWh battery back-up system

Based on the two recommended options the calculations are executed, which will reveal the energetic, ecologic, economic and marketing results and relevance. In the conclusion the most suitable option is suggested for which a summary of its feasibility is given.

4.5 Energetic results and relevance

In this section the energetic point of view of the two recommended systems will be analyzed. This includes the calculation of the electricity yield and the solar fraction. It also discusses the overall energetic relevance and the possibilities to boost it. The option for a 32 kWp plant is still included in case that more space will become available. Nevertheless focus will be put on the recommended size of 16 kWp.

The formula to calculate the electricity yield of a PV system is the following:

$$Eele = A * \ QSol * \ r * \ \eta$$

Eele Electric energy yield (kWh)
A Total solar panel area (m²)
QSol Annual solar irradiation (W/m²)
r Solar panel efficiency (%)
η Performance ratio, coefficient for losses

The PR (Performance Ratio) is an important value to evaluate the quality of a photovoltaic installation as it calculates the performance of the installation independently of the orientation, inclination of the panel. It also includes all losses like inverter losses (4-15%), temperature losses (5-18%), AC and DC cable losses (2-6%), losses due to weak irradiation (3-7%) and losses due to dust and snow (2%)[96].

When applying the formula the calculation looks as following:

$$Eele = 114.84\,m^2 * \frac{2362\,\frac{W}{m^2}}{y} * \ 14.4\% * \ 0.78$$

The estimated electricity for the 16,8 kWp plant equals approximately 30,000 kWh/a.

The next formula shows a similar approach to calculate the annual electricity yield. Here, the area, as well as the efficiency of the solar panel is replaced by the total capacity of the PV plant in kWp. Multiplying the solar irradiation times the performance ratio (PR), equals the yield in kWh/kWp. This ratio is commonly used in the PV business. By multiplying the yield times the total capacity, the yield for the PV plant will be identified.

$$Eele = \ QSol * \eta * P$$

Eele Electric energy yield in kWh/kWp
QSol Annual solar irradiation in kW/m²
η Performance ratio
P Power (kWp)

When applying the formula to the specific power plant, the calculation looks as following:

[96] Photovoltaic Software (2012), Performance ratio, http://photovoltaic-software.com/PV-solar-energy-calculation.php

$$Eele = 2362\frac{kW}{m^2} * \ 0.78 * 16\ kWp$$

The estimated annual electricity for the 16, kWp plant equals also approximately 30,000 kWh.

The next table shows the above explained conducted calculation in an excel sheet. The values are based on the solar radiation which was sourced from the US Energy Department. The values here called global average in the third row reflect the solar radiation in Trivandrum in W/m²/day. In the following row it is simply converted from watt to kilowatt. In order to calculate the yield in kWh per kWp of installed capacity, a performance ratio (PR) of 0.78 was used[97]. The yield per installed kWp per day ranges from 4 – 6 kWh, per year it is in total 1,842 kWh. In the lower part of the table the yields for the 16 kWp and 32 kWp plant are calculated by multiplying the results of one kWp times the capacity.

Table 2: Conversion of Solar Radiation into yield per kWp[98]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM	Unit
Global Avg W/m²/day	5737	6756	7528	7868	7954	6872	4977	5210	6595	6359	5964	5893		
Global Avg kW/m²/day	6	7	8	8	8	7	5	5	7	6	6	6		
Conversion to kWh/kWp														
PR (Performance Ratio)	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78		
Yield: kWh/kWp/DAY	4	5	6	6	6	5	4	4	5	5	5	5		
Days per month	31	28	31	30	31	30	31	31	30	31	30	31		
Yield: kWh/kWp/MONTH	139	148	182	184	192	161	120	126	154	154	140	142	1842	kWh/kWp /year
Monthly sum:														
16 kWp	2220	2361	2912	2946	3077	2573	1926	2016	2469	2460	2233	2280	29472	kWh
32 kWp	4439	4722	5825	5892	6154	5146	3851	4031	4938	4920	4466	4560	58944	kWh
Daily sum:														
16 kWp	72	84	94	98	99	86	62	65	82	79	74	74		kWh
32 kWp	143	169	188	196	199	172	124	130	165	159	149	147		kWh

The electricity yield of 1842 kWh/kWp is almost double as much as the mid European average. As the next graph reveals, the productions does vary over the

[97] Burgess, R (2012), Your new solar array actual performance may vary, http://www.renewableenergyworld.com/rea/news/article/2012/04/your-new-solar-array-actual-performance-may-vary

[98] Own calculation based on data of the US Energy Department, http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

year. Here the electricity produced from the 16 kWh PV plant per month is shown. In average about 2300 kWh are produced per month, peaking in spring, just before the monsoon period with up to 3100 kWh. A lower yield in July and August, with about 2000 kWh is the consequence of the monsoon, when it is covering Kerala with rain.

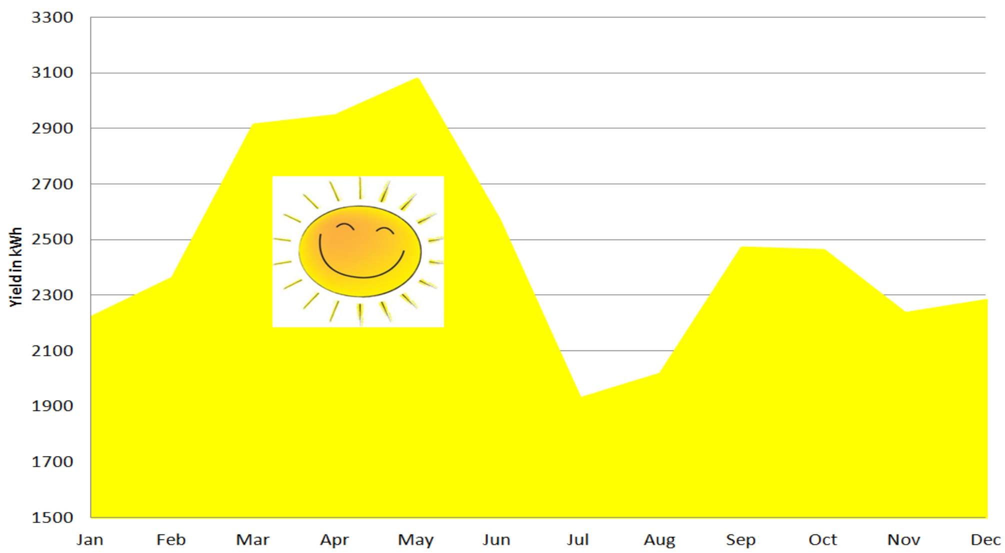


Figure 26: Electricity yield in kWh of the 16 kWp PV plant[99]

The solar fraction, meaning the share of PV considering the total demand is illustrated in the table below. It is ranging from 9% to 29 % for the small and the large plant. The average solar fraction is 12% for the 16kWp plant and 24% for the double sized plant. The reason for this crucial difference is mainly the size of the plant, but also the demand is varying according to the number of guests staying in the hotel. The variance of the supply of the sun is another factor impacting the solar fraction.

The formula to calculate the solar fraction of a PV system is the following:

$$SF = \frac{Eele}{D}$$

SF	Solar fraction (%)
Eele	Total electric energy yield (kWh)
D	Total demand (kWh)

When applying the formula to the specific power plant, the calculation looks as following:

[99] Own graph according to own calculation

$$SF = \frac{29,472}{243,397}$$

The estimated annual solar fraction for the 16, kWp plant equals in average 12%.

Table 3: Solar fraction[100]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM YEAR	Unit
Total Demand	22917	25293	24226	25964	20924	17824	13479	16262	17882	20277	17125	21221	243397	kWh
Yield 16 kWp	2220	2361	2912	2946	3077	2573	1926	2016	2469	2460	2233	2280	29472	kWh
Solar fraction with 16kWp	10%	9%	12%	11%	15%	14%	14%	12%	14%	12%	13%	11%	12%	
Yield 32 kWp	4439	4722	5825	5892	6154	5146	3851	4031	4938	4920	4466	4560	58944	kWh
Solar fraction with 32kWp	19%	19%	24%	23%	29%	29%	29%	25%	28%	24%	26%	21%	24%	

The next graph illustrates the influence of the demand on the solar fraction. The curves are moving contrarily. The higher the demand, the lower is the solar fraction. A lower demand in the off-peak season increases the solar fraction. The lowest solar fraction of about 9% can be observed at the peak season in January and February. While in the off-peak season from May to July it reaches its peak, when less electricity is needed, and almost 15% can be covered by the PV plant.

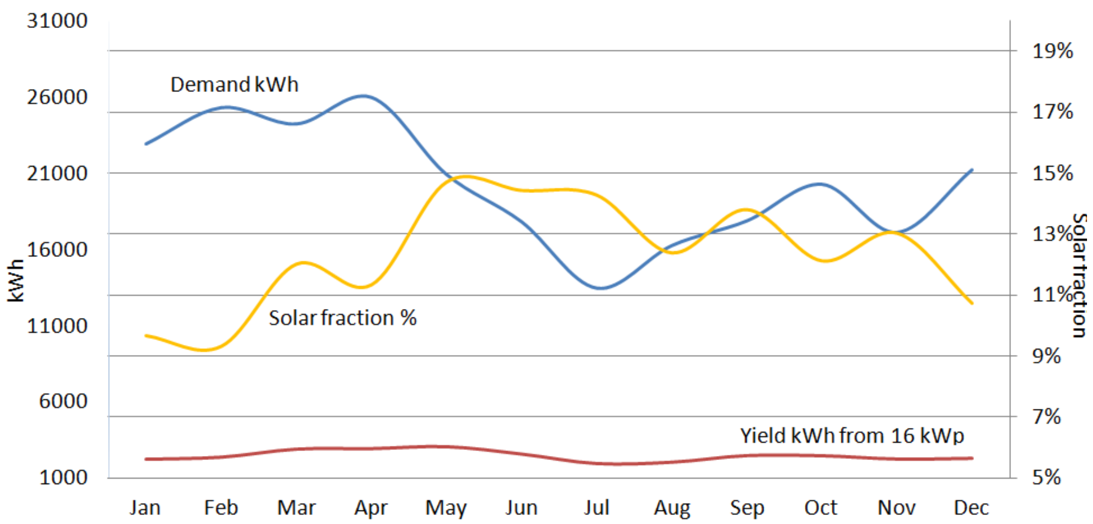


Figure 27: Solar Fraction of a 16 kWp PV plant[101]

[100] Answers (2013), Solar fraction, http://www.answers.com/topic/solar-fraction-1
[101] Own graph based on the calculated solar fraction data

The energetic advantage of the PV system including the battery back-up system is an increase of energy security. The great plus of the PV system including the battery back-up system is, that it can cover power cuts and replaces a huge share of the diesel generator, so that in total it almost reaches a 100% uninterruptible power supply (UPS).

4.5.1 Option 1: 16 kWp PV, without battery back-up system

The 16 kWp PV plant produces per day 60-100 kWh, per month 2000-3000 kWh and per year about 30,000 kWh.
The solar fraction as described above amounts to an average value of 12%, calculated throughout the time period of a year.

4.5.2 Option 2: 16 kWp PV, with 160 kWh battery back-up system

The 16 kWp PV plant with the battery back-up system produces the same amount of electricity as Option 1, but the difference here is, that almost all the production is stored in the battery to be able to cover the power cuts.
The total average solar fraction of 12% stays also the same.

Theoretically, comparing the dischargeable kWh from the battery and the average demand of kWh of the diesel generator, it can be confirmed that the battery can substitute the diesel generator a 100%.
Practically, if the demand of the resort at peak season and peak time is higher than 30kW per hour, then probably the battery cannot discharge at such a fast rate, and the diesel generator has to jump in. It is assumed that the battery can substitute the diesel back-up system with about 80% in peak season, equaling a yearly average substitution of 90%.

4.5.3 Energetic relevance

Considering the small size of the PV plant, the solar fraction of 12% is very satisfying. The fact that the stored PV electricity in the battery can theoretically substitute the diesel generator a 100%, and about 90% throughout the year is a positive result, which exceeds the expectations.

4.5.3.1 How to boost the energetic relevance?

The energetic relevance could be boosted, by lowering the demand. The demand can be lowered by a more efficient use of electricity. Having a lower demand but the same supply, increases the solar fraction.
Increasing the size of the plant increases the solar fraction as well. The second building with the same size could add another 16 kWp of PV. Instead of 12% the solar fraction will result in 24% – nearly a quarter of the electricity would then come from the sun.

4.6 Ecologic benefit results and relevance

After having analyzed the energetic aspects of the PV plant, the ecologic point of view will be discussed.
In this section it will be focused on the avoided CO2eq emission, the energy payback time and the carbon footprint.

4.6.1 CO2Equ emissions

The main ecologic benefit of PV is the avoided CO2Equ. The current system is based on the electricity supply from the diesel generator and the supply from the public grid. Substituting a part of this fossil fuelled electricity supply with PV saves CO2Equ emissions.

PV itself is not emitting any CO2Equ emissions during electricity production, unlike most other generators. CO2Equ is only emitted during the production of the PV system. The CO2Equ emission during the production of the system heavily depends on various factors, mostly though on the electricity mix from the country of the silicon and wafer manufacturer. For the calculations 30 g CO2/kWh will be used as this is the average figure sourced from EPIA[102]. Moreover it makes a big difference what length of life time one uses to calculate the emissions per kWh.

The CO2Equ emissions from the diesel generator are very high. The energy density of one liter diesel is about 10 kWh. But when the diesel is used in a diesel generator to produce electricity, due to losses only about 2,5 kWh per liter are reached. One liter diesel emits approximately 2,64 kg CO2Equ[103]. That would equal around 1 kg CO2Equ per kWh electricity. In practice this means, turning on the A/C (2000W) for one hour, it needs 2 kWh per hour and is emitting about 2 kg of CO2Equ.
The CO2Equ emissions for electricity from the public grid of India's southern grid area equal 760 g/kWh[104]. The average value for India is 963 g/kWh[105], as the share of coal power plants is quite high, compared to Austria with only 155 g/kWh[106].

The formula to calculate CO2Equ emissions for the electricity consumed is the following:

$$CO2Equ = fCO2Equ\ i * E$$

F CO2Equ i	Factor CO2Equ content per kWh electricity (gCO2/kWh)
E	Electricity consumed (kWh)

The CO2Equ content of a specific fuel is given in gCO2Equ per kWh electricity consumed:

$$fCO2Equ\ i = \frac{g\ CO2Equ}{kWh}$$

In order to determine the annual total CO2Equ emissions at Somatheeram the above mentioned formula was applied twice, as there are two types of electricity suppliers, the diesel generator and the public grid:

102 EPIA (2013), European PV Industry Association, About photovoltaics, key facts and figures http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiafactsheets/110513_Fact_Sheet_on_the_Carbon_Footprint.pdf&t=1378758557&hash=06f0f16a9db58a3dd83dadf2808fa34591b423cf

103 Energiemanagement und Klimaschutz in der Landwirtschaft (2011), http://www.lkv-st.de/index.php?name=download&dlid=223

104 CEA (2013), Central electricity Authority of India, CO2 Baseline database for the Indian power sector, http://www.cea.nic.in/reports/planning/cdm_co2/user_guide_ver8.pdf

105 Energy efficiency report India (2011), CO2 emissions, http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/bcb30e13c8cbe734c125786400512e26/$file/india.pdf

106 Österreichs Energie (2013), Die Interessenvertretung der österreichischen E-Wirtschaft, Erzeugung, http://oesterreichsenergie.at/daten-fakten/statistik/erzeugung.html

$$CO2Equ = 1000gCO2Equ \ * \ 22{,}000 \ kWh = 22 \ tons$$

+

$$CO2Equ = 760gCO2Equ \ * 221{,}000 \ kWh = 168 \ tons$$

=

$$190 \text{ tons of CO2Equ}$$

Currently the estimated annual total CO2Equ emissions at Somatheeram equal approximately 190 tons.

The table below again sums up the current yearly CO2Equ emissions at Somatheeram based on the average demand. Somatheeram produces about 10% of its consumed power on its own with the diesel generator. Adding the emissions from the grid (South Indian Electricity mix) to the one's of the diesel generator results in 190 tons of CO2Equ emissions per year.

Table 4: Current, yearly CO2Equ emissions at Somatheeram from conventional energy sources[107]

PV	CO2Equ g/kWh	tons CO2Equ/ MWHele	MWHele total year	tons CO2Equ / year	MWHele total 20 yrs	tons CO2Equ/ 20 yrs	MWHele total lifetime	tons CO2Equ/ lifetime
Diesel Generator	1000	1	22	22	442	442	774	17.094
South Indian Electricity mix	760	0,76	221	168	4.420	3.359	7.735	1.299.171
CO2 emissions				**190**		**3.801**		**1.316.265**

The next graph reflects the volume of CO2Equ emissions of the current fossil fuelled electricity supply. The diesel generator emits about one kilogram of CO2Equ per kWh consumed, whereas the power supplied from the public grid has about 25% less emissions, but still causes about 760 grams.

[107] Own calculations based on researched emission data listed in the footnotes above

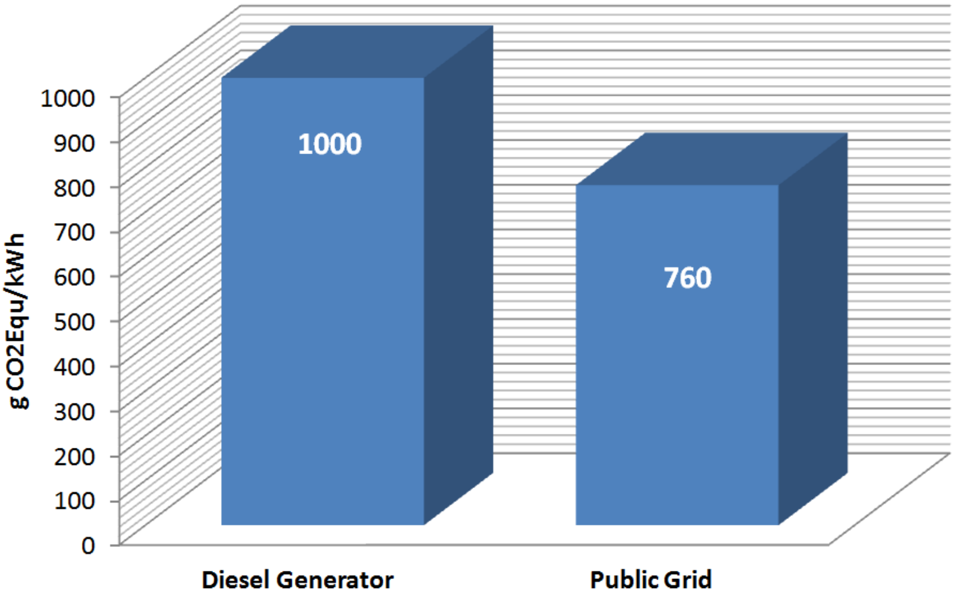


Figure 28: CO2Equ emissions in grams per kWh consumed[108]

Talking about emissions, another ecologic advantage of PV is that no noise is emitted.

4.6.2 Energy payback time

The Energy payback time (EPBT) is another aspect of the ecologic relevance.

The EPTB is the time taken for power generation to compensate for the energy used in production. According to EPIA[109] PV systems already have an EPBT of 1 to 3.5 years. Once the invested energy is paid back, the PV system produces extra energy. This could be compared to a plus energy house, which produces more energy that it needs.

The EPBT is linked to the CO2Equ emissions during production of the equipment and therefore is varying. The irradiation of the region where the system is installed, resulting in the amount of energy produced has a vast impact on the EPBT. The higher the yield, the faster the energy payback time and the less CO2Equ emissions/kWh over lifetime.

It has to be addressed that no fossil fuel ever pays back. An EPBT cannot be applied here, as there is no point of time, when suddenly the harvested energy

[108] Own graph based on researched emission data listed earlier

[109] EPIA (2013), European PV Industry Assosiation, About photovoltaics, key facts and figures, http://www.epia.org/about-us/about-photovoltaics/key-facts-figures/

meets the amount of invested energy for producing it. For each consumed kWh supplied by fossils CO2Equ is emitted, which is shown in the diagrams above.
Here rather fits the concept of the carbon footprint[110], which gives a picture of how much carbon is emitted per activity.

4.6.3 Option 1: 16 kWp PV (without battery back-up system)

The table below reflects the CO2 savings from the 16 kWp PV plant without battery.
The total PV production of 29.472 kWh is split into two parts. As the diesel generator is mostly used in the evening and during night, the PV system without battery cannot substitute the diesel during that time.
As there are also minor blackouts and power cuts during the day it is assumed that the diesel generator is needed 25% during the day (when there is sun), and 75% during evening and night time. The 25% during the day can be substituted by the produced electricity from the PV plant immediately. 19% of the production is used to substitute about 25% of the diesel generator during the day, which equals 5,53 kWh/year. Each kWh produced by the sun instead of the diesel generator saves almost a kilogram of CO2Equ. Adding up all the kWh substituting the diesel generator due to only a small PV plant of 16kW results in 5,3 tons a year.
81% of the production is used to substitute about 11% of the electricity supplied by the public grid, which results in 23.947 kWh/year.
The PV system without battery can substitute about 11% of the electricity taken from the public grid. Per kWh 730 g of CO2 are avoided. During a whole year this figure increases up to 17,5 tons a year.

Summing up the CO2Equ avoided from the diesel generator and the grid per year, the environment can be spared with around 23 tons.

[110] Carbon Footprint (2013), http://www.footprintnetwork.org/en/index.php/gfn/page/carbon_footprint/

Table 5: CO2Equ emission savings PV without battery back-up system[111]

PV	CO2Equ g/kWh	tons CO2Equ/ MWHele	MWHele total year	tons CO2Equ / year	MWHele total 20 yrs	tons CO2Equ/ 20 yrs	MWHele total lifetime	tons CO2Equ/ lifetime
Diesel Generator	1000	1	5,53	5,53	110,50	110,50	193	1.068
PV	30	0,03	5,53	0,17	110,50	3,32	193	32
CO2 Savings	**970**	**0,97**		**5,36**		**107,19**		**1.036**
PV	**CO2Equ g/kWh**	**tons CO2Equ/ MWHele**	**MWHele total year**	**tons CO2Equ / year**	**MWHele total 20 yrs**	**tons CO2Equ/ 20 yrs**	**MWHele total lifetime**	**tons CO2Equ/ lifetime**
South Indian Electricity mix	760	0,76	23,95	18,20	479	637	838	15.254
PV	30	0,03	23,95	0,72	479	25	838	602
CO2 Savings	**730**	**0,73**		**17,48**		**612**		**14.652**
TOTAL CO2 Savings				**22,84**		**719,03**		**15.688**

The formula to calculate the CO2Equ savings is the following:

$$CO2Equ\ s = (CO2Equ\ d + CO2Equ\ g) - CO2Equ\ pv$$

CO2Equ s	Total CO2Equ savings in tons
CO2Equ d	CO2Equ emissions from diesel generator in tons
CO2Equ g	CO2Equ emissions from public grid in tons
CO2Equ pv	CO2Equ emissions from PV in tons

When applying the formula to the specific electricity sources at Somatheeram, the calculation looks as following:

$$CO2Equ\ s = (5{,}53\ tons + 18{,}2\ tons) - 0.89\ tons$$

The total CO2Equ avoided equals 22.84 tons as earlier shown in the table.

When the emissions are directly compared, the picture becomes clearer as it can be observed in the graph below. A power system including a 16 kWp PV plant, without a battery backup system, saves around 12% of CO2Equ emissions per year.

[111] Own table based on researched emission data listed earlier

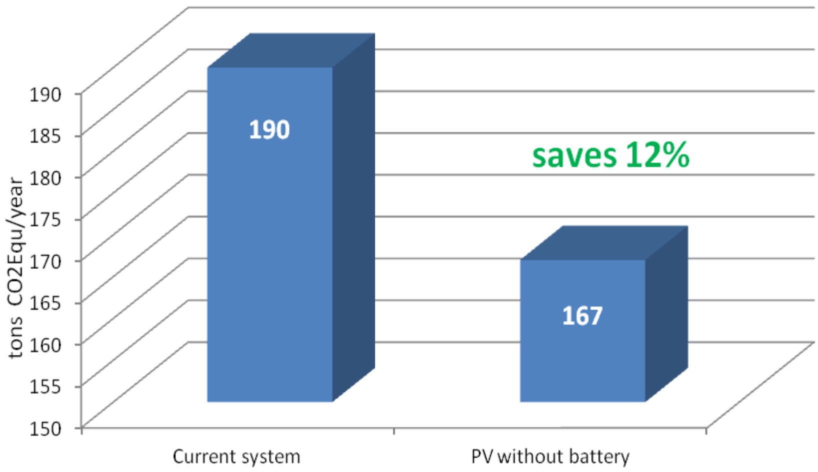


Figure 29: CO2Equ emissions of PV plant without battery backup system[112]

4.6.4 Option 2: 16 kWp PV, with 160 kWh battery back-up system

For option 2 – on the contrary - the CO2 emissions of the battery have to be included especially those from the production and its recycling process. According to a Japanese research team[113] the CO2 emission of a lead battery is about 60 kg per kWh storage capacity. For a 160 kWh back-up system this equals 9.600 kg, dividing the emissions by the kWh produced during the 10 year lifetime, is 50 g/kWh.

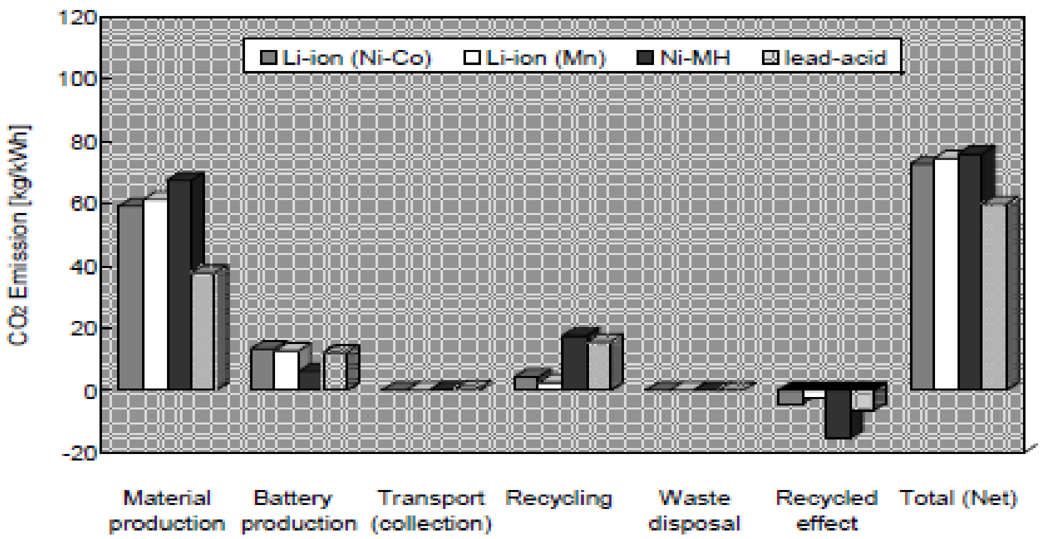


Figure 30: CO2 emissions of different types of batteries per kWh capacity[114]

[112] Own graph based on own calculations
[113] Ishihara, K., Kihira, N., Terada, N., Iwahori, T., (no date), Environmental burdens of large lithium-ion batteries developed in a Japanese national project, http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF
[114] Ishihara, K., Kihira, N., Terada, N., Iwahori, T., (no date), Environmental burdens of large lithium-ion batteries developed in a Japanese national project, http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF

The next table shows the CO2 savings from the 16 kWp PV plant with battery.

The total PV production of 29.472 kWh is split into two parts, focusing on the substitution of diesel. It is estimated that 75% of the diesel are needed during evening and during night. The aim is to almost completely substitute the diesel generator with the help of a battery system. 75% of the production is used to substitute about 90% of the diesel generator, which equals 19.890 kWh/year.

In this case, every kWh produced by the sun instead of the diesel generator saves 920 g of CO2. Substituting the diesel generator realistically 90% results in avoiding 18,3 tons a year.

25% of the production is used to substitute about 4% of the electricity supplied by the public grid, which results in 9.582 kWh/year. Substituting the electricity from the grid saves around 730 g kWh of CO2. When replacing 4%, 7 tons of CO2 per year are avoided.

Table 6: CO2Equ emission savings PV with battery back-up system[115]

PV	CO2Equ g/kWh	tons CO2Equ/ MWHele	MWHele total year	tons CO2Equ / year	MWHele total 20 yrs	tons CO2Equ/ 20 yrs	MWHele total lifetime	tons CO2Equ/ lifetime
Diesel Generator	1000	1	19,89	19,89	397,80	397,80	696	13.846
PV	30	0,03	19,89	0,60	397,80	11,93	696	415
Battery	50	0,05	19,89	0,99	397,80	19,89	696	692
CO2 Savings	**920**	**0,92**		**18,30**		**365,98**		**12.739**
PV	CO2Equ g/kWh	tons CO2Equ/ MWHele	MWHele total year	tons CO2Equ / year	MWHele total 20 yrs	tons CO2Equ/ 20 yrs	MWHele total lifetime	tons CO2Equ/ lifetime
South Indian Electricity mix	760	0,76	9,58	7,28	192	255	335	2.441
PV	30	0,03	9,58	0,29	192	10	335	96
CO2 Savings	**730**	**0,73**		**6,99**		**245**		**2.345**
TOTAL CO2 Savings				**25,29**		**610,75**		**15.084**

Again the emissions from the current power supply system are directly compared with the integrated PV system including a battery backup system.

The graph below shows are saving of 25 tons of CO2Equ. Each year it saves 13%, one percent more than the PV system without a battery backup system. Even though the carbon footprint of the battery is included in the calculation the avoided

115 Own table according to researched emission data listed earlier

amount of CO2 is higher. This is a consequence of the advantage of the battery backup system, which focuses on substituting the diesel generator. By substituting the diesel generator more CO2 can be spared.

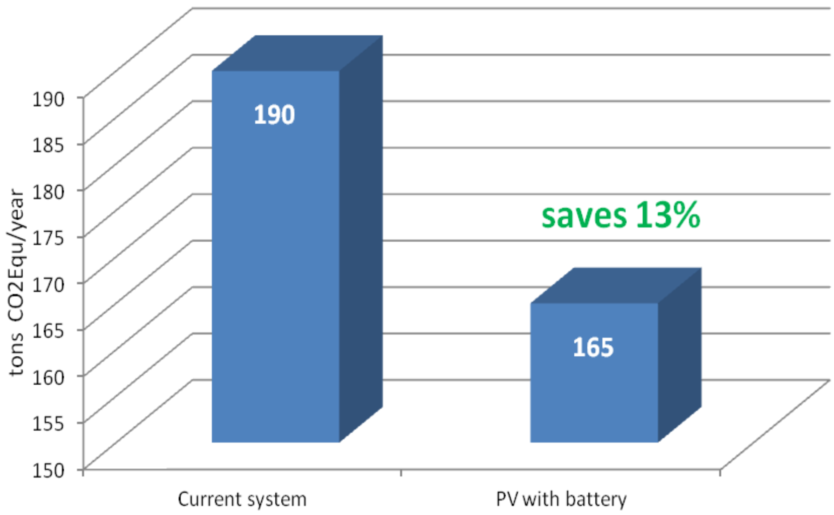


Figure 31: CO2Equ emissions of PV plant with battery backup system[116]

4.6.4.1 Carbon footprint per cottage and night

Somatheeram's current carbon footprint for electricity, without PV is 8 kg per cottage per night. The almost emission free 16 kWp PV plant reduces it to 7 kg per cottage per night.

4.6.5 Ecologic relevance

The core question of the thesis concerning ecologic relevance can be answered clearly. PV is of high relevance for a low-carbon economy.

Basically the PV system doesn't emit any emission and noise during the electricity production. The small part of emissions is dating from the time of manufacturing the equipment. PV plays a major role concerning a clean way of electricity production and can cut CO2 emissions tremendously.

The quite small PV system can save in average (with or without battery) 20 tons of CO2 per year!

[116] Own graph based on own calculation

Electricity from PV is emitting 92-97% less CO2 than the electricity generated from diesel or taken from the grid.

Option 1, without battery, can substitute only the activity of the diesel generator during the day, which is estimated to about ¼ of the total requirement. Instead of turning on the diesel back-up system, PV can used immediately when produced.

Option 2 is designed that way, that the size of the battery is capable of storing pretty much the amount of electricity which in average is needed during power cuts. Theoretically, kWh-wise the system can substitute 100% of the diesel generator. Practically it might be around 90%, which is a great achievement.

Also the ecologic relevance could be leveraged by lowering the demand. Each kWh saved equals about 1 kg of CO2 emitted into the atmosphere. It might be quite motivating and figuring out how much of the GHG one can save by responsible electricity consumption.
Table 6 reveals that any additional kWp of PV installed saved around 1,5 tons of CO2 emission per year by dividing 25,29 tonnes of $CO2_{Equ}$ by 16, the capacity of the PV plant.

4.7 Economic results and relevance

In this section the results of the calculations are summarized. The detailed calculations are attached in the annex.

The calculations include a 5% price escalation of the Indian electricity from the grid as well as for the diesel. For both options a 30% capital subsidy is taken into account.
In general the calculations are done in a rather conservative way. For example the investment costs of the PV system and battery system are set at the rather higher end. There could be some room for negotiation and for above the average quality products. For the replacement of the battery in ten years, the same as today's price is assumed.
The exchange rate for converting EUR into Indian Rupees was taken from 20th of August 2013.

The economic key ratios are calculated based on a dynamic investment calculation, including the following factors and values:

Capital Recovery Factor

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

n = depreciation time, i = interest rate

Net Present Value (NPV)

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Ct = cash flow in the year t; Co = Initial Investment; r = WACC

The NPV is the sum of in and outgoing cash flows, discounted by the weighted average cost of capital (WACC). A positive NPV means the project should be realized. Comparing two projects, the higher the NPV the more favorable is the project.

Annuity A:

A = NPV * CRF

Long Run Generation Costs LRGC:

Annuity of Costs / yearly energy production

The long run generation costs (LRGC) are the costs of a kWh produced calculated over the depreciation period. The formula to calculate the LRGC incorporates the NPV of all costs and the capital recovery factor (CRF).

4.7.1 Option 1: 16 kWp PV, without battery back-up system

The following financial parameters are the base for the economic calculation.

Investment horizon	20 years
WACC	4 %
Investment cost	1500 EUR/kWp (excl. subsidy)
O&M	368 EUR
Electr. price	9 rps = 0,106 EUR/kWh
Diesel generation costs	27 rps = 0,318 EUR/kWh
Solar Irradiation	1842 kWh/kWp

Key ratios Option 1:

The LRGC of the PV system amount to 7 EUR cents/kWh, which is 3 EUR cents below the grid costs – this means grid parity is achieved. Every kWh supplied from the PV system is cheaper than from the electricity supplier. There are no fuel costs compared to the diesel generator.

The substitution of 11% out of the grid and 25% of diesel creates a virtual income of about 4.000 EUR per year, increasing per year to about 6.000 EUR in year ten, compared to only about 300 EUR costs for O&M.

Due to this income the investment pays back in year 5. After that, it can be perceived as a cash cow. Electricity is generated for free and even creates savings due to the avoided costs for diesel and grid.

As a matter of fact, the NPV is positive, meaning the investment saves 60.425, 11 EUR.

4.7.2 Option 2: 16 kWp PV, with 160 kWh battery back-up system

The 30% capital subsidy is not considered for the replacement of the battery system after ten year.

The financial parameters for the second calculation are as mentioned below:

Investment horizon	20 years
WACC	4 %

Investment cost	1500 EUR/kWp (excl. subsidy)
Battery	32000 EUR (excl. subsidy)
O&M	368 EUR
Replacement of battery	32000 EUR
Electr. price	9 rps = 0,106 EUR/kWh
Diesel generation costs	27 rps = 0,318 EUR/kWh
Solar Irradiation	1842 kWh/kWp

Key ratios Option 2:

The LRGC costs of the PV system including a battery is 11 EUR cents below the electricity costs from the diesel generator – this means diesel parity is achieved by far, having a 35% cheaper alternative. Every kWh in case of power cuts supplied from the PV system instead from the diesel generator is a plus. There are no fuel costs.
The substitution of about 4% out of the grid and 90% of the diesel creates a virtual income of about 7.000 EUR per year, increasing per year to about 10.000 EUR in year ten, compared to only about 300 EUR costs for O&M.
Due to this income the investment pays back in year 6. After that, it can be perceived as a cash cow. Electricity is generated for free and even creates savings due to the avoided costs for diesel and grid.
The replacement of the battery pays back in year 4.
The NPV of 74.705,35 EUR is very attractive.

4.7.3 Economic relevance

The table below is comparing and summarizing the economic key ratios.

It has to be stated that none of the conventional energy sources ever pays back, as they are always causing running costs.
Therefore the answer to the economic core question is that PV can cut down running costs perceivably.

Table 7: Comparison of economic key ratios[117]

	Spec. Investment Costs EUR/kW	NPV EUR	LRGC EUR/kWh	Year of payback	Fuel costs EUR/month
Option 1	1.500	60.425,11	0,07	5th	none
Option 2	3.500	74.705,35	0,20	6th	none
Grid	-		0,10	No payback	2000
Diesel G.	-		0,31	No payback	1000

The investments are breaking even in the 5th and 6th year. Considering the long lifetime of about 30-35 years it is an extremely attractive result.
The LRGC are in both cases below the costs for the diesel generator and the electricity from the grid. As both, grid parity and "diesel parity" are achieved; any kWh from the PV system or from the battery substituting the diesel engine is decreasing the expenses. The economic relevance seems to be already boosted. It might get even better, if the system costs will further decrease.

4.8 Marketing results and relevance

Putting effort into green initiatives creates a positive image of the hotel, which expands the marketing activities.
Going green helps the hotel to stand out of the huge crowd of hotels, to differentiate itself from the others. This offers new possibilities to position the hotel in a new way and to address a specific target group.
Nevertheless the core topic of renewable energy, sustainability and to go easy on resources is also matching the health lifestyle of Ayurveda. Both can address the same target group, even stronger together.

The marketing relevance could be boosted by going green even further, and to undergo a green certification program, like LEED - Leadership in Energy and Environmental Design, to mention only one. Being certified creates a clear picture of what the guest can expect from the hotel, being another selling argument. Also, being part of a certification program offers the opportunity to be found easier.

[117] Own calculations

4.9 Conclusion and Recommendations for Somatheeram Ayurvedic Health Resort

In this section a conclusion of the feasibility study for Somatheeram will be drawn. Based on the conclusion, the most suitable and feasible PV system for the resort will be recommended. After explaining its energetic, ecologic, economic and marketing benefits and relevance, possibilities how to boost them are shared.
As the application of RES work best while being energy efficient at the same time, an idea of an energy concept is mentioned.

4.9.1 Recommended PV system for the case study

The triggering point of considering a PV plant at Somatheeram is the interrupted energy supply from the public grid, with its daily power cuts and the expensive and dirty operation of the diesel generator. As a matter of fact the main aim of integrating a PV plant is to increase energy security by decreasing the dependency on the public electricity provider and to reduce the expensive electricity from the diesel generator.
Bearing that in mind and considering the results, option 2, a 16 kWp PV system including a 160kWh battery back-up system, is recommended.
The recommended PV plant has the potential to replace the diesel generator almost by 100%. The diesel generator should then only have the role as a back-up of the battery back-up system.
The prime purpose of the PV plant is to store the produced solar energy in the battery in order to discharge it when there is power interruption from the public grid.
This means if power supply from the public grid is available, it should be used. In this situation the PV plant should not substitute the grid. Only in the special case that there is overproduction from the PV plant during the day, and that the batteries are already fully charged, then PV can be used directly to substitute the supply from the grid.
The reason for that is the quite small size of the PV plant due to restricted available area at the resort. If the PV plant would be bigger so that it can produce more power than what is needed to overcome the daily interrupted power supply, then it can start to substitute the grid as well. Each kWh from the PV plant is then also cheaper than

from the grid, as no additional battery costs need to be included in the calculation of the LRGC.

4.9.2 Energetic benefit

The geographic location and its climatic specifications are a perfect precondition for PV. The energetic yield of 1.842 kWh per installed kWp PV system in Trivandrum is almost double as high as in Germany.

Considering the rather small size of the PV plant, a solar fraction result of 12% is very satisfying. The solar fraction indicates the share of PV in relation to the total energy demand. The main goal to increase the energy security and independence by bridging the energy gap with PV is achieved. The battery is dimensioned in a way that it can substitute the diesel generator theoretically kWh-wise a 100%, and about 90% throughout the year, considering peak loads in peak season.

4.9.3 Ecologic benefit

The ecologic benefit is enormous.

PV is emitting 92 % less CO2 than the electricity generated from diesel or the grid.

The quite small PV system saves approximately 25 tons of CO2 per year in average. Each kWh saved equals about 1 kg of CO2 not emitted into the atmosphere. PV emits no CO2 and noise during the electricity production. The small part of emissions, included in the calculation is dating from the time of manufacturing the equipment.

With the 16 kWp PV plant, the carbon footprint can be reduced by 12% from 8 kg per cottage per night to 7 kg.

Any additional kWp of PV installed at Somatheeram would save another 1,5 tons of CO2 emission per year.

4.9.4 Economic benefit

Below a comparison of the LRGC and the break-even for both options (with and without a battery) is shown. The results for the recommended system including a battery system are explained in more detail.

Both options cut down the running costs perceivably.

The LRGC of 20 EUR cents of the PV system including a battery are 35% below today's generation costs from the diesel generator which amount to approx 31 EUR cents. This means "diesel parity" is achieved by far. Every kWh in case of power cuts supplied from the PV system instead from the diesel generator is a plus.

The LRGC of 7 EUR cents of the plant without a battery are below the grid costs. This means grid parity is reached.

	16kWp without battery	16kWp with 160kWh battery
LRGC/kWh	7 EUR cent	20 EUR cent
Break-even	in year 5	in year 6

Thinking about the worst case, that the 30% capital subsidy wouldn't be available anymore, the scenario would look like this:

	16kWp without battery	16kWp with 160kWh battery
LRGC/kWh	9 EUR cent	25 EUR cent
Break-even	in year 7	in year 9

The investment is still attractive, as the PV generation costs are in both cases below today's prices from the costs per kWh from the diesel generator (31 EUR cent) and from the grid (10 EUR cent), if a system without a battery is installed.

The investment for the PV plant including the battery system is breaking even in the 6th year. Bearing in mind some minor O&M expenses and the replacement of the battery backup system after around 10 years, after year 6 the electricity is generated for a forecasted lifetime of about 30-35 years for free.

Actually it creates savings due to the avoided costs for diesel and grid.

The substitution of the diesel and partly the grid creates a virtual income of about 7.000 EUR per year, increasing per year to about 10.000 EUR in year ten, compared to only about 300 EUR costs for O&M.

4.9.5 Marketing benefit

Being active at the green front creates a positive image of the hotel, which expands the marketing activities and helps to stand out of the huge crowd of hotels.

The core topics renewable energy and the healthy lifestyle of Ayurveda are consistent. The issues sustainability and to go easy on resources are overlapping. Together the effect might be even stronger and more authentic.

4.9.6 How to boost the relevance of PV

The relevance and at the same time the impact of the PV system can be enforced by various measurements mentioned below. Energy efficiency is playing the most decisive role.

4.9.6.1 Energy efficiency first

In order to leverage the relevance of PV as a source of electricity at Somatheeram, it is recommended first to undergo an energy audit, checking potential to save energy and a more efficient use.
As in the case of Spice Village it reduced the total connected load by 80%, including getting rid of the A/Cs.
If the reduction of electricity is done in a more moderate way, allowing some comfort due to the hotter climate around Trivandrum, there is still enough potential to save electricity. In the additional chapter “new energy concept” rough ideas are given how to lower the demand.

4.9.6.2 Additional use of renewable energy sources: Biodiesel

The remaining amount of conventional fossil diesel which will be needed could be exchange by biodiesel.
As there is a lot of waste oil primarily from the ayurvedic treatments and from the kitchen, it could make sense to look for a waste oil collection system, which provides a decent priced biodiesel in exchange.
This substitution is not economically calculated in the course of this master thesis.

4.9.6.3 Awareness rising

Raising the guest's and staff's awareness, informing them about the electricity problem all over India, pointing out that this is not a specific negative aspect at Somatheeram only, could create a better comprehension and understanding of the problem. Once the guests and the staff learns and understands the issue, they might be willing to support a more aware electricity use. Possibilities would be to visibly place in the cottages a summary and explanation of the energy topic in India. This could also include some rough energy figures of Somatheeram and examples of the demand of e.g. water heater, A/C including rough calculations of the use per hour and minutes, to get an idea and feeling about kWh and CO2 emitted or avoided.
Within that scope the role of the PV plant and any other green initiatives could be perfectly marketed here. Presenting the positive impacts creates a positive image.
In addition to this printed information, stickers could be placed on the various appliances which are to be spotted easily every day in order to create awareness.

The below pictures show example of these stickers which are placed in the rooms of the world's first net-zero-energy hotel Boutiquehotel Stadthalle in Vienna, Austria.

Figure 32: Informative stickers to create awareness[118]

The first pictures informs the guest, how much CO2 is saved per year, while not having a mini bar in the rooms. The picture in the middle tells the demand of a LED light during an hour. The last sticker is an example to show how much water can be saved by having installed water saving taps.
Awareness creation leads to the next point.

[118] Boutiquehotel Stadthalle Wien (2013): Null-Energie-Bilanz, http://www.hotelstadthalle.at/

4.9.6.4 Change of behavior

Knowing of the problem could influence the behavior of the guests and the staff. Besides the target of a more efficient use of the resources, a shift of the consumption time could support the system. As there is mostly lack of energy during Kerala's peak time from 6 to 10 pm, it would help to shift any electricity consuming activity to the normal or off-peak time. Also if a PV system without battery would be considered, the demand should match the sun's electricity production time (from 6 am – 6 pm). This could apply to the guests' habits like the use of A/C, heating up water for showering, charging cell phones or using laptops etc. The staff's activities like doing the laundry could also be affected.

4.9.6.5 Larger PV plant

Any additional kWp of PV is a plus and influences the energetic, ecologic and economic relevance. If there is additional space for a PV installation available, it is suggested to expand.
Assuming the forecast is correct, that most of the diesel can be substituted by the 160kWh battery system, no additional storage capacity needs to be added.

4.9.7 New energy concept

In order to run the resort more efficiently, first an energy audit should be executed. The current status will be checked, the main electricity consumers identified and analyzed with what kind of measurements the rate of energy saving could be achieved.
Having a reduced power demand, the impact of PV as a RES can be scaled up.
This new energy concept should give a short overview on how to reduce electricity demand and mentions one more already widespread sustainable activity in the hotel industry.

4.9.7.1 Electricity

A reduction of the connected load could be accomplished by many small actions, but looking at the pie chart in chapter "2.2.2.1 The role of Air-Condition in the load profile" answers the question for the main consumers.
Cooling is influencing the electricity demand enormously. For new buildings a better insulation should be considered. Avoiding A/C as much as possible and rather push the use of fans would lower the demand significantly.
Lights are consuming around 20% of the total electricity. Switching to LED bulbs saves a lot and pays off quickly. Adding light sensors along the walkways of the spacious resort would support savings as well.
Replacing ordinary PCs by laptop is another opportunity to save on energy.

A key card system, which deactivates all electronic devices when leaving the room, could give some control over wasting energy caused by unawareness.

4.9.7.2 Water heater

The share of the connected load of the water heater is almost 50%. Switching from electrical water heater to solar thermal heaters would make a huge change. Similar situation as with the PV, there is sufficient sun light available heating up the collectors to provide enough hot water available.
Combating already scarcity of water, exchanging the current water taps with water saving taps could save up to 35%, as indicated by the Boutiquehotel Stadthalle.

4.9.7.3 Miscellaneous sustainable activities

Linen and towels should only be exchanged if expressively wished for. The wish could be expressed by putting a sign on the bed sheets for example. This activity is very eco friendly as it is saving energy to heat up water, saving water and saving detergent.

5 Conclusions

In this chapter it will be reviewed whether the core questions of the thesis are answered, whether the objectives are met and what can be concluded from results.
It also includes the major lessons learnt during the elaboration of the work and makes recommendation for further research.

5.1 The relevance of PV

Summarizing the core questions, the thesis should assess the relevance of PV as an electricity source in the hotel business in developing countries. The relevance was split up into four aspects – the energetic, the ecologic, the economic and the marketing relevance -- which describes the influence of the PV plant on the marketing and sales activities of Somatheeram.
The energetic benefits show that PV can cover a substantial part of the electricity demand. Even with a small PV plant a vital part of the demand can be served. Having supply of sun at the same time when electricity is needed is ideal. Although batteries can assist as they allow storing electricity for a time of consumption when there is no sun.
To attain a more stable and reliable electricity supply, PV can play a major role to improve the situation. The self-production of power with a decentralized PV plant reduces the dependency on the public power supply. As a matter of fact it helps to accomplish a certain degree of autonomy and an improvement of energy security.
Having conducted the economic calculations reveals that PV is a cheaper power source than conventional power supply. Grid parity and “diesel-parity” are achieved in South India; meaning the kWh electricity produced from the PV plant is less expensive than the power from the public grid or from a diesel generator. The only exception is that grid parity is not achieved if a huge battery back-up system is included.
The upfront investment is high, but pays back within 5 or 6 years, depending on the profile of the consumer. Despite some minor O&M costs, power is produced for free, after the plant breaks even.

PV is ecologically relevant as it cuts down emissions tremendously. CO2Equ emissions can be avoided by substituting the power from the grid and from the diesel generator. As emissions are avoided, which are either inhaled by humans or absorbed by nature, it improves the health conditions and protects the environment. Considering those benefits it can be confirmed that PV contributes significantly to a change towards a more sustainable tourism and consequently improves the living standard.

The sum of advantages of PV in the hotel industry creates a positive image, which helps to market the resort easier.

The high relevance of a PV plant at Somatheeram is only one example but can be utilized for the whole hotel industry in developing countries with similar preconditions.

The overall objective of compiling this thesis is to be a medium for knowledge transfer for the tourism business in developing countries, but in a broader sense also for any potential electricity consumer. It should prove that PV can boost the tourism business.

The realization of the project is the base for this objective. By realizing the projects it becomes a showcase for the region it should raise awareness concerning renewable energy not only in the hotel industry sector, but should also stimulate smaller case tourism projects and even the application of RES in households. Perceiving PV as a strong alternative to the conventional power supply should be established in the people’s mind.

5.2 Major lessons learnt

Besides the positive results emerging from the feasibility study, other major lessons have been learnt while elaborating the thesis. PV makes a big difference. It is a highly relevant source of electricity, especially in developing countries with power insecurity and rural un-electrified areas.

The economic viability shows that PV can trigger business and enforce the economy. For start-up companies in un-electrified areas, using PV as their main power supply, it can create jobs and income, as it offers the opportunity to open up a business in first place. For existing tourism businesses, switching from fossil fueled applications to PV, it increases power security, saves on running expenses and has economic advantages. Having access to power has the power to access tourism business and create income.

An obstacle for the realization of an own PV plant might be the high upfront investment. This could be a reason especially for smaller companies and start-ups no to switch to PV. Still the costs have been decreasing a lot in the last years and it is said that there is still some more potential for reduction. In addition the government is offering support schemes to overcome or at least reduce this barrier. On a smaller scale, like for households micro-finance solutions exist which support the dispersion of PV installations.

Another major key message is that the demand profile of hotels and supply profile of the sun are matching well. There is only a small gap in the evening hours, when demand is high, but no sun supply is available. Comparing the load profiles with the supply curves shows that there is almost always demand at the moment of time when electricity is supplied. Nearly all the produced electricity from the PV plant can be used. Demand is starting in the morning, when sun rises, it goes up as the sun does at well, during the day, when people need electricity for cooking, cooling, entertainment and electronic devices. During night time the demand is disappearing just like the sun. For any incompatibility, especially for the evening hours, a storage system is needed to balance demand and supply.
Talking about load profiles, it was observed that the one of Kerala is quite specific. The shape of the load profile is the contrary to many other countries in the world. Having a low industrial rate, the region's demand is low during the day and reaches its peak in the evening. That is why during 6-10 pm the country is lacking power, but during the day there is enough. If, in other developing countries power would lack rather during the day, PV could even have a greater impact, as it is more urgent needed during the day when it is amply available than during the evening.

Even though there are plenty arguments for PV, the distribution of this technology in developing countries is only at its beginning. It still lacks of knowledge and experience in that field. That is the reason why it is not as easy as in Europe to find a professional PV company in the neighborhood which takes care of the installation.

Digging deeper into the ecological aspects of RES in tourism gave insight into the green hotel movement which is happening globally.

After convincing skeptical guests, hotel owners and operators who were thinking sustainable tourism would impact guest satisfaction negatively, even major hotel chains are now committed to energy efficiency and the integration of renewable energy. The gain of a competitive advantage for a hotel is not the only reason for that. International hotel chains are setting up programs to save on energy because they are forced to due to the scarcity of resources. That is the case in many developing countries like India with a low electrification rate, but also in western countries like the US, where water is a scarce asset.
An increased profitability is another trigger for green hospitality. As energy costs are predicted to rise and in contrary the decentralized production of own power with RES yields very low running costs a higher profitability is reached.
Nevertheless greening the hotel industry is only a first step in tourism, compared with the transport sector causing 75% of the emissions as mentioned in "2.2 Energy consumption in tourism".
But as Lao Tzu said "A journey of a thousand miles begins with a single step".

5.3 Issues for further research

The preconditions for the use of PV in India and other developing countries with a high solar irradiation are excellent. Yet, by 2013 only about 1,7 GW of PV is installed in India. It is suggested to investigate the reasons for this moderate capacity deployed and how to enforce the development. Are the major barriers high upfront investments, or maybe bureaucratic hurdles? It is suggested that further research is undertaken in assessing alternative policies which could boost the PV industry in India.

If the debate of RES in India is to be moved forward, a better understanding of the countries strategic power plans needs to be developed. This would include finding out about whether investments in the electricity infrastructure are planned or if the country is financially capable of investing at all. Based on that, it can be projected if power cuts will be a growing problem within the next years, or whether it is likely that the situation will improve, considering the country`s thirst for energy.

Another interesting aspect to be focused on might be the impact of PV for India's national economy. A study on the savings by reducing the dependence on energy from other countries could be supportive to establish a greater degree of accuracy on this matter. It could be explored whether a higher energy security influence India’s economic upraise and which social changes it brings implicates.

Acknowledgements

I would like to express my gratitude to the director of Somatheeram Ayurvedic Health Resort Mr Jaison Arampankudy, an his staff, especially Mr Milten Sunny and Mr Prabha who supplied me with a lot of data without which I couldn't have proceeded that well.

Special thanks to Mr John Prasanth, Engineer at Spice Village, for sharing his expertise and experience and answering my many questions.

I would like to thank my business partner Mr Volker Helfrich, BBA from Europe Solar Concept GmbH in Germany for giving me practical insights into technical issues.

I highly appreciate the guidance of my supervisor Univ. Prof. Dr. Dipl.-Ing. Reinhard Haas, who gave great support and kept me focused.

References / Literature

Allcot (2013), The first hotel reservation "application" that systematically offsets the carbon footprint for all reservations, Access July 20, 2013
http://www.allcot.com/2013/02/18/hot-co-uk-the-first-hotel-reservation-application-that-systematically-offsets-the-carbon-footprint-for-all-reservations/

ANERT (2013), Agency for Non-Conventional Energy and Rural Technology, Access July 9, 2013
www.anert.gov.in

Answers (2013), Solar fraction, Access August 26, 2013
http://www.answers.com/topic/solar-fraction-1

Battery University (2013), The best battery, Access November 6, 2013
http://batteryuniversity.com/learn/article/whats_the_best_battery

Blackburne, A. (2012): Sustainable tourism labelled a "key trend" by luxury travel network, in: Blue and green tomorrow, Access July 24, 2013
http://blueandgreentomorrow.com/2012/08/23/sustainable-tourism-labelled-a-key-trend-by-luxury-travel-network/

Boutiquehotel Stadthalle Wien (2013): Null-Energie-Bilanz, Access August 2, 2013
http://www.hotelstadthalle.at/

Bridge to India (2013), The India Solar Handbook, June 2013 edition, A complete industry overview for solar energy in India

Burgess, R. (2012), Your new solar array actual performance may vary, in: Renewable Energy World, Access August 7, 2013
http://www.renewableenergyworld.com/rea/news/article/2012/04/your-new-solar-array-actual-performance-may-vary

Carbon Footprint (2013), Access October 23, 2013 http://www.footprintnetwork.org/en/index.php/gfn/page/carbon_footprint/

CEA (2013), Central electricity authority of India, CO2 Baseline database for the Indian power sector, Version 8.0, p. 17, Access September 6, 2013 http://www.cea.nic.in/reports/planning/cdm_co2/user_guide_ver8.pdf

Ehrenstein, C., (2013), Photovoltaik-Bau kollabiert nach Förderkürzung, In: Die Welt, July 8, 2013, Access July 10, 2013 http://www.welt.de/politik/deutschland/article117830961/Photovoltaik-Bau-kollabiert-nach-Foerderkuerzung.html

EMMVEE photovoltaics (2013), polycrystalline modules
Access August 23, 2013
http://emmveepv.com/pdf/EMMVEE_ES_275-295_P72_SEpt2012.pdf

Energiemanagement und Klimaschutz in der Landwirtschaft (2011), Leitfaden für die praktische Umsetzung, S. 10, Access September 5, 2013
http://www.lkv-st.de/index.php?name=download&dlid=223

Energy efficiency report India (2011), CO2 emissions, Access September 6, 2013 http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/bcb30e13c8cbe734c125786400512e26/$file/india.pdf

Enkhardt, S., (2013), Germany hits 32,6 cumulative PV capacity, In: PV-Magazine, March 1, 2013, Access July 10, 2013
http://www.pv-magazine.com/news/details/beitrag/germany-hits-326-gw-cumulative-pv-capacity_100010394/#axzz2YeTneIDT

EPIA (2013), European PV Industry Association, About photovoltaics, key facts and figures, Access September 5, 2013
http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiafactsheets/110513_Fact_Sheet_on_the_Carbon_Footprint.pdf&t=1378758557&hash=06f0f16a9db58a3dd83dadf2808fa34591b423cf

EPIA (2013), European Photovoltaic Industry Association, Global market outlook for photovoltaics 2013-2017, p 5, Access July 10, 2013
http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=/uploads/tx_epiapubli

cations/GMO_2013_-_Final_PDF_01.pdf&t=1373554465&hash=4f0bec7eca4c422af168d1dbab2a0e35023db0f0

Fechner, H., (2012), MSc Program, Renewable Energy in CEE, Module 3, Solar Energy, p. 11

FWHT (2013), Professional association, Reverse auction bidding, Access August 27, 2013
http://www.fwhlaw.com/articles/reverse_auction_bidding.cfm

George, A. (2012), Analytical and experimental analysis of optimal tilt angle of solar photovoltaic systems, in: IEE Explore, Access August 28, 2013
http://ieeexplore.ieee.org/xpl/login.jsp?reload=true&tp=&arnumber=6477978&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6477978

Green Clean Guide (2013), MNRE capital subsidy scheme for off-grid solar systems, Access August 27, 2013
http://greencleanguide.com/2013/07/17/mnre-capital-subsidy-scheme-for-off-grid-solar-system/

Hasek, G. (2012): TripAdvisor survey unveils hospitality industry's top eco trends, in: Green Lodging News, Access July 24, 2013
http://www.greenlodgingnews.com/tripadvisor-survey-unveils-hospitality-industrys-top

Hjørland, B., Sejer Christensen, F. (2002). Work tasks and socio-cognitive relevance: a specific example. Journal of the American Society for Information Science and Technology, 53(11), p. 964

Holzer, P. (2011), Donau Uni Krems , Vergleichende Lebenszyklusanalyse unterschiedlicher Haustechniksysteme, Access August 26, 3013
http://www.donau-uni.ac.at/imperia/md/content/department/bauenumwelt/news/manuskript_110216.pdf

Hotelverband (2013), Energieeffizienz, p 2, Access August 16, 2013
http://www.hotelverband.at/Energieeffizienz_Folder.pdf

India Core (2013), Information on Indian infrastructure and core sectors, power, unbalanced growth and shortages, Access August 6, 2013
http://www.indiacore.com/power.html

Intersolar Award Ceremony (2012), Access July 9, 2013
http://www.intersolar.in/fileadmin/Intersolar_India_2012/INTERSOLAR_AWARD_INVITATION.pdf

Intersolar Europe (2013), Access May 20, 2013
http://www.intersolar.de/de/intersolar-europe.html

Ishihara, K., Kihira, N., Terada, N., Iwahori, T., (no date), Environmental burdens of large lithium-ion batteries developed in a Japanese national project, Access September 6, 2013,
http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF

KSEB (2012), Kerala State Electricity Board, Electricity Generation, Access August 6, 2013
http://www.kseb.in/~ksebuser/index.php?option=com_content&view=article&id=69&Itemid=70

Maps of Kerala (2011), Latitude and Longitude, Access August 26, 2013,
http://www.mapsofindia.com/lat_long/kerala/

Markusson, N., Monsen, K., Russell, S. (2009), Promotion of efficient heat pumps for heating, Access November 19, 2013
http://www.geos.ed.ac.uk/homes/nmarkuss/HPNorway.pdf

Mavisis (2013), Access October 22, 2013
http://www.mavisis.com/uploads/y-inverter.pdf

Mercom Capital Group (2013), Indian solar market update, 2nd quarter 2013, Access August 27, 2013
http://mercomcapital.com/indian-solar-market-update-2nd-quarter-2013

Middleton (2013): Spice Village Resort, India, in: EQ International, Edition April 2013, Access July 23, 2013
http://issuu.com/gouravgarg/docs/april_2013

Millar, M. (2013): Five important benefits of green certification, in: Hotel Executive, Eco friendly practices, Access July 24, 2013
http://hotelexecutive.com/business_review/2857/five-important-benefits-of-green-certification

Ministry of new and renewable energy (2012), Annual Report 2012-2013

Ministry of new and renewable energy (2013), Access May 20, 2013
http://www.mnre.gov.in/

Ministry of New and Renewable Energy (2013), Scheme Documents, Jawaharlal Nehru National Solar Mission, Access July 2, 2013
http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/

Ministry of New and Renewable Energy (2010), Jawaharlal Nehru National Solar Mission, Guidelines for off-grid and decentralized solar application, issued June 16, 2010

Natural Resources Canada (2009), Office of energy efficiency, determine where you use energy, Access August 16, 2013
http://oee.nrcan.gc.ca/publications/commercial/m144-10-2003e/2803

Obiko Pearson, N. (2013) India may expand solar anti dumping probe to EU and Japan, in: Bloomberg, Access July 23, 2013
http://www.bloomberg.com/news/2013-07-19/india-may-expand-solar-anti-dumping-probe-to-eu-japan.html

Ökoenergie Cluster (no date), Biomass heating in Upper Austria, p. 4,
Access November 19, 2013
http://www.oec.at/fileadmin/redakteure/ESV/Englisch/Publikationen/Biomass_heating_Upper_Austria_engl_US_Letter_216x279_2013_Sicht.pdf

Österreichs Energie (2013), Die Interessenvertretung der österreichischen E-Wirtschaft, Erzeugung, Access September 5, 2013
http://oesterreichsenergie.at/daten-fakten/statistik/erzeugung.html

Parisi, S. (2013): Sustainability hospitality reporting showing positive trends, in: EcoGreenHotel News, no date, Access July 24, 2013
https://www.ecogreenhotel.com/Sustainability_Hospitality_Reporting_Showing_Positive_Trends.php

Photon International, The Photovoltaic Magazine (2013), Access May 20, 2013
http://www.photon-international.com/

Photovoltaic Software (2012), Performance ratio, Access November 5, 2013
http://photovoltaic-software.com/PV-solar-energy-calculation.php

Prasad, A., (2013), Joint technical director at ANERT, Agency for non-conventional energy and rural technology, Trivandrum, Kerala Personal Interview, June 2013

Prasanth, J., (2013), Engineer at Spice Village, Personal Interview, June 2013

PV magazine (2013), Access May 20, 2013
http://www.pv-magazine.com/#axzz2TqyImZPG

Ranjan, V. (2013), Manager at Team Sustain, Personal Interview, June 2013

Renewable energy world (2013), mono crystalline or poly crystalline,
Access September 2, 2013
http://www.renewableenergyworld.com/rea/blog/post/2012/07/monocrystalline-or-polycrystalline

Schletter GmbH (2013), Verschattungsrechner, Vers.4.1.

Shiming, D., Burnett, J. (2002), Energy use and management in hotels in Hong Kong, Access August 30, 3013
http://jyjs.gzhu.edu.cn/jzsb/upload_file/201052176464785.pdf

Simple Solar Set-up (2013), Battery, Access August 30, 2013 http://www.simplesolarsetup.com/battery4.html

Singh, S. (2013): Swamped by a flood of imports. In: PV Magazine, Solarpraxis AG, 06/2013, pp 54-59

Solaranlagenportal (2013), Marktübersicht Photovoltaik-Speicher, Access October 22, 2013
http://www.solaranlagen-portal.com/photovoltaik/stromspeicher/photovoltaik-speicher

SolarGIS (2013), Maps, Access November 19, 2013
http://solargis.info/doc/71

Solargis (2013), Solar Map India, Access June 28, 2013
http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-India-en.png

Solarkonzept (2013), Offer per Email September 3, 2013

Somatheeram (2013), Ayurveda in India, Access July 1, 2013
http://www.somatheeram.org/de/?gclid=COGPtYmaj7gCFYGz3godeVYAaQ

Somatheeram (2013), Emails and Interview, May - August 2013

Special Correspondent (2013): Solar units seek anti-dumping duty on imports from China, in: The Hindu, Access: April 23, 2013
http://www.thehindu.com/todays-paper/tp-business/solar-units-seek-antidumping-duty-on-imports-from-china/article4635385.ece

Spice Village (2013), Access July 1, 2013
http://www.cghearth.com/spice-village

Stromspeicher (2013), Stromspeicher, Access September 2, 2013
http://www.strom-speicher.org/photovoltaik-stromspeicher/

The Economist (2012), An area of darkness, Access November 19, 2013
http://www.economist.com/node/21559977

Tiwari, R. (2012), Hydropower supply falls 15% as reservoirs dry up, in The Economic Times, Access November 19, 2013
http://articles.economictimes.indiatimes.com/2012-07-18/news/32730680_1_temperatures-and-trade-winds-surface-temperatures-and-trade-tonne

The New Indian Express (2013), South to see maximum power shortage this fiscal, p.13, Edition: Kochi, June 8, 2013

Trendforce (2013), PV market to flourish in Asia in 2013, January 7, 2013, Access July 10, 2013
http://pv.energytrend.com/research/20130107-4841.html

TripAdvisor (2012): TripAdvisor survey insights, Access July 24, 2013
http://www.tripadvisor.com/PressCenter-c7-Survey_Insights.html

Trojan Batteries (2013), products, Access November 6, 2013
http://www.trojanbatteryre.com/Tech_Support/ComparingFlood2VRLA.html

UNEP (2011), Tourism, Investing in energy and resource efficiency, p 414, Access August 13, 2013
http://www.unep.org/resourceefficiency/Portals/24147/scp/business/tourism/greeneconomy_tourism.pdf

UNWTO (2008), Climate change and tourism, Responding to global challenges, p. 34, Access August 13, 2013
http://sdt.unwto.org/sites/all/files/docpdf/climate2008.pdf

UNWTO (2013), UN World Tourism Organization, Why Tourism, Access August 13, 2013
http://www2.unwto.org/en/content/why-tourism

US Department of Energy (2013): EnergyPlus Energy Simulation Software, weather data, India, Trivandrum, Access August 7, 2013
http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

VDI (2012), Verein deutscher Ingeneure, CO2 Emissionen der Stromerzeugung, Access August 26, 3013
http://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/geu_dateien/FB4-Internetseiten/CO2-Emissionen%20der%20Stromerzeugung_01.pdf

Verbund (2013): Load profile of a comparable hotel, email conversation, August 2013

Wikipedia (2013), Diesel generator, Access August 17, 2013
http://en.wikipedia.org/wiki/Diesel_generator

Wikipedia (2013), Solar Power in India, Access July 5, 2013
http://en.wikipedia.org/wiki/Solar_power_in_India

Annexes

South to See Maximum Power Shortage this Fiscal: CEA Report

ENS Economic Bureau

New Delhi: Here is the bad news - India is likely to see a power shortfall of 6.7 per cent in the present fiscal and the southern region is expected to be the worst affected, the Central Electricity Authority — country's apex power sector planner — said on Friday.

The power sector is already besieged with problems including coal shortage, lack of environmental clearances for new and upcoming power projects were cited as the recurring reasons for underperformance of the sector.

Overall energy shortfall is expected to be 70,232 million units resulting in a deficit of 6.7% this fiscal. The requirement would be 10,48,533 million units whereas the availability is pegged at 9,78,301 million units.

"The country is expected to experience energy shortage of 6.7% and peak shortage of 2.3% despite very high shortages likely to be experienced by Southern region," the CEA said in its report published on Friday.

The report further said, "This is due to transmission constraints between Northern-north Eastern-eastern-Western-Southern regional grid that restricts flow of power to the Southern region."

In the current fiscal the capacity addition would be 18,432 MW with majority contribution coming from thermal sources, the report said.

Out of the estimated additional capacity thermal plants would account for 15,234 MW, hydro sources 1,198 MW and the remaining 2,000 MW could be added from nuclear energy.

According to the report, "Considering transmission constraints, all India peak shortage works out to 6.2%." The projections have been made after taking into consideration power availability from operating stations, fuel and water availability at hydro electric plants.

The CEA has assessed that gross energy generation will be in the vicinity of 975 billion units from operational power plants and also those that are expected to be commissioned during the year.

The Southern region is projected to see the maximum electricity shortages of 19.1% this financial year. It would be followed by Northern-Eastern 11.3%, Northern 5.8% and Western 1.2%. Meanwhile, Eastern region is likely to see an energy surplus of 10.2%.

CEA noted that peaking shortages in the Northern, Southern and North-Eastern regions would be 1.3%, 26.1% and 10% respectively.

Peaking shortage refers to the shortfall in electricity supply when the demand is maximum.

To meet the increased power requirement India will need to add 2,41,000 MW by 2020.

ENERGY SCENE

Country's power sector map is divided into five regions – North, West, South, East and North East

Installed capacity **2,23,626 MW**

Demand **10,48,533 million units**

Availability **9,78,301 million units**

Shortage **70,232 million units**

Deficit 6.7%

PEAK SHORTAGES	MAXIMUM SHORTAGES
North **1.3 per cent**	South 19.1%
South **26.1 per cent**	North-East 11.3%
North-East **10 per cent**	North 5.8%
	West 1.2%

Eastern region likely to see an energy surplus of 10.2%

CAPACITY ADDITION: 18,432 MW

Thermal plants 15,234 MW

Hydro sources 1,198 MW

Nuclear energy 2,000 MW

In 2012-13, energy shortfall touched 8.7% while peak shortage reached 9%

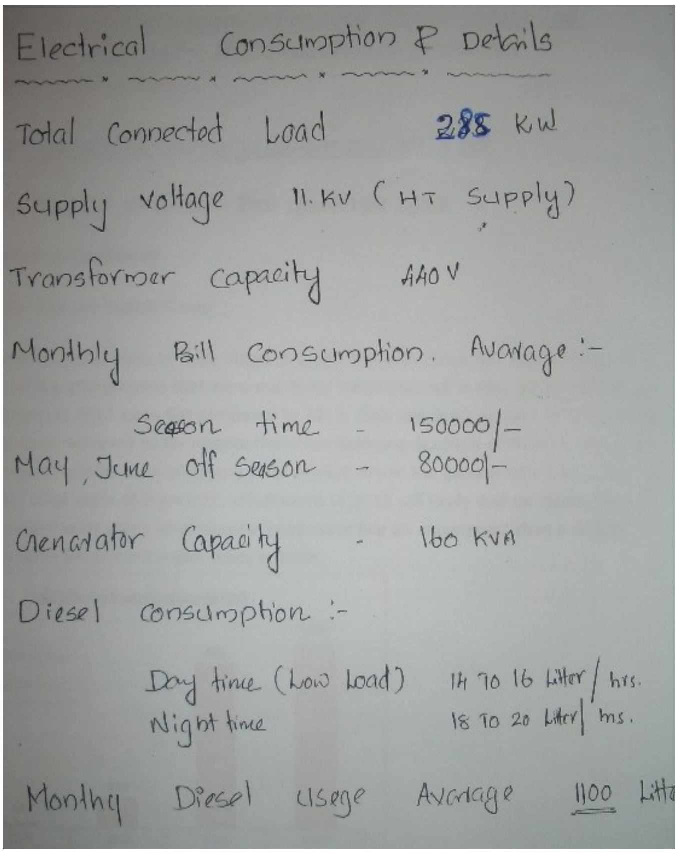
Source: CEA

The New Indian Express (2013), South to see maximum power shortage this fiscal, p.13, Edition: Kochi, June 8, 2013

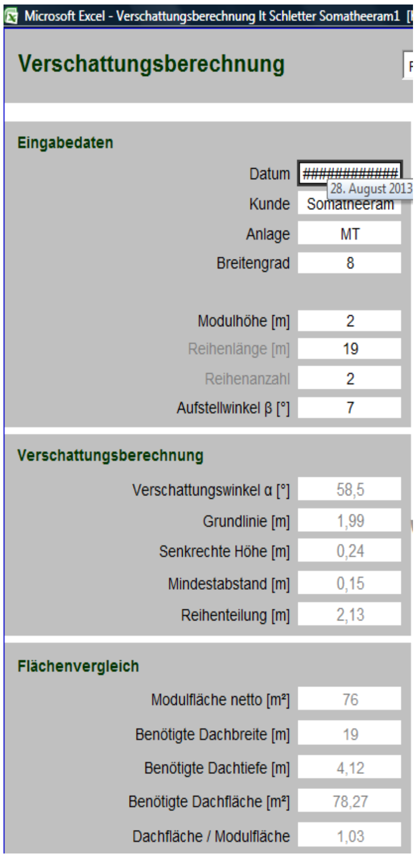
1		***Energy Consumption(One Year)***									
2		***Tariff HT. IV (Commercial)***									
3		H in %/day	50%	17%	33%						
4		Hours	12	4	8						
5		Electricity Period	Normal Time	Peak Time	Off Peak Time	Total Units	Electricity price	Electricity price	Monthly Amount	Monthly Amount excl diesel	Diesel costs average 1100 l	Monthly Amount incl diesel
6	Year	kWh	6Am-6Pm	6Pm-10Pm	10Pm-6Am	kWh consumed	rs/kWh	EUR/kWh	(In Rs.)	(in EUR)	in EUR	in EUR
7	2012	January	12.680	4.248	3.906	20.834	7	0,0990	140.445,00	€ 2.062,57	€ 913,00	€ 2.975,57
8	2012	February	14.032	4.754	4.208	22.994	7	0,0990	149.711,00	€ 2.276,41	€ 913,00	€ 3.189,41
9	2012	March	13.150	4.796	4.078	22.024	7	0,0990	145.318,00	€ 2.180,38	€ 913,00	€ 3.093,38
10	2012	April	14.306	4.734	4.564	23.604	6	0,0990	151.640,00	€ 2.336,80	€ 913,00	€ 3.249,80
11	2012	May	11.580	2.824	4.618	19.022	7	0,0990	127.559,00	€ 1.883,18	€ 913,00	€ 2.796,18
12	2012	June	10.306	2.470	3.428	16.204	7	0,0990	114.796,00	€ 1.604,20	€ 913,00	€ 2.517,20
13	2012	July	7.662	1.926	2.666	12.254	6	0,0990	78.987,00	€ 1.213,15	€ 913,00	€ 2.126,15
14	2012	August	9.532	2.368	2.884	14.784	10	0,0990	143.400,00	€ 1.463,62	€ 913,00	€ 2.376,62
15	2012	September	10.280	2.670	3.306	16.256	10	0,0990	154.440,00	€ 1.609,34	€ 913,00	€ 2.522,34
16	2012	October	11.972	2.878	3.584	18.434	9	0,0990	168.669,00	€ 1.824,97	€ 913,00	€ 2.737,97
17	2012	November	9.910	2.434	3.224	15.568	10	0,0990	151.056,00	€ 1.541,23	€ 913,00	€ 2.454,23
18	2012	December	12.690	2.922	3.680	19.292	9	0,0990	174.379,00	€ 1.909,91	€ 913,00	€ 2.822,91
19		**Year 2012**	**138.100**	**39.024**	**44.146**	**221.270**	**kWh/yr**					
20		plus ca 10% from diesel	13.810	3.902	4.415	22.127	kWh/yr					
21		**2012 incl diesel**	**151.910**	**42.926**	**48.561**	**243.397**	**kWh/yr**		**1.700.400,00**	**21.905,73**	**10.956,00**	**€ 32.861,73**

Somatheeram demand 2012 | Load Profile per hour | Loads | Load Profile assumptionAUG13

Electricity consumption and costs of Somatheeram in 2012


Electrical Consumption & Details

Total Connected Load 288 KW
Supply voltage 11. KV (HT Supply)
Transformer capacity 440 V
Monthly Bill Consumption. Avarage :-
Season time - 150000/-
May, June off Season - 80000/-
Generator Capacity - 160 KVA
Diesel consumption :-
Day time (Low load) 14 TO 16 Litter/hrs.
Night time 18 TO 20 Litter/hrs.
Monthy Diesel usege Avarage 1100 Litt


Microsoft Excel - Verschattungsberechnung lt Schletter Somatheeram1

Verschattungsberechnung

Eingabedaten

Datum	############ (28. August 2013)
Kunde	Somatheeram
Anlage	MT
Breitengrad	8
Modulhöhe [m]	2
Reihenlänge [m]	19
Reihenanzahl	2
Aufstellwinkel β [°]	7

Verschattungsberechnung

Verschattungswinkel α [°]	58,5
Grundlinie [m]	1,99
Senkrechte Höhe [m]	0,24
Mindestabstand [m]	0,15
Reihenteilung [m]	2,13

Flächenvergleich

Modulfläche netto [m²]	76
Benötigte Dachbreite [m]	19
Benötigte Dachtiefe [m]	4,12
Benötigte Dachfläche [m²]	78,27
Dachfläche / Modulfläche	1,03

Facts and Figures from the maintencance dept, Somatheeram Ayurvedic Health Resort, June 2013

Schletter GmbH (2013), Verschattungrechner, Vers.4.1.

- Average Hourly Statistics for Global Horizontal Solar Radiation Wh/m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
0:01- 1:00	0	0	0	0	0	0	0	0	0	0	0	0					
1:01- 2:00	0	0	0	0	0	0	0	0	0	0	0	0					
2:01- 3:00	0	0	0	0	0	0	0	0	0	0	0	0					
3:01- 4:00	0	0	0	0	0	0	0	0	0	0	0	0	**Supply/hours during "normal-time"**				
4:01- 5:00	0	0	0	0	0	0	0	0	0	0	0	0			kWh av.	kWh av.	
5:01- 6:00	0	0	0	0	0	0	0	0	0	0	0	0	**Wh/m²/h av.**	**kWh/kWp**	**16**	**32**	
6:00- 7:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00- 8:00	6	12	32	81	124	113	58	53	76	90	82	25	62,67	0,05	0,78	1,56	0,97%
8:00- 9:00	199	223	275	377	396	359	244	241	301	340	326	256	294,75	0,23	3,68	7,36	4,55%
9:00-10:00	476	517	595	685	717	584	417	433	562	612	585	521	558,67	0,44	6,97	13,94	8,63%
10:00-11:00	741	810	906	987	1002	806	600	580	784	867	818	771	806,00	0,63	10,06	20,12	12,45%
11:00-12:00	858	968	1064	1130	1129	924	669	703	949	931	904	919	929,00	0,72	11,59	23,19	14,35%
12:00-13:00	910	1012	1131	1140	1126	993	736	774	986	950	917	911	965,50	0,75	12,05	24,10	14,91%
13:00-14:00	808	956	1053	1053	1057	928	672	749	947	833	773	830	888,25	0,69	11,09	22,17	13,72%
14:00-15:00	700	843	916	933	902	831	606	628	799	706	643	701	767,33	0,60	9,58	19,15	11,85%
15:00-16:00	524	670	720	710	721	639	471	497	603	542	499	510	592,17	0,46	7,39	14,78	9,14%
16:00-17:00	357	489	521	504	505	431	313	343	395	353	309	333	404,42	0,32	5,05	10,09	6,24%
17:00-18:00	153	235	268	238	243	221	164	184	184	137	107	116	187,50	0,15	2,34	4,68	2,90%
18:00-19:00	6	23	44	29	32	42	27	25	9	0	0	0	19,75	0,02	0,25	0,49	0,30%
19:00-20:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20:01-21:00	0	0	0	0	0	0	0	0	0	0	0	0	**6.476**	5,05	**80,82**	**161,64**	**100,00%**
21:01-22:00	0	0	0	0	0	0	0	0	0	0	0	0	2.363.740		16kWp	32kWp	

22:01-23:00	0	0	0	0	0	0	0	0	0	0	0	0	
23:01-24:00	0	0	0	0	0	0	0	0	0	0	0	0	
Max Hour	13	13	13	13	12	13	13	13	13	13	13	12	
Min Hour	1	1	1	1	1	1	1	1	1	1	1	1	
TOTAL/day	5738	6758	7525	7867	7954	6871	4977	5210	6595	6361	5963	5893	77712

Electricity Yield | Demand | hourly statistics | Matching SupplyDemand

US Department of Energy (2013): EnergyPlus Energy Simulation Software, weather data, India, Trivandrum, Access August 7, 2013
http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=IND/cname=India

Current, yearly CO2 emissions at Somatheeram without PV

Current average distribution of electricity production:			CO2 emissions
Diesel	10%	22.100 kWh/year	1000 g/kWh
Grid	90%	221.000 kWh/year	760 g/kWh
Total demand	100%	243.100 kWh/year	

PV	CO2Equ g/kWh	tons CO2 Equ/ MWhele	MWhele total year	tons CO2 Equ/year	MWhele total 20 yrs	tons CO2 Equ/ 20 yrs	MWhele total lifetime	tons CO2Equ / lifetime
Diesel Generator	1000	1	22	22	442	442	774	17.094
South Indian Electricity mix	760	0,76	221	168	4.420	3.359	7.735	1.299.171
CO2 emissions				190		3.801		1.316.265

Source:
Co2 Emissions: India, Southern grid, CEA of India, 760g/kWh
CEA (2013), Central electricity Authority of India, CO2 Baseline database for the Indian power sector, h
PV, only during production of equipment, EPIA 30g/kWh
http://www.epia.org/about-us/about-photovoltaics/key-facts-figures/
Lead Battery, 60kg/kWh capacity, for 160kWh = (9.600 kg /kWh output over 10 yrs = 198.900) = 50 g/kWI
http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF

Emission Savings > Electricity production > 16 kWp PV (no battery)

Lifetime PV:	35	yrs	
Depreciation:	20	yrs	
PV Plant size:	16	kWp	
PV yield:	1842	kWh/kWp	
	29.472	kWh/year	

! No emissions from PV during production

Current average distribution of electricity production:

Diesel	10%	22.100	kWh/year
Grid	90%	221.000	kWh/year

Electricity Production from 16kWp PV:

Solar fraction	12%	29.472	
19% of PV Substitute 25% of Diesel		5.525	kWh/year
81% of PV substitues 11% of grid suppl		23.947	kWh/year

PV	CO2 eq g/ kWh	CO2 eq t / Mwhele	MWhele total year	CO2 eq t / year	Mwhele total 20 yrs	CO2 eq t / 20 yrs	MWhele total lifetime	CO2 eq t / lifetime
Diesel Generator	1000	1	5,53	5,53	110,50	110,50	193	1.068
PV	30	0,03	5,53	0,17	110,50	3,32	193	32
CO2 Savings	**970**	**0,97**		**5,36**		**107,19**		**1.036**

PV	CO2 eq g/ kWh	CO2 eq t / Mwhele	MWhele total year	CO2 eq t / year	Mwhele total 20 yrs	CO2 eq t / lifetime	MWhele total lifetime	CO2 eq t / lifetime
South Indian Electricity mix	760	0,76	23,95	18,20	479	637	838	15.254
PV	30	0,03	23,95	0,72	479	25	838	602
CO2 Savings	**730**	**0,73**		**17,48**		**612**		**14.652**
TOTAL CO2 Savings				**22,84**		**719,03**		**15.688**

Source:

Co2 Emissions	India, Southern grid, CEA of India, 760g/kWh
	CEA (2013), Central electricity Authority of India, CO2 Baseline database for the Indian power sector,
	PV, only during production of equipment, EPIA 30g/kWh
	http://www.epia.org/about-us/about-photovoltaics/key-facts-figures/
	Lead Battery, 60kg/kWh capacity, for 160kWh = (9.600 kg /kWh output over 10 yrs = 198.900) = 50 g/kW
	http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF

Emission Savings > Electricity production > 16 kWp PV with 160 kWh battery

Lifetime PV:	35	yrs	
Depreciation:	20	yrs	
PV Plant size:	16	kWp	
Lifetime Battery:	10	yrs	
PV yield:	1842	kWh/kWp	
	29.472	kWh/year	

! No emissions from PV during production

Current average distribution of electricity production:

Diesel	10%	22.100	kWh/year
Grid	90%	221.000	kWh/year

Electricity Production from 16kWp PV with 160 kWh battery :

Solar fraction	12%	29.472	
75% of PV Substitute 90% of Diesel		19.890	kWh/year
25% of PV substitues 3% of grid supply		9.582	kWh/year

PV	CO2 eq g/ kWh	CO2 eq t / Mwhele	MWhele total year	CO2 eq t / year	Mwhele total 20 yrs	CO2 eq t / 20 yrs	MWhele total lifetime	CO2 eq t / lifetime
Diesel Generator	1000	1	19,89	19,89	397,80	397,80	696	13.846
PV	30	0,03	19,89	0,60	397,80	11,93	696	415
Battery	50	0,05	19,89	0,99	397,80	19,89	696	692
CO2 Savings	**920**	**0,92**		**18,30**		**365,98**		**12.739**

PV	CO2 eq g/ kWh	CO2 eq t / Mwhele	MWhele total year	CO2 eq t / year	Mwhele total 20 yrs	CO2 eq t / lifetime	MWhele total lifetime	CO2 eq t / lifetime
South Indian Electricity mix	760	0,76	9,58	7,28	192	255	335	2.441
PV	30	0,03	9,58	0,29	192	10	335	96
CO2 Savings	730	0,73		6,99		245		2.345
TOTAL CO2 Savings				25,29		610,75		15.084

Source:

Co2 Emissions	India, Southern grid, CEA of India, 760g/kWh
	CEA (2013), Central electricity Authority of India, CO2 Baseline database for the Indian power sector, h
	PV, only during production of equipment, EPIA 30g/kWh
	http://www.epia.org/about-us/about-photovoltaics/key-facts-figures/
	Lead Battery, 60kg/kWh capacity, for 160kWh = (9.600 kg /kWh output over 10 yrs = 198.900) = 50 g/kWh
	http://www.electrochem.org/dl/ma/202/pdfs/0068.PDF

Economic calculation without battery:

Somatheeram Ayurvedic Health Resort		EMMVEE Poly-Crystalline 290W			
Financial Parameters			Disc. CF:	Nominal CF/((1+WACC)^yr)	
			CRF:	(WACC*((1+WACC)^15))/((1+WACC)^15)	0,08994
Investment horizon	20	yrs	Annuity:	CRF*NPV	
WACC/risk adjusted disc. rate	4%	per year	Investment subsidy:		30%
Solar irradiation	1.842	kWh/kW			7.200
Rated Capacity	**16**	**kW**	Electr. price India	9	rps/kWh
Investment costs per kW	1500	EUR		0,106	EUR/kWh
Investment costs total	24.000	EUR		5%	escalation rate
Investment costs subsidy deducte	16.800	EUR	Diesel gen. costs	27	rps/kWh
O&M, incl replacement of inverter -	368	of investment costs		0,318	EUR/kWh
		inverter maintenance/exchange		5%	escalation rate

Year	Discounted CF	Nominal CF	O&M/ Replacement	Investment	Electricity Saved from Grid	Electricity Saved from Diesel	Discounted Costs	
0	-€ 16.800,00	-€ 16.800,00		-€ 16.800,00			€ 16.800,00	
1	€ 3.776,28	€ 3.927,33	-€ 368,00		€ 2.538,38	€ 1.756,95	€ 353,85	
2	€ 3.787,90	€ 4.097,00	-€ 368,00		€ 2.638,65	€ 1.826,35	€ 340,24	
3	€ 3.799,01	€ 4.273,37	-€ 368,00		€ 2.742,87	€ 1.898,49	€ 327,15	
4	€ 3.809,60	€ 4.456,70	-€ 368,00		€ 2.851,22	€ 1.973,48	€ 314,57	
5	€ 3.819,72	€ 4.647,27	-€ 368,00		€ 2.963,84	€ 2.051,43	€ 302,47	
6	€ 3.829,37	€ 4.845,38	-€ 368,00		€ 3.080,91	€ 2.132,46	€ 290,84	
7	€ 3.838,58	€ 5.051,31	-€ 368,00		€ 3.202,61	€ 2.216,70	€ 279,65	
8	€ 3.847,35	€ 5.265,37	-€ 368,00		€ 3.329,11	€ 2.304,26	€ 268,89	
9	€ 3.855,72	€ 5.487,89	-€ 368,00		€ 3.460,61	€ 2.395,27	€ 258,55	
10	€ 3.863,68	€ 5.719,19	-€ 368,00		€ 3.597,31	€ 2.489,89	€ 248,61	
11	€ 3.871,27	€ 5.959,64	-€ 368,00		€ 3.739,40	€ 2.588,24	€ 239,05	
12	€ 3.878,49	€ 6.209,58	-€ 368,00		€ 3.887,11	€ 2.690,47	€ 229,85	
13	€ 3.885,35	€ 6.469,39	-€ 368,00		€ 4.040,65	€ 2.796,75	€ 221,01	
14	€ 3.891,88	€ 6.739,47	-€ 368,00		€ 4.200,25	€ 2.907,22	€ 212,51	
15	€ 3.898,08	€ 7.020,22	-€ 368,00		€ 4.366,16	€ 3.022,05	€ 204,34	
16	€ 3.903,96	€ 7.312,05	-€ 368,00		€ 4.538,63	€ 3.141,43	€ 196,48	
17	€ 3.909,55	€ 7.615,41	-€ 368,00		€ 4.717,90	€ 3.265,51	€ 188,92	
18	€ 3.914,85	€ 7.930,76	-€ 368,00		€ 4.904,26	€ 3.394,50	€ 181,66	
19	€ 3.919,86	€ 8.258,56	-€ 368,00		€ 5.097,98	€ 3.528,58	€ 174,67	
20	€ 3.924,61	€ 8.599,31	-€ **368,00**		€ 5.299,35	€ 3.667,96	€ 167,95	
NPV	€ **60.425,11**		-€ 7.360,00	-€ 16.800,00	€ 75.197,20	€ 52.048,00	€ 21.801,24	**NPV of Costs**
Annuity	€ **5.434,70**						€ 1.960,83	**Annuity of Costs**

Specific Investment Costs	€	**1.050,00**	EUR/kW	**Yearly electricity production**	**29.472**	kWh
Specific O&M Costs	€	**23,00**	EUR/kW/yr		**29**	MWh
LRGC	€	**0,07**	EUR/kWh			
The investments pays off in		**5**	years	Production share		
				instead of grid 81%	23.947	kWh
				instead of diesel 19%	5.525	kWh
				Substitution		
				Substitutes grid 11%	of total supply from grid	
				Substitutes diesel 25%	of total supply from diesel generator	

Economic calculation with battery:

Somatheeram Ayurvedic Health Resort | **EMMVEE Poly-Crystalline 290W** | **Elisabeth Reinthaler**

Financial Parameters			Disc. CF:	Nominal CF/((1+WACC)^yr)	
			CRF:	(WACC*((1+WACC)^15))/((1+WACC)^15)	
Investment horizon	20	yrs	Annuity:	CRF*NPV	
WACC/risk adjusted disc. rate	4%	per year	Investment subsidy	30%	
Solar irradiation	1.842	kWh/kW		16.800	
PV, Rated Capacity	**16**	**kW**			
Battery Capacity	**160**	**kWh**			
Investment costs per kWp PV	1.500	EUR	Electricity price India	9	rps
Investment costs total PV	24.000	EUR		0,106	EUR
Investment costs for battery	32.000	EUR	Diesel generation co	5%	escalation rate
Investment costs total PV+battery	56.000	EUR		27	rps
Investment costs subsidy deducte	39.200	EUR			
				0,318	EUR
O&M, incl replacement of inverter -	368	EUR		5%	escalation rate
Replacement of battery system -	32.000	EUR			

Year	Discounted CF	Nominal CF	O&M/ Replacement	Investment	Electricity Saved from Grid	Electricity Saved from Diesel	Discounted Costs	
0	-€ 39.200,00	-€ 39.200,00		-€ 56.000,00			€ 39.200,00	
1	€ 6.704,53	€ 6.972,71	-€ 368,00		€ 1.015,69	€ 6.325,02	€ 353,85	
2	€ 6.714,75	€ 7.262,67	-€ 368,00		€ 1.055,81	€ 6.574,86	€ 340,24	
3	€ 6.724,44	€ 7.564,08	-€ 368,00		€ 1.097,52	€ 6.834,57	€ 327,15	
4	€ 6.733,63	€ 7.877,40	-€ 368,00		€ 1.140,87	€ 7.104,53	€ 314,57	
5	€ 6.742,34	€ 8.203,09	-€ 368,00		€ 1.185,93	€ 7.385,16	€ 302,47	
6	€ 6.750,59	€ 8.541,65	-€ 368,00		€ 1.232,78	€ 7.676,87	€ 290,84	
7	€ 6.758,39	€ 8.893,58	-€ 368,00		€ 1.281,47	€ 7.980,11	€ 279,65	
8	€ 6.765,76	€ 9.259,41	-€ 368,00		€ 1.332,09	€ 8.295,32	€ 268,89	
9	€ 6.772,72	€ 9.639,70	-€ 368,00		€ 1.384,71	€ 8.622,99	€ 258,55	
10	-€ 14.838,77	-€ 21.965,00	-€ 32.368,00		€ 1.439,40	€ 8.963,60	€ 21.866,66	
11	€ 6.785,47	€ 10.445,92	-€ 368,00		€ 1.496,26	€ 9.317,66	€ 239,05	
12	€ 6.791,29	€ 10.873,07	-€ 368,00		€ 1.555,36	€ 9.685,71	€ 229,85	
13	€ 6.796,75	€ 11.317,09	-€ 368,00		€ 1.616,80	€ 10.068,29	€ 221,01	
14	€ 6.801,88	€ 11.778,65	-€ 368,00		€ 1.680,66	€ 10.465,99	€ 212,51	
15	€ 6.806,68	€ 12.258,45	-€ 368,00		€ 1.747,05	€ 10.879,40	€ 204,34	
16	€ 6.811,17	€ 12.757,19	-€ 368,00		€ 1.816,06	€ 11.309,13	€ 196,48	
17	€ 6.815,36	€ 13.275,63	-€ 368,00		€ 1.887,79	€ 11.755,84	€ 188,92	
18	€ 6.819,25	€ 13.814,56	-€ 368,00		€ 1.962,36	€ 12.220,20	€ 181,66	
19	€ 6.822,88	€ 14.374,77	-€ 368,00		€ 2.039,87	€ 12.702,90	€ 174,67	
20	€ 6.826,23	€ 14.957,11	-€ **368,00**		€ 2.120,45	€ 13.204,66	€ 167,95	
NPV	€ **74.705,35**		-€ 39.360,00	-€ 56.000,00	€ 30.088,93	€ 187.372,81	€ 65.819,29	**NPV of Costs**
Annuity	€ **6.719,08**						€ 5.919,86	**Annuity of Costs**

Specific Investment Costs wo batte	€ **450,00**	EUR/kW				
Specific Investment Costs w batter	€ **2.450,00**	EUR/kW	**Yearly electricity production**		**29.472**	kWh
Specific O&M Costs	€ **23,00**	EUR/kW/yr			**29**	MWh
LRGC	€ **0,20**	EUR/kWh		Production share		
The investments pays off in	**6**	years	instead of grid	33%	9.582	kWh
			instead of diesel	67%	19.890	kWh
				Substitution		
			Substitutes grid	3,94%		
			Substitutes diesel	90,00%		

16 kWp PV plus a 160kWh battery system is assumed, exchanging the batteries every 10 y
160kWh batteries can substitute 80kWh from the diesel generator, using mostly in peak times
the 100kWh discharged per day would replace the diesel generator almost a 100%, as the discharge rate of the battery per hour is up to 30 kW
30kWh per hour is in average the peak demand per hour in the peak season
replacement of battery calculated conservatively, assuming price will remain the same
there is no subsidy included for the replacement costs of the battery system
replacement of battery is paying off always after about 4 years

$$a = NPV * \frac{r * (1+r)^T}{(1+r)^T - 1}$$

$$CRF = \frac{r \cdot (1+r)^T}{(1+r)^T - 1}$$

Angebot Nr. 2013386

Lieferung einer Batteriebank zur Notstromversorgung

Pos	Menge		Text	Einzelpreis EUR	Gesamtpreis EUR
1	48,00	Stück	Hoppecke 16 OPzS solar.power 2900 verschlossener Bleiakku (Säure) Kapazität C10: 2150 Ah Spannung: 2 V Bleibatterie mit hoher Zyklenfestigkeit wartungsarm, sehr gute Kontrollmöglichkeit des Elektrolystandes Verbundpole mit Schraubgewinde für Systemverbinder Gewicht: 151 kg Maße: 215 x 400 x 815 mm gefüllt und geladen projektbezogenene Fertigung, Stornierung oder Rückgabe nach der Bestellung sind ausgeschlossen.	753,98	36.191,04
A	48,00	Stück	Alternativposition Hoppecke Aquagen Rekombinationsstopfen Aquagen- Stopfen zur Verhinderung des Austritts von Gasen und Aerosolen bei stationären Bleibatterien. Zur Verlängerung der Wassernachfüllintervalle	32,89	(1.578,72)
A	48,00		Alternativposition Akku Hoppecke 16 OPzV 2300 solar.power Kapazität: 2020Ah (C10) 2V-Einzelzelle Elektrolyt in Gelform Maße: (LxBxH) 215 x 400x 815 mm Gewicht: 165 kg gefüllt und geladen projektbezogenene Fertigung, Stornierung oder Rückgabe nach der Bestellung sind ausgeschlossen.	853,52	(40.968,96)
Zwischensumme					36.191,04

Gesamt Netto		36.191,04
zzgl. 19,00 % USt. auf	36.191,04	6.876,30
Gesamtbetrag		**43.067,34**

Lieferung frei Haus

Zahlungsbedingungen:
Bei reiner Materiallieferung an ausländische Kunden bitten wir um Vorkasse mit 2 % Skonto.

Offer for a 200 kWh gross battery back-up system from a German company, Sept 3, 2013:

EMMVEE
ES 275-295 P72
Photovoltaic Module

EMMVEE photovoltaics

Electrical Data at 1000 W/m², 25°C and AM 1.5 (STC in Accordance with EN 60904-3)					
rated power at STC [1]	275 Wp	280 Wp	285 Wp	290 Wp	295 Wp[2]
module efficiency at STC [3]	13.7%	13.9%	14.2%	14.4%	14.7%
cell effiiciency	15.8%	16.1%	16.4%	16.7%	17.0%
open-circuit voltage V_{oc}	43.92 V	44.20 V	44.42 V	44.56 V	44.78 V
short-circuit current I_{sc}	8.04 A	8.15 A	8.20 A	8.25 A	8.30 A
rated voltage V_{mpp}	35.48 V	35.62 V	35.81 V	36.21 V	36.51 V
rated current I_{mpp}	7.75 A	7.86 A	7.96 A	8.01 A	8.08 A

[1] The measurement tolerance of the rated power is ± 3%. The modules delivered are sorted in a range of ± 2.5 Wp. [2] Available in limited amounts upon request. [3] At low irradiance (200 W/m² , 25°C and AM 1.5) the module yields at least 97% of the STC efficiency.

Electrical Data at 800 W/m², NOCT, 1m/s Wind Speed and AM 1.5					
rated power P_{max}	222.8 W	226.8W	230.9 W	234.9 W	239.0 W
open-circuit voltage V_{oc}	43.51 V	43.78 V	44.00 V	44.14 V	44.36 V
short-circuit current I_{sc}	6.46 A	6.55 A	6.59 A	6.63 A	6.67 A
rated voltage V_{mpp}	35.61 V	35.75 V	35.94 V	36.34 V	36.64 V
rated current I_{mpp}	6.26 A	6.35 A	6.43 A	6.47 A	6.52 A

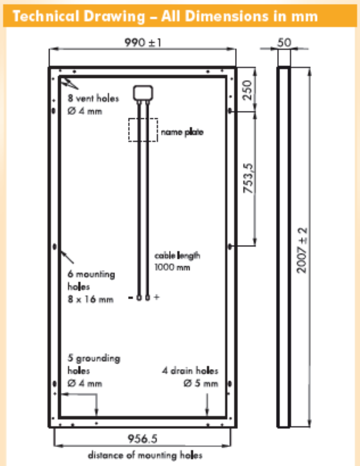
Thermal Data	
temperature coefficient open-circuit voltage	- 0.36%/K
temperature coefficient short-circuit current	+ 0.06%/K
temperature coefficient rated power	- 0.43%/K
noct (normal operating cell temperature)	47°C ± 2°C

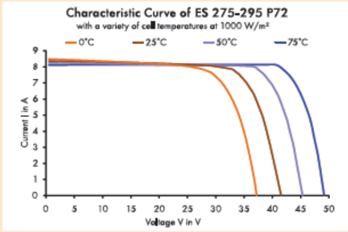
Mechanical Data	
number of cells and cell type	72 polycrystalline solar cells (156 x 156 mm, 3-Bus-Bar)
cell manufacturer	Q - Cells, Germany
dimensions: length x width	2,007 mm x 990 mm
frame thickness	50 mm anodized aluminum
weight	28.5 kg
front glass	4 mm high transmission, low iron, tempered glass
embedding	EVA (Solutia Solar)
back sheet	TPT Tedlar®/Polyester/Tedlar® (Krempel) KPK Kynar®/Polyester/Kynar® (Krempel)
junction box	Spelsberg / Lumberg; plastic, protection class IP 65, 141 x 101 x 28 mm
number of bypass diodes	3
cables	4 mm² solar cables, length 1000 mm
connectors	MC4/LC4

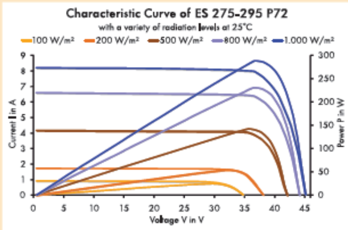
Permissible Operating Conditions	
operating temperature range	- 40°C to 85°C
max. system voltage	1000 V DC
max. reverse current	12.5 A
maximum surface load capacity	5400 Pa or 550 kg/m²
resistance against hail	maximum diameter of 24 mm with impact speed of 83 km/h
protection class	II

Warranty and Certificates	
product warranty	5 or 10 years (subject to warranty terms)
performance warranty	90% up to 10 years and 80% up to 25 years
certifications	IEC 61215 Ed. 2, IEC 61730, IEC 61701 and Ammonia resistance test CEC accredited

Technical Drawing – All Dimensions in mm







Your Retailer:

www.tuv.com TÜVRheinland ID: 0000025744
- Qualified, IEC 61215
- Safety tested, IEC 61730
- Periodic Inspection

Clean Energy Council

CE

PV CYCLE

ISO 9001 DNV REGISTERED · ISO 14001 DNV REGISTERED · OHSAS 18001 DNV CERTIFIED FIRM

within the scope of product improvement.

For more details, see Installation Manual.
Datasheet according to EN 50380.

Emmvee Photovoltaic Power Pvt. Ltd.
#13/1, International Airport Road, Bettahalasur Post, Bengaluru - 562 157, India
Phone: +91 80 4323 3544 · info@emmvee.in

Emmvee Photovoltaics GmbH
Franz-Jacob-Str. 4a · 10369 Berlin, Germany
Phone: + 49 (0) 30 91 42 68 90 · info@emmveephotovoltaics.com

http://emmveepv.com/pdf/EMMVEE_ES_275-295_P72_SEpt2012.pdf