Small Solar Trough Power Plant in Thailand

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ABSTRACT

This article introduces a solar trough technology, that was first installed in Thailand. Parabolic trough solar systems become quite popular in recent times as they seem to be a very economical solution for future electrical power needs. The economical efforts can be reached at adequate climate conditions by means of medium to high direct solar radiation and partly cloudy on particular sites. The station in Koachan, Chonburi province has a capacity of 100 kW thermal with an aperture area of 205 m². A direct steam producing receiver sends steam to a 10 kW electric steam screw. The solar radiation and the operation performance of this German technology were measured and surveyed during a full year. The results show that this technology can be an appropriate solution for the energy problems in the rural areas of South East Asia where solar conditions permit. The average values show 5 kWh/m² even under tropical conditions. The investment cost may reach a level in future below 100,000 THB per kW. Some technological adaptations and may be developments still have to be reached to optimize this solution for the local needs.

Keywords: *Solar Thermal Power Plant, Small CSP, Solar Radiation, Economic Small Solar Thermal*

1. Introduction

In the period Summer 2005 until end of the year 2006 a first parabolic trough system has been constructed and operated in Chonburi province, Thailand. The aim was to demonstrate this environmental friendly technology for energy production in Southeast Asia. The regional governments have made decisions to promote solar and biomass energy production by implementing an adder system in 2007. Solar and biomass electricity producers get a fixed additional price per kilowatt hour fed into the national grid. This allows that the private sector invests in renewable energy power plants in the rural areas to meet the demand of electricity. This decentralized energy production ensures the economical development in the rural areas and communities away from the central cities.

Solar energy can be collected by photovoltaic systems (PV) or solar trough either. PV is working with total radiation, while solar trough or concentrated solar power systems (CSP) needs direct solar radiation only. But PV is losing efficiency, if the temperature goes up, while CSP as a thermal technology, is performing the better the hotter it gets. CSP is also known as the more economical technology, which can produce electricity for less than PV. While PV can produce electricity only, CSP can provide thermal and electrical energy at the same time. Therefore CSP systems are interesting for co-generation and process heat applications. They can be combined with other steam generator technologies, as there are biomass, biofuel, gas, oil and lignite. CSPs thermal energy can also be stored easier in buffer systems than electricity from PV in batteries. This allows having solar power also at night time.

2. Solar trough station in Chonburi / Thailand

The station in Chonburi consists of four rows parabolic troughs, which can create up to 100 kW thermal energy. It supplies to a single stage steam screw micro turbine which can generate up to 10 kW electricity. The heat is then used for process heat for a neighbouring company. The system includes a biomass boiler, which allows operation, even after sunset. It is also possible to attach a storage facility for the energy, but we found out, that it is more practical in Thailand to operate directly with manpower, instead of making use of larger investments for automatic service.

The solar troughs generate steam and operate with an average temperature of 160 °C and a pressure of 6 bar. This operating condition was set up in order to be easy for local community staff in the case that such a system will be utilize in local communities. However the temperature and pressure can be increased.

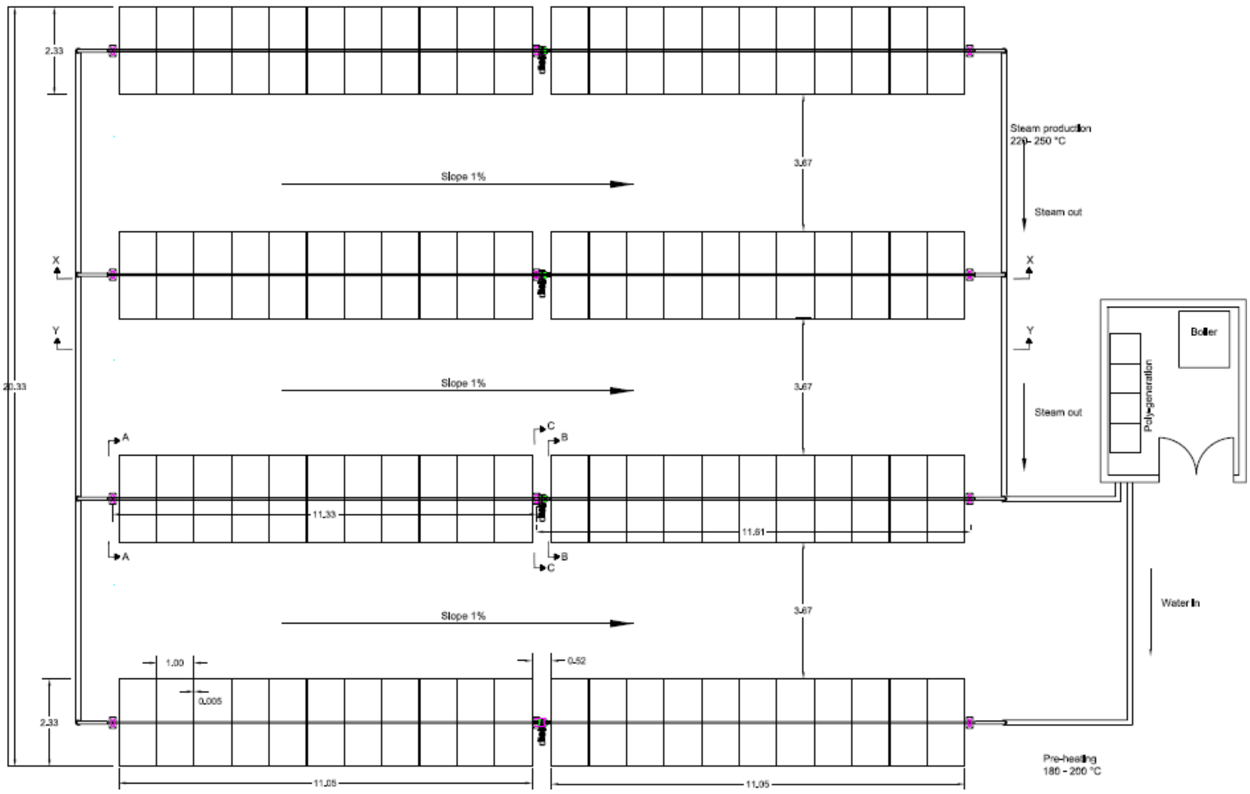

Fig 1. Layout plan of the station, showing the troughs and the turbine house

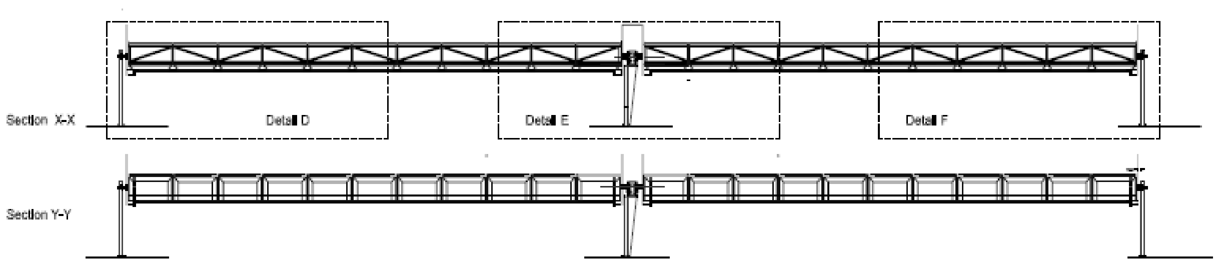

Fig 2. Detail drawing of the side view of the solar troughs including the drives

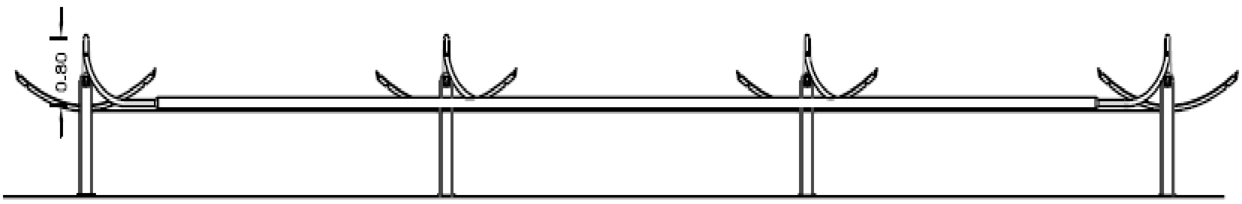

Fig 3. Side view of the parabolic troughs, the absorbers and the steam pipe

The area of the station is 25 by 35 m with a distance of nearly 4.0 m between the rows to avoid the impact of shadows. The structure of the solar trough rows is created with a light steel frame, while the solar panels are made out of FRP (fiber reinforced plastic) with a minimum weight of just 28 kg each. The troughs are operated with a direct drive with a minimized electricity consumption of roughly only 170 W. They are connected to a tracking system, which makes the panels tracks the sun constantly. A weather station protects the system from bad weathers impacts, such as strong wind and heavy rain. To take the system out of operation, it is necessary to stop it only with a switch. The sun continues its way and the rays are going out of the focus and no more heat is produced.

Fig 4. View on the station with solar field and boiler house

3. Concentrating Solar Power Resources Potential

Global renewable energy resource map illustrates the general potential of concentrating power from direct solar irradiation in the following picture:

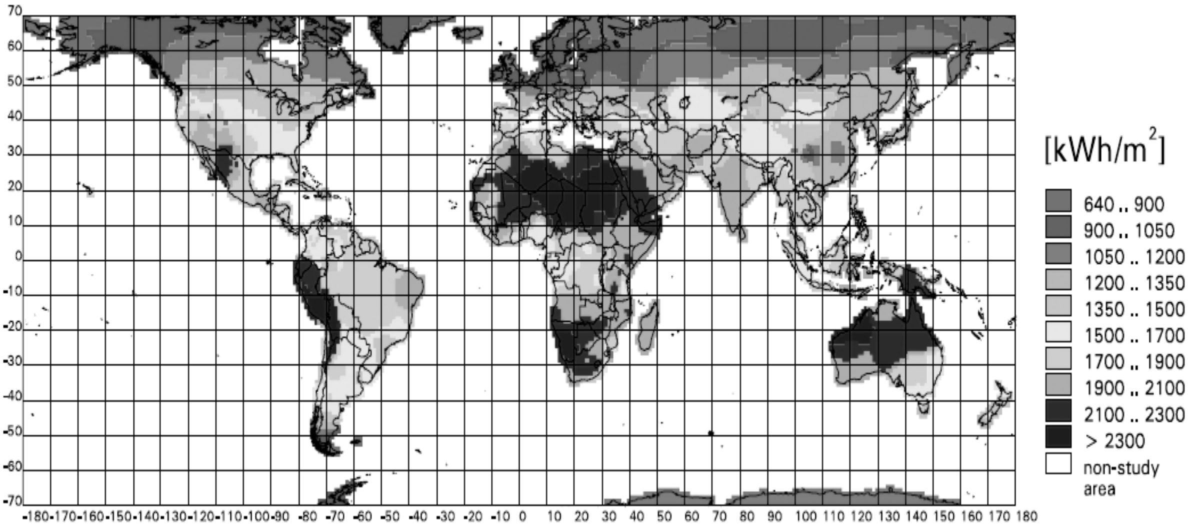

Fig 5. Concentrating solar power resource Potential Map [1]

The above figure shows an average value of solar irradiation in several areas in the world. The largest potentials we find in Northern Africa and on the Arabian Peninsula, as well as in South Africa and Australia. And also the values of Spain and Southeast Asia are recommending solar thermal power plants. The global solar irradiation in Thailand is between 1700 and 1900 kWh/m^2-a. If considering direct radiation, which is essential for solar thermal power plants, has an average percentage of 52 % of the global radiation under the tropical climate conditions of Thailand [2], than 850 and 950 kWh/m^2-a are an effective potential. Cloud coverage impact is an important issue and needs to be considered while choosing a suitable site. Some areas in Thailand can not provide enough stable weather conditions to create a constant electricity production with CSP / steam turbine configurations.

If we compare this result with experiences gained in Europe, we come to the following results. Solar trough power plants are installed in Southern Spain, where the global radiation is between 1600 and 1800 kWh/m^2-a, which is more or less the same amount of radiation. But the part of direct radiation is higher, as there is no tropical climate effect, what allows us to calculate with 61 % of the global yearly radiation [2,3]. Especially the monsoon season between May and September reduces the radiation on the ground. The months between September and March reach average direct radiation values of 80 % [4].

The Fig. 6 shows the global radiation in Thailand in MJ per m² and year. It comes to the same result as well as the measurements during the project.

4. Global Solar Radiation in Chonburi

The following graph compares the global solar irradiation from different sources of data. It shows that the data from all sources are possible to be used in calculation of solar application system efficiency. The data from National Aeronautics and Space Administration (NASA) and Department of Alternative Energy Development and Efficiency of Ministry of Energy of Thailand (DEDE) are close. These data are shown in the curve of the School of Renewable Energy Technology (SERT) / Environmental Competence Center (ECC) measurements on site. They demonstrate the impact of the monsoon season on the amount of irradiation reaching the ground and the impact of the cloudy sky during this period.

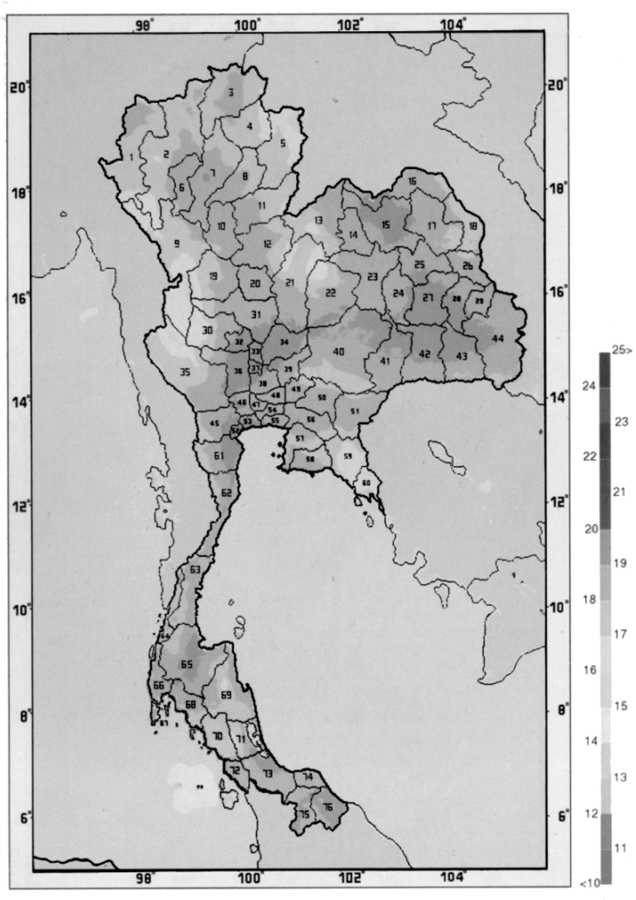

Fig 6. Average yearly global radiation (MJ/m²-day) [3]

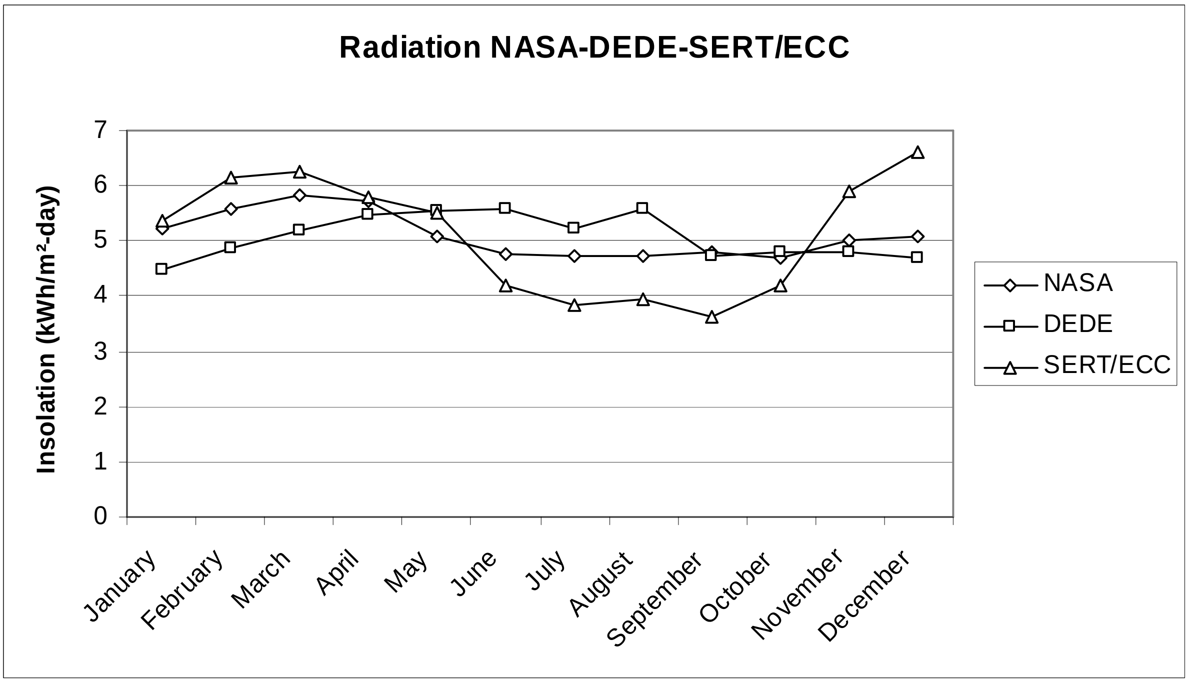

Fig 7. The comparison of solar global irradiation from three data sources

To validate the radiation data from Chonburi, it is useful to compare with the data from Almeria in Spain, where long term experience with solar thermal power plants have been achieved by German Aerospace Center – Deutsches Zentrum für Luft- und Raumfahrt (DLR). The graph below shows that the deviation depends on the seasons.

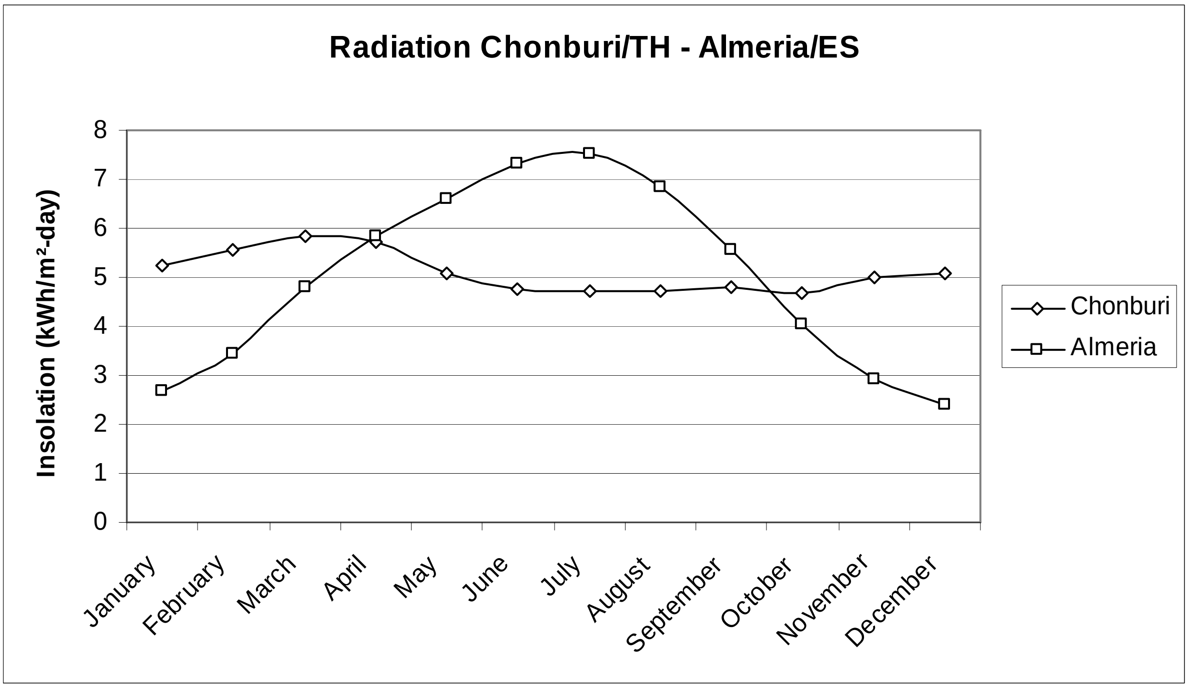

Fig 8. The comparison of solar global irradiation between Chonburi / Thailand and Almeria / Spain

The average global solar radiation on the surface for Almeria is 5.1 kWh/m²-day while the average radiation for Chonburi is 5.0 kWh/m²-day. The deviation is quite small, which leads us to the recommendation of using this technology and its suitability for the weather conditions of Thailand and Southeast Asia.

From the above demonstrated data, it can be noted that the installation of parabolic troughs generating heat from solar energy for any purposes is an effective choice of technologies. Since solar parabolic trough applications, only direct solar irradiation can be used, therefore, the direct solar irradiation was investigated. The observation from many data taken during the project period of January 2006 to December 2006 show that an average percentage of 61 % [4] can be used as direct radiation in the Koachan area.

5. Economical aspects and results

The construction of this small scale demonstration unit can not be compared to large scale installations regarding to the possible financial impacts. Nevertheless the construction chosen allowed making use of a broader amount of locally produced parts as steel structures and common installation measures.

The design based on low temperature steam screw generators was selected to work with low pressure and to integrate a self-securing operation. This led to the fact that the total project investment could be limited within a budget of 400,000 Euros and a technical installation of 200,000 Euros. Large scale units are reaching prices between 2,800 and 3,800 Euros per kW depending on local conditions today [5, 6, 7, 8, 9]. This price is suitable for present adder conditions in Thailand and other South East Asian states.

The payback period for a 5 MW solar power plant can reach nowadays 6.8 years including financing. In the future the pay back period may be reduced to less than 6 years, when prices are down to 2,800 Euro per kW. Until 2020 prices below 2,000 Euro should be reached and allow adequate economics without state support [5, 6, 7, 8, 9]. A prolongation of the adder contract period now to 15 to 20 years instead of 10, would be useful not only to promote and support the solar technology but to allow the creation of local solar thermal industry and to speed up the climate protection speed regarding saving of CO_2.

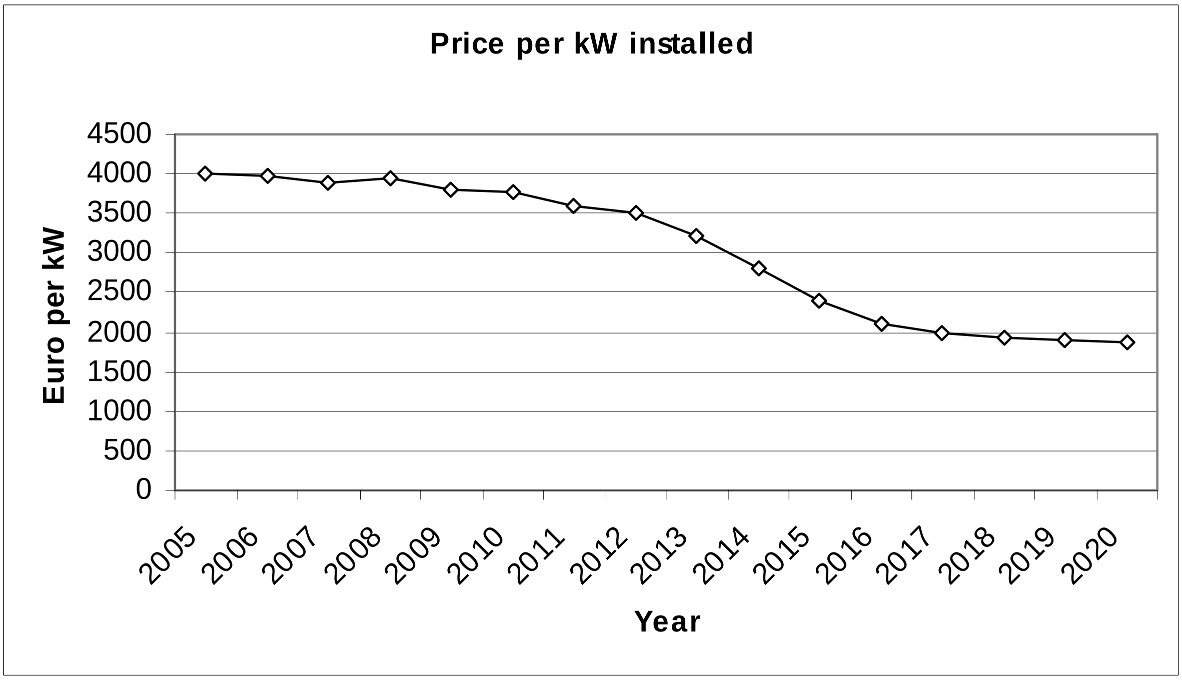

Fig 9. The development of solar thermal power plant pricing [5, 6, 7, 8, 9]

The project in Chonburi was made for demonstration and scientific purposes only, a commercial use of the electricity or the thermal energy was not intended. Nevertheless the electricity and heat production achieved, demonstrated the economical suitability. An average daily operation of 6 hours over a calculative year with 300 full load days was possible – assumed a constant operation would have taken place, a yearly production of 21,900 kWh would have been achieved with the 10 kW steam screw machine. The thermal carbon saving of the station is roughly 37.8 t CO_2 per year or 12.6 t CO_2 per year electrical carbon saving. As this technology allows co-generation and produce electricity and thermal energy at the same time an average carbon saving per 100 kW thermal between 40 and 50 tons is possible.

A larger scale system achieves other economical results as the efficiency of the converting unit – turbine instead of steam screw – is much higher. A 5 MW unit in Thailand may be able to produce 9 million kWh per year on pure solar mode without using co-generated thermal energy. The CO_2 saving in this size will reach 5,200 tons per year.

As this station was a pure demonstration facility, we have to make assumptions for investment costs for such a small unit, when we want to discuss economical aspects. A commercialized system of 10 to 100 kW_e would need at first a suitable small turbine. At this period of time machine producing companies are working world wide to development suitable technologies in the scale between 10 and 200 kW. Until today only prototypes and pre-series are available. Assuming that this technology will be ready within the next years, it has to fit into the market price levels. Such a steam screw should not cost more than 1,000 Euro per kW_e installed.

Assuming a 10 kW unit would be installed with an electrical efficiency of 8 to 10 % [10, 11, 12]. a 100 kW_{th} solar field would be required. This equals an aperture surface of 200 m². 200 m² with a price of 250 Euro installed would end up with a total investment of roughly 60,000 Euro including the assumed 10,000 Euro steam screw set up. For pure electricity production these costs are too high in comparison with other technologies, for example photovoltaic. The turbine can not be competitive in this size. If co-generation is required, then the situation changes as photovoltaic can not supply thermal heat. Assuming the steam screw produces electricity and afterwards the waste heat is used for cooling purposes, than this additional value needs to be taken into our calculation.

Taking the above mentioned data into consideration and the technical data of the station, this consists of 4 rows parabolic trough with a span of 2.3 m, aperture 2.1 m and a length of 22.0 m each. The total surface of the trough systems is therefore approximately 185 m². For the electrical efficiency we estimate a grade of 10 % based on the performance of an Ergion or Spilling machine. From calculation, it can be concluded that energy production for thermal and electric are up to 100 kW_{peak} and up to 10 kW_{peak}, respectively and average yearly production for thermal and electric are 112,792 kWh_{th} and 11,279 kWh_e, respectively.

Calculation for Heat Gain

The annual heat gain can be calculated from the following steps by using the direct normal solar irradiation data from 12 months (from Table 4) which can be effective on the site. The data were collected between January 2006 and December 2006 as shown in Table 1.

Table 1: Annual heat energy production between January 2006 and December 2006

Month	Direct (kWh/m²)	Days	Monthly sum (kWh/m²)
January	3.27	31	101.37
February	3.64	28	101.92
March	3.84	31	119.04
April	3.78	30	113.40
May	3.69	31	114.39
June	3.19	30	95.70
July	2.83	31	87.73
August	3.13	31	97.03
September	2.73	30	81.90
October	3.31	31	102.61
November	3.53	30	105.90
December	3.72	31	115.32
Total			**1236.31**

If the direct normal solar irradiation can only be used on 300 days per year due to climate conditions, then the annual sum should be only 1,016.15 kWh/m^2*a. While the trough efficiency is assumed with 60 %, then the annual sum of thermal energy gain is 609.69 kWh_{th}/m^2*a.

In case the surface area of receiver is 185 m^2, the annual sum of thermal energy gain of the demonstration station is 112,792.6 kWh_{th}. And if the surface area and the efficiency of the electrical system is 10% from estimation, the annual sum of electricity gain of the demonstration station is 11,279.26 kWh_e (or 60.7 kWh_e/m^2).

CO_2 - Savings

Another important economical factor of the technology might be the saving of carbon dioxide emissions beside its importance for climate protection measure. We assume the calculation parameters, that 1 kWh electric equals 1.000 g CO_2 and 1 kWh thermal equals 300 g CO_2. The CO_2 savings are 33.8 t CO_2/a (or 0.18 t CO_2/a) for thermal and 16.9 t CO_2/a (or 0.09 t CO_2/a) for electrical, respectively [13].

These results show the importance of a thermal application, i.e. industrial steam production or air conditioning with adsorption chilling systems to make use of a maximized economical output.

Economical results

Table 2 shows the technical calculation on power production (Solarlite 2300 parabola with Ergion exchanger)

Table 2. Economical analysis of a small scale 10 kWe solartrough power plant under tropical radiation conditions and reduced investment assumptions

Calc. radiation, max.	800	W/m²
Efficiency grade collector	52	%
> actual power	610	kWh/m²/a
Efficiency grade exchanger	10	%

1. electrical energy			**2. thermal energy**		
Electrical power	61	kWh/m²/a	Thermal power	549	kWh/m²/a
Thermal losses	10	%	Thermal losses	10	%
Actual electrical power	54.9	kWh/m²/a	Actual thermal power	494.1	kWh/m²/a
Power per 6 m segment; 2,3 m² panel	757.62	kWh/kWp	Power per 6 m segment; 2,3 m² panel	6818.58	kWh/kWp
Feed-in fee; according german law EEG Solar 2006	0.24	€	Fee equivalent to oil (6 € Cent final consumer)	0.06	€
Payment per year and segment	**181.83**	**€**	**Payment per year and segment**	**409.11**	**€**

Table 2 (Continue)

Profit through carbon credits		
Savings per 6 m segment	2.772	t/CO²*a
Fee per ton	10.00	€
Fee per segment and year	27.72	€
Total payment per year and segment	**618.66**	**€**
Calc. cost per m² parabola	250	€
Calc. cost per m² exchanger	100	€
Calc. cost per segment	4830	€
Calc. ROI	7.8	years

The above mentioned calculation is based on pure solar operation. In combination with biomass operation and 24 h service of the plant the ROI will be different – such a hybrid system shows the latest development in the field of decentralized technology. For future installation such a design will be the solution, not because of necessary economical reasons, but of climate protecting reasons.

Since December 2006 a feed-in-law exists in Thailand and permits a tariff of 3 Baht plus another 8 Baht for solar produced energy. We also assume to receive and advance carbon credit of 470 THB per t. The average income for pure solar systems is 667.7 THB/m²*a and plus carbon credit is 84.6 THB/m²*a. Then, the total income is 752.3 THB/m²*a.

The costs of an installation depend on size and availability of local resources. For the following calculation, we assume the use of local products and production facilities to meet an affordable ROI.

6. Technical aspects and results

The turbine used was a prototype of an Ergion steam screw with a capacity of 10 kWe, which is operated at a temperature between 170 and 220 °C with a peak efficiency of 11 % and average electrical efficiency of 7 to 8.5 %. A turbine of 2 MW size may reach 19 % efficiency, while a 5 MW turbine already reaches up to 26 % and 50 MW units may reach nearly 40 % [14, 15]. The difference is that a steam screw can be operated at 170 °C, while a turbine needs 330 °C and good steam quality to reach the above mentioned values. Unfortunately there is no commercial small scale electricity generating units in the market yet. Several institutions are working in this field to develop solutions, but only a few are installed until today. If suitable engines are available, than small scale solar trough installations are going to be seen in larger numbers in sunny regions around the world.

The part load behavior of the prototype is described in Table 3. The steam screw showed that it performs with direct steam injection. Its efficiency is of course not competitive with larger turbine design specifications. Nevertheless it shows an option for future applications and an alternative to existing low temperature engines design.

Table 3. Part load behavior of the Ergion steam screw prototype in Chonburi / Thailand during November 2005 and February 2006

DNI W/m²	Thermal part load from solar field %	part load turbine efficiency %	Electrical output kWe
300	33	3.11	1.0
400	44	5.13	2.3
500	56	6.81	3.8
600	67	8.14	5.4
700	78	9.11	7.1
800	89	9.73	8.6
900	100	9.99	10.0

The technical reason to make use of the Ergion machine was the ability to coop with direct steam injection. Normally a greasing additive is required to protect the bearings of the steam screw. Several different additives were tested, but cracked through the achieved high temperatures of the solar field. An operation temperature of 180 °C was reached also on days with a few clouds. During the testing period the station could be started between 8 and 9 am and operate until 4 or 5 pm. At these early and late times of the day typical radiation conditions of 400 W/m² DNI were measured. The following graphic shows such a typical situation and the ratio of direct and diffuse radiation on site during the month November until February.

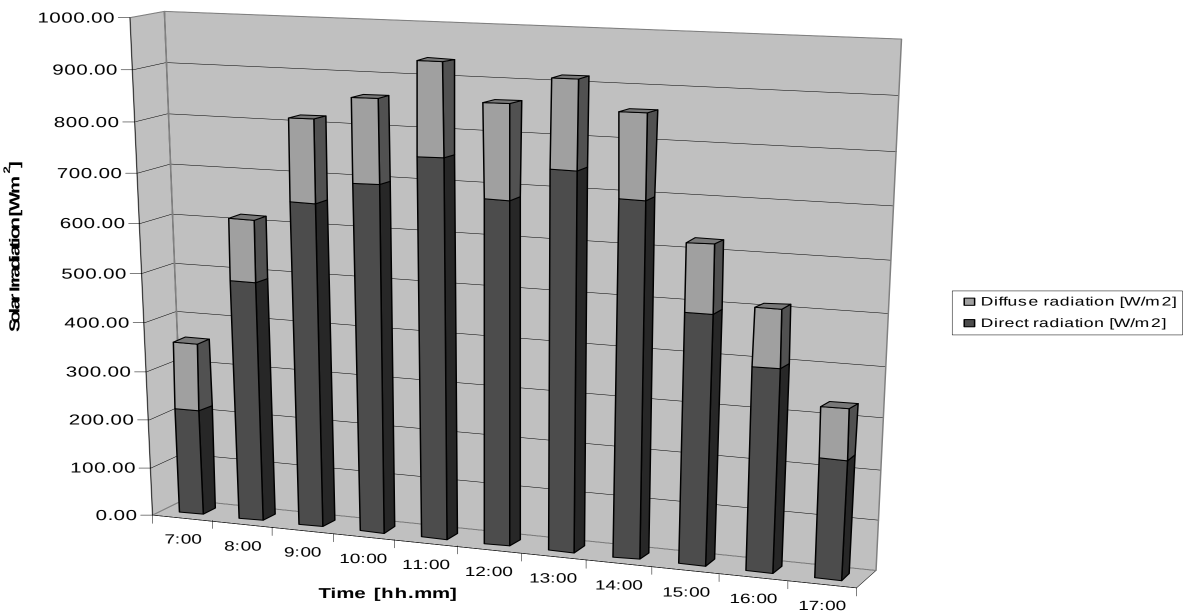

Fig 10. Diffuse and direct irradiation between 7 am and 5 pm in Chonburi / Thailand during November 2005 and February 2006

The start up time was not longer than 30 min until normal operation with 180 °C was reached. Transitions of clouds had an impact on the electrical output as the system was designed in a direct way with short pipe distances between the solar steam generator and the power unit; no expansion vessels were required as a storage device for the feed water allowed compensation as well as the sizing of the system. The reduced energy from the solar field, when clouds crossed the field had no mechanical impact of the system. The turbine reacted in a smooth way as still some temperature and pressure came from the field. The thermal behavior is slowly and suitable measures allow operation and partly cloudy days.

It came to the result that a solar thermal installation can operate up to 6 hours per day on a calculative year of 300 days, which takes the rainy season into consideration. These full load hours can be extended easily, if hybrid systems are used, which for example allow the use of biomass boiler systems to operate the station on constant basis. Such a base load design would be the most economical and ecological.

As direct saturated steam is used and no ORC circle, storage requires a phase change module design (PCM). This technology allows the supply of necessary high energy inputs in very short time to change the hot water into steam. Unfortunately these systems are still expensive and matter of research and development. Once these systems are commercially available, they will support the CSP technology and allow full solar operation. Systems with storage times of 2 hours and more are technically feasible already, but the economics do not fit to the existing feed-in tariffs in Asia. We can assume that this may change within the next three years and operation time of CSP will be doubled. Fortunately CSP investments can be adapted easily to storage devices also at later stages of existing stations.

7. Conclusion

The project has demonstrated the economical use of appropriate solar thermal technology in Thailand. The radiation is strong enough for the use of solar parabolic installations and its combination ability with local biomass technology shows a suitable solution for the energy demands in rural areas in Southeast Asia.

There are still more opportunities to be followed and examined for renewable energy technologies, as well as their use in typical applications such as cooling and food processing facilities. The use of solar thermal technologies in combination with adsorption or absorption chillers can replace other cooling or air conditioning technologies and would help in reducing the bottleneck of electrical energy as thermal energy is demanded only. More electrical energy would then be available for small and medium size industries or craft companies like the OTOP promoting measure.

Investment costs are still high and need to be subsidized by the adder system, but in future the cost will come down and allow suitable prices for electricity production. Small scale systems need high financial support as their electricity production cost may reach 0.46 Euro per kWh. At sites with good direct solar irradiation conditions and 5 MW size of the turbines minimum, the price per kWh may drop from 0.11 to 0.19 Euro today to 0.05 to 0.08 Euro in 2020.

The technology is interesting and shows currently its feasibility under tropical conditions too. Larger units show interesting commercial figures, while small scale units of several hundred kilowatts are too expensive in comparison to other technologies. The expected storage technology gives a large advantage to CSP in comparison to PV as the operation times can be increased to a large extend.

The protection of the climate can be supported with the described technology in terms of the CO_2 savings achieved as well as the ecological balances of the used parts which are worthy amounts.

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