CHAPTER IV

RESULTS AND DISCUSSION

The above mentioned ways of calculating solar projects go deep into each single project and are necessary. They need to be done and show already the importance of the criteria, we have to use in the solar attractiveness equasion. They also give an indication about the value of the factors. The factors of each criteria need to be clearly defined. The smaller their sensitivity is, the higher their percentage is, as only small irritation are possible and their expressed value allows a proper statement.

Kaiser-Guttman-Criteria

Following the factor analysis approach and the Kaiser-Guttman-Criteria a simple identifying method is the result. Four main criteria with a large impact in the variance through their factors and its definition are chosen and defined with a general factor value. The factor value is validating its criteria and in total the equation by summing up to 1. A further step is the use of the multi factor analysis approach as it is done in other economical fields like site identification and their advantage discussion. In this case the explanations of Kroening [32] were used and transferred into our solar model to identify the solar attractiveness **SOLAR A**.

Location discussions by means of economical positioning of companies, but also by means of economical most suitable solutions for power plants or other economical units make use of the approach with multi factor analysis. This work transfers these models into solar necessities and defines values in the following chapters.

Factor Discussion

The chosen criteria are a result of logical necessities and the outcome of the above mentioned points. An infrastructural project needs to take into consideration general and technical criteria. As we use the criteria **climate, investment, technical**

character and **public impact** to describe a project, we can draw a connection to normally used validation calculations and statistics.

To identify the weight of the factors a multi factor analysis has to take place. Its results lead to the factors values, which are needed in the solar attractiveness equation. The values of the factors can be found by putting the criteria into a matrix. The importance of the criteria gives a value: more importance in comparism to another criterion gives 2, same importance gives 1 and less important gives 0.

The table below shows how the values are developed following this approach of importance of factors. Comparing each factor with each other allows to identify the prioritized factor and give him by mathematic approach the highest value and vice versa. Nevertheless each criteria show be discussed and the values may be adjusted regarding their identified value without changing the priority.

Table 2 Multi factor analysis to identify the factors value; own calculation and Kroening

Criteria	Climate	Investment	Technical Character	Public Impact	...	Points	Weight Factor	Chosen weight factor
Climate		2	2	2		6	0,5	0,5
Investment	0		1	2		3	0,25	0,25
Technical Character	0	1		0		1	0,08	0,1
Public impact	0	0	2			2	0,17	0,15
...								
SUM						12	1	1

Legend:
2: Criteria in line is more important than criteria in row
1: Both criteria have the same importance
0: Criteria in line is less important than criteria in row

Source: Kroening, 2011

The criteria **Technical Character** and **Public Impact** deserve a little adjustment as a result out of this mathematical approach. The importance of the **Technical Character** shall be slightly higher and defined with 0.1, while the **Public Impact** should be adjusted to 0.15. The next paragraphs explain in a non-mathematic way, why the values of then factors are chosen in the way it is done.

Selected Criteria

Climate as criteria is normally already included in a basic decision. A solar station would not be installed in areas, where no or low radiation only occurs. The choice of technology can be related to this criterion, as we know already that we check a solar application project. So we just turn around the need. If we have the right climate, than we can use solar power. As there is no alternative to the radiation condition, the answer can be a simply yes or no only. This fact and the importance of the criterion allows a validation of the factor of 0.5.

The minimum radiation condition has to be checked frequently as technological developments may allow to use solar systems at lower radiation in future. In 2009 the broad opinion in Europe by DLR, Solarmillenium or Abengoa and other institutions was that the minimum radiation required for CSP stations shall be not less than 2,000 kWh/m²/a and a minimum size of 50 MWe for a station would be necessary. This has changed already, projects with a small scale design and reduced temperature can start at 1,400 kWh/m²/a and at a few MWe.

Nevertheless this criterion is a first decision pro solar or pro biomass or pro other technology. The equation itself would be used by a solar interested person only. This reason also determines the factor of 0.5.

Investment is of course a major criterion, that is part of all commercial calculation. As we are working on a model, which can be used before a feasibility study, we need to include rough estimations or useable market prices. This work is using market prices and develops a criteria value for different sizes of solar power units. The next chapter validating the criterions is showing actual values of CSP systems in the period between 2010 and 2013. It is understood that the prices will fall by time and implemented size and numbers of stations.

As todays economies are not valuing nature in the same way as commercial aspects, the importance of this factor becomes rather important too. An appropriate value for this factor is given by 0.25.

The importance becomes clearer, if we look at the technical character and public impact factors value. The ratio between the three criterions needs to describe the whole picture of the technical solution. The economical impact has to be strongest criteria to point out the bearable solution. The public impact has the next level of importance, while the technical impact has to understand as the weakest. The technical character is more or less referring to quality, efficiency and maintenance issues.

The **technical character** is newly described as this work is about a new technology, which is not largely spread in the market yet. But as a criterion it is essential to give a value about the performance and to integrate it into the equation. In LCOE the efficiency or the technical character is part of the yearly produced energy amount. In specific feasibility studies we find more precise data in the yearly assumptions on O+M as mentioned above. So this criterion is clearly mentioned in details in chapter III. Its weight factor is defined with a value of 0.1 as it is the weakest criteria of all. The technical character describing the technology, the performance and the produced quality as well as the O & M characteristics need to be on a good level to be used anyhow. Therefore we can assume that the technical grade that is reached is sufficient and the decision maker using the equation can rely on the performance.

The criteria **public impact** is normally integrated in the LCOE as well as an additional income. For the socio-economic model it essential that this possible impact is part of the equation, but not in value as we need it in the levelized cost analyses. Here the positive impact is more important than the value, as the financial security is more important for investors. As discussed previously this criteria is of higher importance as the Technical Character of a solar system. Following the mathematical validation and the adjustment in comparism with the other criteria the value of the factor is defined with 0.15.

The result "Solar attractiveness" gives a quick information or a yes or no for a solar project for specialist and non-specialists. The equation is created as a linear model adding the criteria values. The value will be between 1 and 10, as a positive result, and allows an immediate orientation about the project. Therefore the linear equation has to be set up like this:

$$Y = ax_a + bx_b + cx_c + dx_d$$

When Y is the solar attractiveness

A, b, c and d are the criteria

x_a to x_d are the relevant factors for each criteria a to d

and where the sum of the factors x_a to x_d must be "1".

This linear equation allows with its simplicity to add up the necessary and relevant criteria, which are weighted by their factor, and to come to an easy understandable result. The result must therefore be between "1" and "10", where "10" stands for the best possible result and "1" for bad project. It permits to identify the projects quality by first view and even an average result makes the user understand the average quality. The use of the equation is easy and can be followed by non-technicians as well. This model should be useful for all people concerned, for example an interested politician in Northern Africa must be able to use the model to understand if his wish to create a solar power plant is possible or not. Using the model, he gets an answer "yes" or "no" – the detailed project calculations and the necessary engineering must be done by specialists anyhow at a later stage. They will use the detailed equations mentioned in chapter III and the economical and technical models that are state of art. These equations are not subject of this work. The developed equation is a decision finding tool for non-specialists like politicians, bankers and investors, and a quick tool for solar companies orientation.

A model using multiplication would show values in an increasing way, which is difficult for non-specialists to be understood. The results would be highly differentiable with a large need of explanation. Also the variations would be to big to allow the use of the equation as an indicator or tool for orientation purposes.

Using the economical model as shown below with the criteria and factors explained above, it will come to the following results for solar installations:

SOLAR A = CL (* 0.5) + I (* 0.25) + TC (*0.1) + PI (* 0.15)
[Solar attractiveness = climate investment technical character public impacts]

The weight factors for each criteria describe the importance of each of them. The weight factors can vary and depend on the project to be observed. For example a climate factor is a major criterion. If the climate is not suitable for a solar installation, then any investment becomes obsolete.

The criteria for "Solar attractiveness" need to be valued according to the suitability of the sites criteria and the available technologies as well as other circumstances. The following criteria are discussed and equipped with values. The values are matter of future discussions and remain dynamic in the development of society and technology.

First Criteria: Climate and Radiation Potential

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

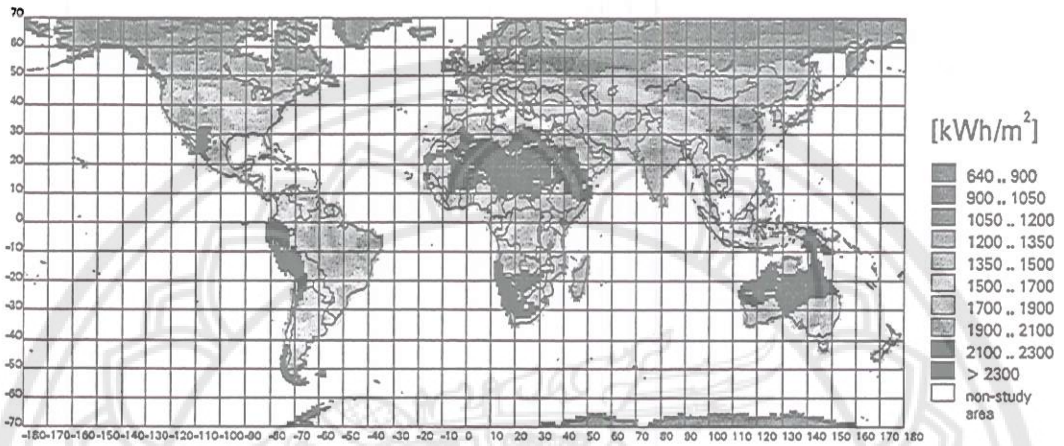

Figure 30 Concentrating solar power resource Potential Map

Source: National Renewable Energy Laboratory, 2006

The above figure shows an average value of solar irradiation in several areas in the world. The largest potentials we find in Northern Africa, America and on the Arabian Peninsula, as well as in South Africa and Australia. The next figure specifies the potential for concentrating solar power plants. It shows areas with suitable radiation only and starts at 2000 kWh/m²-a. Even that no limits are declared in the literature, it is common to work with an optimum value starting at 2000 kWh/m²-a and being unlimited to the top. Small CSP on low temperature basis can work already with lower radiations, but this criteria has to be understood as a clear Yes/No question.

Figure 31 Concentrating solar power plant Potential Map

Source: Docklands Light Railway (DLR), 2008

Having the Yes-No option in mind this criterion has to be weighted with 50 % or a 0.5 factor to be multiplied with the criteria value. As a solar power plant needs to have enough solar radiation and can not be operated without, this the main point needs to be answered with small sensitivity. The other criteria are not of the same importance as a solar power plant can be operated without public impact, but not without solar power.

Regarding the radiation values it can be stated that also the values of Spain and Southeast Asia are recommending solar thermal power plants. The global solar irradiation in Thailand is between 1,900 and 2,100 kWh/m^2-a [25]. 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, 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.

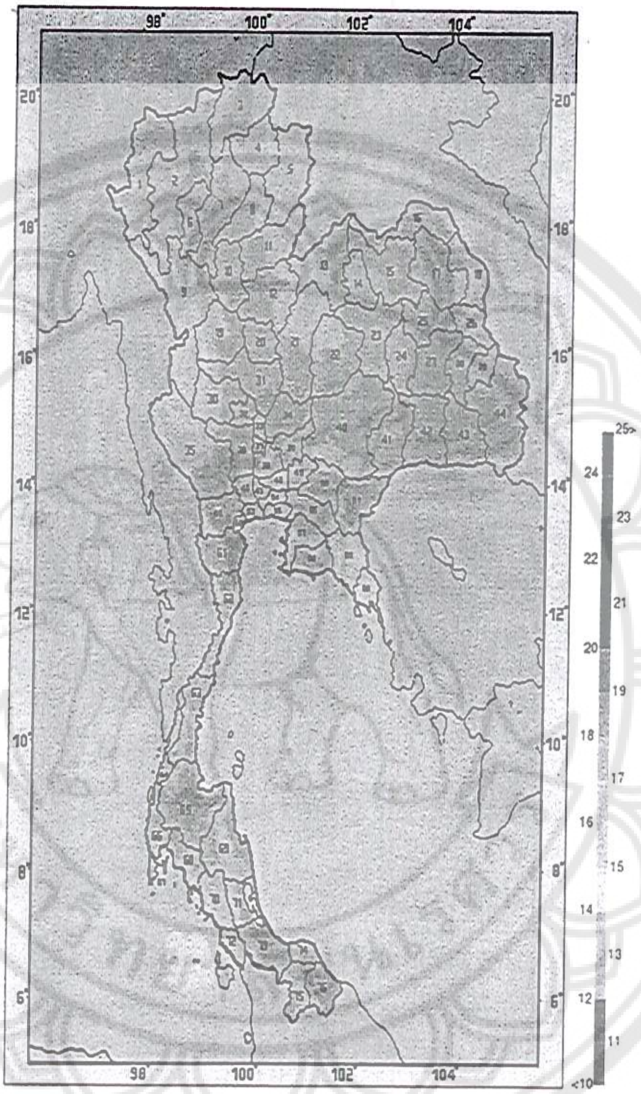

Figure 32 Average yearly global radiation (MJ/m²-day)

Source: Silpakorn University, 2006

The Figure 8 shows the global radiation in Thailand in MJ per m² and year. If we compare the values 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. 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 %. Even that there are variations possible in the radiation, it needs to be stated that the impact on a decision is small. Radiation is a pure yes or no decision.

The following diagram shows the radiation as the main criteria. The availability of a solar system is by nature reduced as it is operating at daytime only. Nowadays storage technologies are allowing longer operation, but the basic understanding for a validation must be daylight operation and maintenance by night time. This leads to a very high amount of operational availability of a solar power plant of close to a hundred percents as the Sandia and Kearney study about the performance of Kramer Junction plant shows [4]. This experience in operation and maintenance since 1984 and its results, let us assume, that improvements done since than, lower the impact of the technical parameter. The newly reached efficiencies of the solar troughs and the turbines also support this fact and underline the approach to select the DNI as main criteria for the climate criteria.

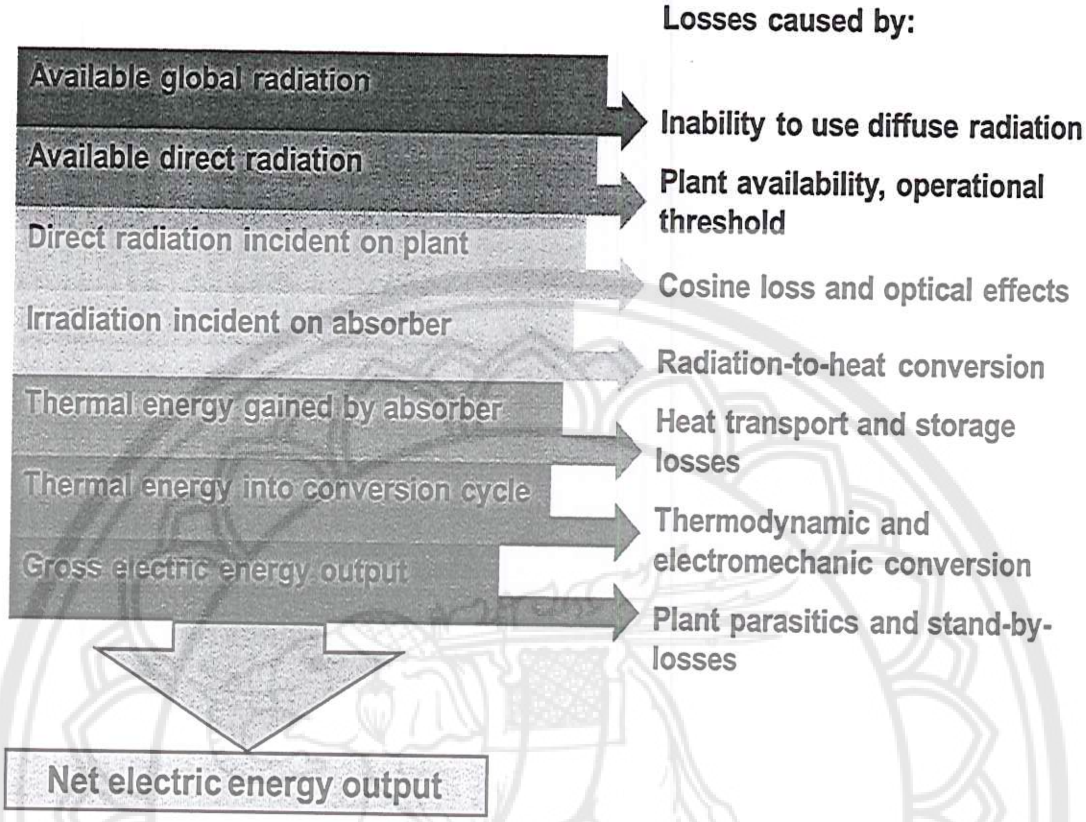

Figure 33 Simplified Sankey-diagram about radiation impact validation

Source: Following Winter, Sizmann and Vant-Hull, 1991

Taking this background used by NREL and DLR into a 5 MWe application with parabolic troughs with an optical efficiency of 71 % (Solarlite) and a steam turbine with a conversion efficiency of 29 % (MAN) under nominal conditions in Thailand, we would find the following values:

Global radiation: 2,000 kWh/m²-a deduct diffuse radiation share [25]
Direct radiation: 1,700 kWh/m²-a deduct plant inavailability (2 %) [33]
Direct radiation incident: 1,666 kWh/m²-a deduct cos loss and opt. effects (10 %)[33]
Irradiation on absorber: 1,499 kWh/m²-a convert radiation-to-heat (29 %) [29]
Thermal energy by absorber: 1,064 kWh/m²-a deduct transport losses (2 %) [33]
Thermal energy into conversion:1,043 kWh/m²-adeduct efficiency losses (71 %) [29]

Gross electric energy output: 302 kWh/m²-a deduct plant parasitics (10 %)
Net electric energy output: 272 kWh/m²-a

This calculation shows properly how we can reach to values of electrical output by following the radiation path. Therefore a use of radiation values as major criteria seems to be appropriate. Taking these values and experience from former measurements into consideration a validation table regarding the validity of the climate factor looks like this:

Table 3 Climate criteria Validation

Global Radiation	Validation	Suitability	Criteria value
640 – 900 kWh/m²	Very low radiation	Very unsufficient	1
901 – 1050 kWh/m²	Very low radiation	unsufficient	2
1051 – 1200 kWh/m²	Low radiation	Very inadequate	3
1201 – 1350 kWh/m²	Low radiation	inadequate	4
1351 – 1500 kWh/m²	Good radiation	average	5
1501 – 1700 kWh/m²	Good radiation	Nearly good	6
1701 – 1900 kWh/m²	Strong radiation	good	7
1901 – 2100 kWh/m²	Strong radiation	Nearly very good	8
2101 – 2300 kWh/m²	High radiation	Very good	9
> 2300 kWh/m²	High radiation	Extremely good	10

Source: National Renewable Energy Laboratory, 2006

The sensitivity of this criterion is low, as the solar direct radiation can be defined precisely and therefore the criteria value is fixed. Nevertheless a little sensitivity can be allowed by choosing a range for the radiation. This becomes even more clear, if we look at another approach by using a Sankey-diagram (or "loss tree") [38] showing the impacts on the net electrical energy output by solar radiation and technical parameters of the solar plant. The losses shown in the graph are caused by the inability of CSP plants of using diffuse radiation, plant availability, cosine losses by position of the plant and seasons and the technical parameter of the plant. The technical parameters are explained more detailed in the clause of technical character.

Conclusion Climate

The table allows to give a factor to validate a solar project and to integrate into the solar activeness equation. Multiplied than with the criteria factor the importance of the criteria is defined. As the radiation is the most important criteria for the functionality of a solar system, and can only be answered with yes or no, this factor is described with 50 % or a multiplication factor of 0.5. The sensitivity can be adjusted by the selection of the radiation only, which very precise if the measurement tools and data were available.

Second criteria: Investment

At this period of project validation a deep investment forecast is not necessary. A general indication can already assist to identify a suitability. A more detailed investment cost validation is made within the pre-engineering or the feasibility study anyhow. The "Socio-economical" model is giving a specific idea about the suitability of the technology chosen. A levelised cost analysis is a common and known tool to validate technologies and projects and not subject of this thesis.

For the solar attractiveness equation a more general value can be used. As solar projects need to compete with existing technologies and need to meet common price levels per kWh, the values of investment are properly defined to be in a certain amount. The price per kW installed is commonly used to compare different energy producing facilities. A solar power plant may differenciated by its size. A small scale system of some kW up to 50 kW has a different price, than an installation of 100 to 500 kW or Megawatts. The scales and classes shall be defined as follows:

Table 4 Electricity Power Size

Elec Power Size	Description	Price per kW installed	Class
1 – 50 kW	Household	5,000 €	1
51 – 499 kW	Individual	4,000 €	2
500 kW – 10 MW	Very small	3,500 €	3
10 MW – 50 MW	Small	3,000 €	4
> 50 MW	Large	< 3,000 €	5

Each class has to define an investment range, that can be validated. As price levels are changing, this needs to be understood as a dynamic sheet to be adjusted on regular basis. For Dec 2009 the value shall be defined as follows:

Table 5 Price per kW installed in Household

Class	Description	Price per kW installed	Criteria value
1	Household	> 9,000 €	1
		9,000 €	2
		8,000 €	3
		7,000 €	4
		6,000 €	5
		5,000 €	6
		4,000 €	7
		3,000 €	8
		2,000 €	9
		< 2,000 €	10

As the price levels are differing from to class to class, the ranges are differing too. Each single project with its particular characteristics needs to be validated in a detailed projects analysis after a general validation was positively ended.

Table 6 Price per kW installed in Individual

Class	Description	Price per kW installed	Criteria value
2	Individual	> 6,000 €	1
		6,000 €	2
		5,500 €	3
		5,000 €	4
		4,500 €	5
		4,000 €	6
		3,500 €	7
		3,000 €	8
		2,500 €	9
		< 2,500 €	10

Table 7 Price per kW installed in Very small

Class	Description	Price per kW installed	Criteria value
3	Very small	> 4,250 €	1
		4,250 €	2
		4,000 €	3
		3,750 €	4
		3,500 €	5
		3,250 €	6
		3,000 €	7
		2,750 €	8
		2,500 €	9
		< 2,500 €	10

Table 8 Price per kW installed in Small

Class	Description	Price per kW installed	Criteria value
4	Small	> 3,300 €	1
		3,300 €	2
		3,200 €	3
		3,100 €	4
		3,000 €	5
		2,900 €	6
		2,800 €	7
		2,700 €	8
		2,600 €	9
		< 2,600 €	10

Table 9 Price per kW installed in Large

Class	Description	Price per kW installed	Criteria value
5	Large	> 3,200 €	1
		3,200 €	2
		3,100 €	3
		3,000 €	4
		2,900 €	5
		2,800 €	6
		2,700 €	7
		2,600 €	8
		2,500 €	9
		< 2,500 €	10

Conclusion Investment

As the prices are precisely defined for each class and updated on regular basis, its deviations will be fairly low. This allows to minimize the multiplication factor. The value of the factor is smaller as the climate factor and defined with 0.25 because it is not a go or no go question. If the investor wants to spend a higher price or if other necessities arise, then the factor is limited. The project can be done with little investment or with investment, so the factor can not exceed 25 %.

The defined prices also show clearly the criteria value, therefore the sensitivity is low. A user can use the price ranges to adjust the value for his needs.

Third criteria: Technical Character

The technical character criteria shall describe the performance or assumed performance of a system. The might be validated through total efficiencies in production of energy. This can be electricity production, thermal energy production or combined production like in co-generation. For this discussion, we will define the criteria on direct solar electricity production. Taking into consideration that the technical character of the system is related to its ability to convert solar radiation into electricity comparism of solar system might be possible.

Later models should be ready to handle co-generation models too, as future energy production should be able to make use of co-generation to optimize the output of energies and to minimize waste energy through cooling towers, vv.

As development of solar systems is very fast at this stage and taking place on monthly basis with improved values, adjustments of the table are necessary on regular basis. The technical character shall be defined through the solar-electrical efficiency as follows:

Table 10 Solar-electrical efficiency

Class	Solar-electrical efficiency	Criteria value
1 - 3	> 6 %	1
	6 %	2
	10 %	3
	14 %	4
	16 %	5
	18 %	6
	20 %	7
	24 %	8
	28 %	9
	< 28 %	10

As this criteria is close to fixed characteristics the value in the equation is low. A power plant will always be designed in a way that newest and most economical technology is installed. A broad average efficiency is in use and performs as state-of-technology. Nevertheless low efficiency systems will have the effect of low investments and therefore reach a higher multiplicator effect under the investment criteria. As this is most important for economical purposes, the equation is showing its performance.

As this work is focusing on small scale solar thermal power plants only, the class is limited from 1 to 3, defining the maximum of 10 MW stations efficiency.

Conclusion Technical Character

The technical character is a stable factor with little variations. As it has to perform in a certain way before entering any market its impact is little and therefore defined with a value of 0.1 only. This percentage can be adopted by its user depending on unknown impacts, like technology improvement or other items that allow an impact in a positive way to modify the equation. This criterion is of little importance also, as the efficiency of a system do not make a project impossible. A system may work constantly on low efficiency basis, but related to a smaller investment it can make economically sense. In regard of these facts the sensitivity is again very low, but can be arranged through the criteria value. The factor is clearly defined.

Fourth criteria: Public Impacts

Many countries in the world have installed regulations to promote renewable energies in the past ten years. Especially solar energies as the major future energy producer need to be supported as the technology is still at the beginning.

The regulations differ in kind and impact. Some countries have created laws for the construction of houses, which forces everybody to install solar thermal applications to produce hot water, like Spain. Other countries like Germany have created a feed-in-tariff, which obliges the electricity companies to buy solar electricity for a certain price. Other countries like Thailand have created an adder system, which also guarantees a price per kWh produced. The United States have created a tax saving system and special support program for renewable energies. All these measures help to develop renewable energies and have an impact on solar power plant projects.

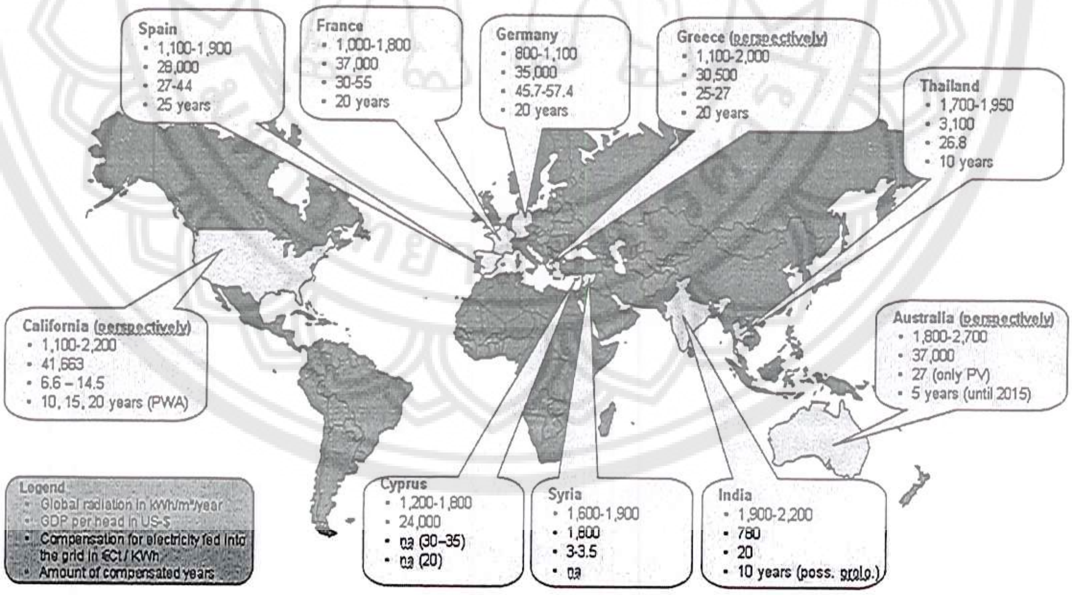

Figure 34 Feed-in regulations in different countries around the world

Source: Solarlite GmbH, 2009

The figure gives an overview of different ways to take influence by the public on solar energy projects. The financial support from the countries differs also. Some countries allow a feed-in-tariff with more than 40 €ct per kWh, while others allow just an amount of 22 €ct. This has of course an impact on the investor's activities. Normally the smaller amounts are paid in countries with higher solar radiation. This effect balances the impact between the different countries and therefore it is not useful as Public Impact factor.

As a matter of security, investors are looking for save investments, where conditions can not change for a certain period of time. In some countries this period is described as long period, when it is more than 15 years. In other countries it is described as long, when it takes more than 5 years. This security character can be used as description of public impact factors.

The longer the state support lasts, the higher the factor. As some projects might be validated at a later project status, periods lower than the legal period need to be allowed also. At this stage 10 years are the minimum, 20 years are the average and 25 years describe the peak period. A two-year increase ratio was chosen to allow a validation of projects of different age. It may occur that mainly 2, 5, 7 and 9 as factor are used for the common, existing projects as regulations permit.

The sensitivity of the criteria is validated by the choice of the criteria value.

Table 11 Solar feed-in tariff binding period

Class	Solar feed-in tariff binding period	Criteria value
1 - 5	> 10 years	1
	10 years	2
	12 years	3
	14 years	4
	16 years	5
	18 years	6
	20 years	7
	22 years	8
	25 years	9
	< 25 years	10

Conclusion Public Impact

The Public Impact factor has large value for investors, therefore it is defined with a value of 0.15. An investor is directly concerned of states activities and financial supports, this leads to the fact that this criteria is more important than the technical one.

The sensitivity is low again as the criteria value can be chosen according to the project time in relation to the public impact time.

Case studies

Three projects were taken to give an overview about the suitability of a decision making tool like the solar attractiveness equation. We remember the basic formula was:

SOLAR A = CL (* 0.5) + I (* 0.25) + TC (*0.1) + PI (* 0.15)
[Solar attractiveness = climate investment technical character public impacts]

The multiplication factors describe the importance of each criteria. The addition of the results describes the effects on positive and negative impacts. A value of 1 is the minimum and describes a solar project that is economically not valuable.

For minimum values the frame equation is:

SOLAR A = 1 (* 0.5) + 1 (* 0.25) + 1 (*0.1) + 1 (* 0.15)

SOLAR A = 0.5 + 0.25 + 0.1 + 0.15

SOLAR A = 1

An average value of 5 allows already a good project according to good economical practice, while a figure if 10 describes the maximum, which does not exist nowadays.

For average values the equation is:

SOLAR A = 5 (* 0.5) + 5 (* 0.25) + 5 (*0.1) + 5 (* 0.15)

SOLAR A = 2.5 + 1.25 + 0.5 + 0.75

SOLAR A = 5

Where maximum values are reached with:

SOLAR A = 10 (* 0.5) + 10 (* 0.25) + 10 (*0.1) + 10 (* 0.15)

SOLAR A = 5 + 2.5 + 1 + 1.5

SOLAR A = 10

The equation integrated into known projects, the results are as follows:

Case 1: Grid connected station in Thailand

The project stands for a typical future installation with decentralized character. The urban areas in Thailand need electricity supply – the demanded size meets our description of class 3, power plants with an electrical output of upto 10 MW. In this particular case a power plant with 5 MW is foreseen. The existing grid can be used for feed- in of the solar power, all necessary lines are available in short distance.

The basis for this project is the feed-in tariff law introduced under the Very Small Power Producer (VSPP) regulations. On November 20 the Thai Energy Policy Committee (EPC) under the National Energy Policy Council (NEPC) approved a significant upgrade of Thailand's Very Small Power Producer (VSPP) regulations. The VSPP regulations allow customers with renewable energy generators (solar, wind, micro-hydro, biomass, biogas, etc.) to connect their generators to the grid and offset their consumption at retail rates. If a net surplus of electricity is generated, the VSPP regulations stipulated that Thai utilities must purchase this electricity at the same tariff that they purchase electricity from the state-owned generation company, EGAT. In autumn 2006, this rate (including FT charge) worked out to be about 3.8 baht per kWh for on-peak hours (weekdays 9 am to 10 pm) and about 2.0 baht/kWh for off-peak hours (weekends, holidays and night time). In case of solar thermal electricity, the price is 8 baht/kWh plus the peak/non-peak hour rates. The law has a limitation on the maximum capacity of the plant which should not exceed 10 MW electrical. The current scenario is that the additional feed-in tariff of 8 baht/kWh is fixed for the next 10 years from the day the plant goes into operation. After this 10 years period, the electricity is to be sold for 3.6 or 2 baht/kWh.

In accordance with the solar thermal electricity feed-in-tariff introduced by the Thai Government several Concentrated Solar Power, CSP, plants are planned to be built over the next years in Thailand. The objective of the project at Chonburi is to construct a 5 MWe net output solar thermal power plant in the sunny area of Chonburi province located in central Thailand. Parabolic trough technology being the more mature and successful technology among the CSP technologies is foreseen for this power plant.

The first criterion is the climate. The following data validate the possible performance:

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 NASA and DEDE are close. These data are shown in the curve of the SERT/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.

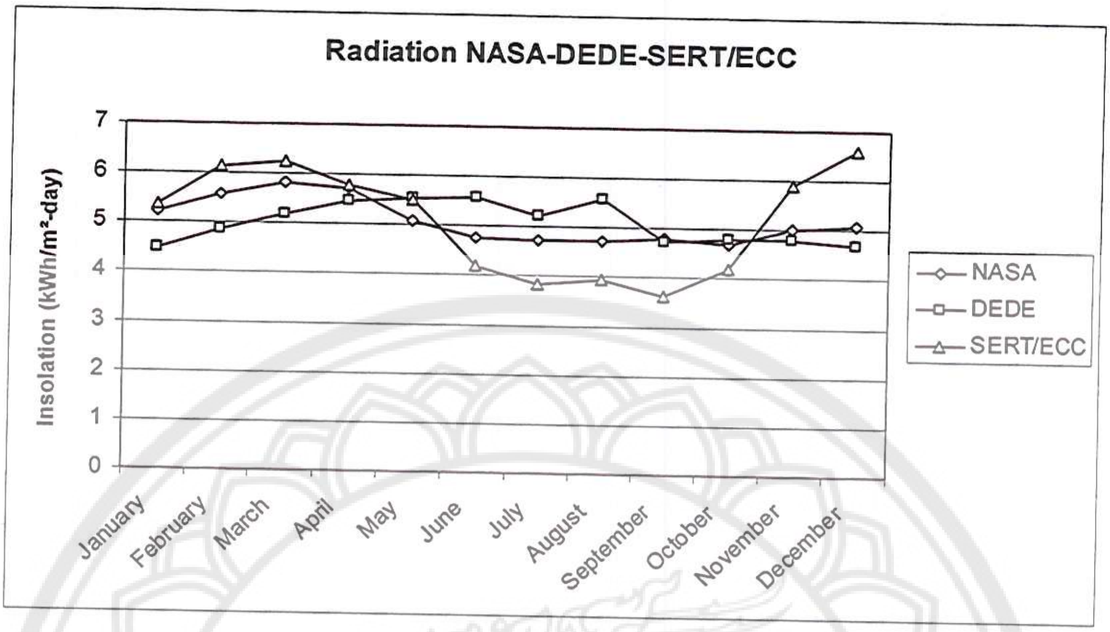

Figure 35 The comparison of solar global irradiation from three data sources

Source: Solarlite GmbH, 2009

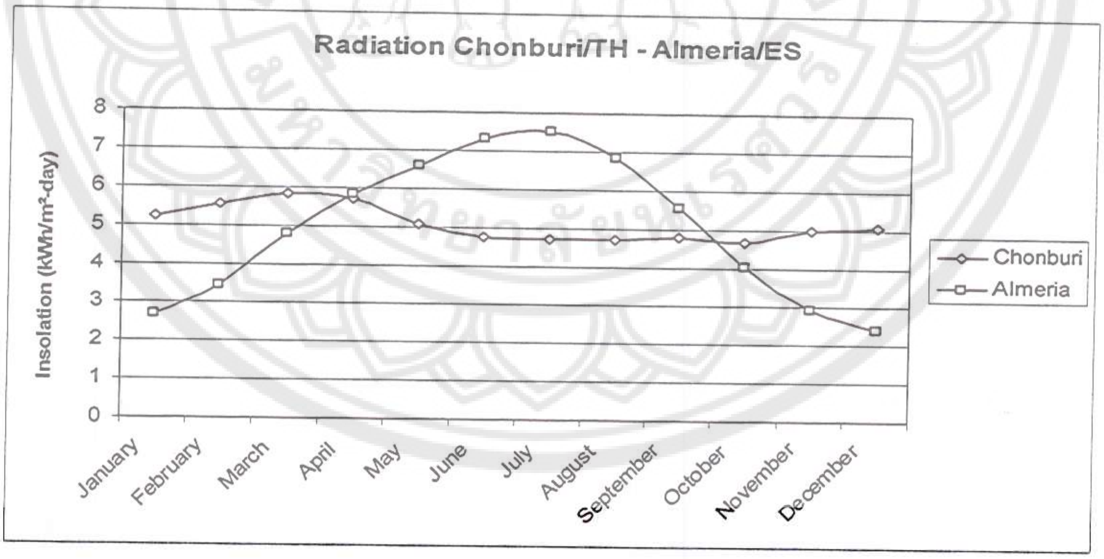

Figure 36 The comparison of solar global irradiation between Chonburi / Thailand and Almeria / Spain

Source: Solarlite GmbH, 2009

To validate the radiation data from Chonburi, it is useful to compare them with data from Almeria in Spain, where long term experience with solar thermal power plants has been achieved by DLR. The graph below shows that the deviation depends on the seasons.

The average solar global radiation on 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 technology. 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 and December 2006 show that an average percentage of 61 % can be assumed as direct radiation in the Koachan area.

Studies at SERT support the above mentioned results. ANAN [32] focused on measurements for direct solar radiation or beam measurements in Thailand. The example of Phitsanulok shows an average value for direct radiation of 66,7 %.

The second criterion is the investment:

Investment for a 5 MW Solar Thermal Power Plant

The investment for solar thermal power plants is of course largely depending on the site, logistical challenges and technical requirements. We talk about typical project development, but it can be assumed that the prices for small and very small power plants can be standardized and large scale production will allow scale effects. Currently the price of a 5 MW solar thermal power plant requires an investment of 680 million THB or 135 million THB/MW or 3,165 million €/MW equalling 3,165 €/kW [31]. Similar levels are found in other sources like company reports and articles about Andasol stations: the price for 50 MW power plant is approximately 200 million € which equals to 4,000 €/kW.

The third criterion is the technical character:

Technical properties of a 5 MW Solarlite STPP

The set up consists of a solar trough field of 45,000 m² aperture surface, on 90,000 m² flat land, BOP and powerblock area. The Solarlite solar trough reaches to a performance of 70 to 72 % from solar direct radiation to energy capture in the receiver.

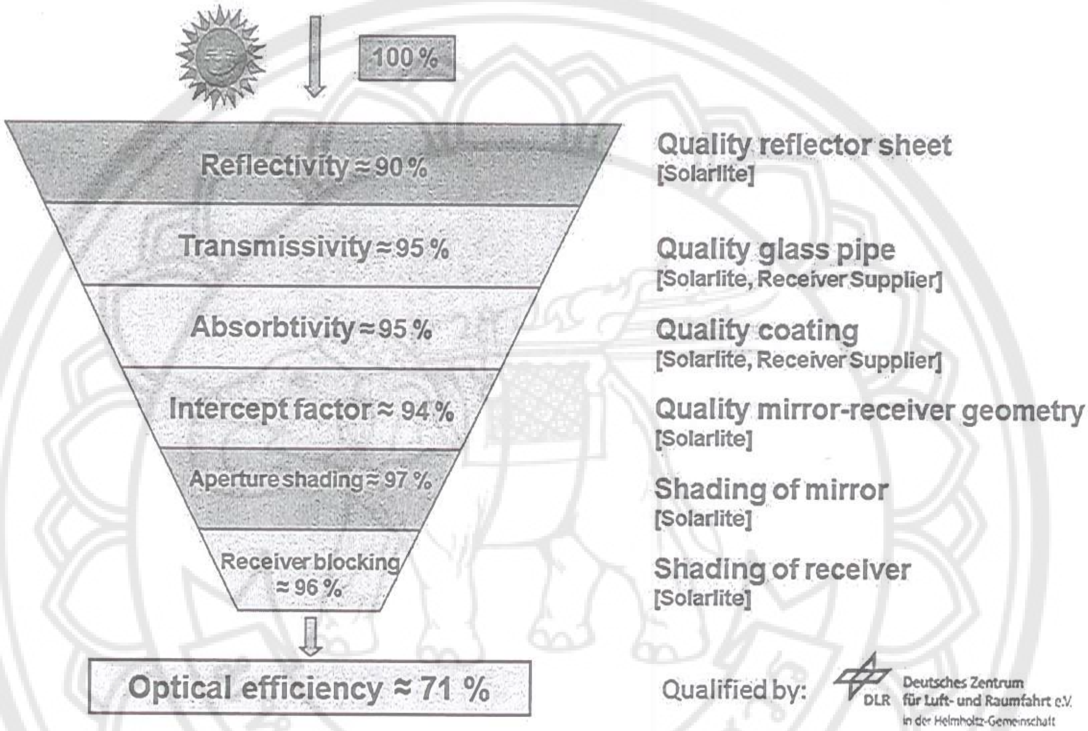

Figure 37 The efficiency of solar parabolic trough Solarlite SL4600

Source: Solarlite GmbH, 2010

The gained thermal energy is conveyed to a power block which is consisting of a superheated steam turbine and its auxiliaries. The efficiency at temperature of 330 °C and pressure of 30 bar is given with 25 % [34]. Assuming the losses in the pipes and auxiliaries of approximately 2 %, the solar electric efficiency reaches 15.6 %

The forth criterion is the public impact:

The Thai solar adder system

Thailand allows the operator of a solar power plant and additional amount on top of the normal electricity price. This normal price consists of an average price of currently 2.4 THB plus a fuel tariff, which is paid, when Diesel is compensated. This FT-fee is approximately 1.5 THB. The average electricity price and the FT-fee are adjustable and therefore subject of increase in relation to inflation. The solar adder with a price of 8 THB per kWh is paid for a period of ten years, if the power purchase agreement is made within the first solar program. Within the current solar program the feed-in amount is reduced to 6.5 THB the period is also 10 years. In other countries such a solar supporting tariff is lasts longer. The period of ten years in Thailand is the shortest, while countries like India or Spain assure a period of 25 years. Other European countries allow a twenty years period for solar electricity.

Adding up the fees under first solar program ends up with a total of 11.9 THB currently, consisting of average electricity fee 2.4 THB plus FT-fee 1.5 THB plus solar adder 8 THB.

Gathering these results lead to the following solar attractiveness indicator:

Solar attractiveness criteria values for Chonburi Thailand:

Radiation: 1500 – 1700 kWh/m² = nearly good > CL = 6

Electrical power: 5 MW = class 3

Price per kW installed: 3,165 € > I = 7

Solar-electrical efficiency: 15.6 % > TC = 5

Period Feed-in-tariff: 10 years > PI = 2

Integrated into the equation gives:

SOLAR A = 6 (* 0.5) + 7 (* 0.25) + 5 (*0.1) + 2 (* 0.15)

SOLAR A = 3 + 1.75 + 0.5 + 0.3

SOLAR A = 5.55

The conclusion for case study 1 must be, that the project is technically and economically valuable. It is possible to put this project into reality as the value is better than average. To validate we now compare with a commonly used LCOE calculation, where an IRR of more than 12 % is required to describe the project as economically viable.

Project Assumptions

The following details of the project are assumed and then broad to an LCOE calculation to validate the project. A comparism with result of the SOLAR A equation is done afterwards to permit to see its correctness.

General assumption

Project lifetime:	20 years
Net Power:	5 MW
Subsidy period:	10 years
Investment:	18 mio € or 775 mio THB turnkey
Degradation:	Not considered
Depreciation:	25 years

Revenue assumption

Operating hours:	6 hours average on 300 days per year
Availability:	More than 98%
Turbine Efficiency:	25,4%
Solar-Electric Efficiency:	15,6%
Electrical output:	9 MWh per year
O+M cost:	1% of invest per year
Inflation:	Not considered
Tax conditions:	Not considered

Financial assumption

Equity capital:	30% of invest
Interest rate:	5,5 %

To calculate the LCOE of the case studies to validate the model, the equation following the IEA model is used (see chapter 2)

$$LCOE_{plant} = \frac{I + OM + L}{E}$$

Where:

I = Installed capital costs

OM = Annual operation and maintenance costs in year zero

L = Annual expenses for input energy

E = Annual energy production (Wh)

Putting the project details into the LCOE equation leads to the following:

$$LCOE_{plant} = \frac{774mioTHB + 7mioTHB + 16mioTHB}{9{,}000mioWhe}$$

The LCOE per kWhe is therefore:

$$LCOE_{plant} = 9THB / kWhe$$

To calculate the internal rate of return (IRR) the net present value formula is used and the values of a project in cash flow per year and its period are inserted.

Where:

C_n = Cash Flow

N = Period

n = year

r = Annual rate of return

$$NPV_{plant} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

$$NPV_{plant} = \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+r)^3} + \ldots + \frac{C_n}{(1+r)^n} = 0$$

$$NPV_{plant} = 15{,}3\%$$

The financial results after using the above mentioned details are shown below:

Investments		
Solar field specific cost	246	EUR/m²
Solar field investment cost	10.989.331	EUR/m²
power block specific cost	1488	EUR/kW
Power block investment costs	7.441.338	EUR
Total investment cost	774.088.065	THB
Specific investment per kWe	154.818	THB/kWe

Financial results		
Total gross revenues	2.016.501.122	THB
Toal revenue from CER	0	THB
Total operating costs	460.196.648	THB
Simple payback period	7,28	
Payback period including financing	8,87	
ROE	14,4%	
IRR	15,3%	
DCSR	1,4	
Levelised cost of electricity	9,446	THB/kWhe

Figure 38 The financial results after using

The financial details in a EBIT business plan are shown below

Financials Solar Trough Power Plant
Chonburi, Thailand

Investment 774.088.064,93 THB

YEAR	25 years	0	1	2	3	...	25
Revenues Solar Trough							
Power of plant in kWel			5.000,00	5.000,00	5.000,00		5.000,00
Power of plant in kWth			13.174,53	13.174,53	13.174,53		13.174,53
Annual full load operational hours			2.136,84	2.136,84	2.136,84		2.136,84
Electricity Sale in THB	2.016.501.122,03		126.608.055,83	127.019.398,45	127.434.854,51		52.229.598,80
Total Revenues in THB	2.016.501.122,03		126.608.055,83	127.019.398,45	127.434.854,51		52.229.598,80
Operating costs	10,09%	6,11					
Own electricity consumption			8.862.563,91	8.862.563,91	8.891.357,89		3.656.071,92
accrual and equipment			3.483.396,29	3.483.396,29	3.483.396,29		3.483.396,29
Maintenance and operation			4.257.484,36	4.257.484,36	4.257.484,36		4.257.484,36
administration and insurance			5.031.572,42	5.031.572,42	5.031.572,42		5.031.572,42
Total operating costs in THB	460.196.648,10		21.635.016,98	21.635.016,98	21.663.810,96		16.428.524,99
EBITDA in THB	1.556.304.473,93		104.973.038,85	105.384.381,48	105.771.043,55		35.801.073,81
Depreciation in THB			30.963.522,60	30.963.522,60	30.963.522,60		30.963.522,60
EBIT in THB	782.216.409,00		74.009.516,25	74.420.858,88	74.807.520,95		4.837.551,21

Figure 39 The financial details in a EBIT business plan

The cash flow is behaving positively from the very beginning of the project.

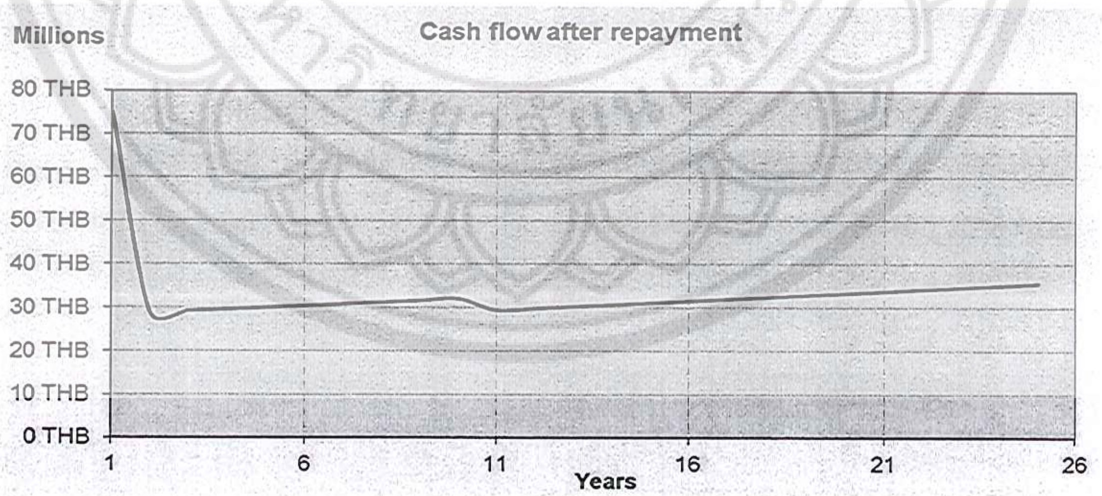

Figure 40 The cash flow is behaving positively from the very beginning of the project

Conclusion

The project is technically and economically viable. The IRR is reaching a value of 15.3 %, which is attractive for investors. The ROE of 14,4 % is a sufficient result as well. The simple payback period of 7,28 years is acceptable too. The LCOE analysis result and business plan prove that the result of the SOLAR A equation is correct.

Case 2: Island solution in Thailand

The project is located in Koh Kood Island, Trat Province, Thailand and is meant to supply energy for a hotel resort. The hotel project has been long recognised as the model environmental friendly tourist resort in the Thailand. Currently, the energy required for the resort is generated and supplied through diesel generators using costly imported fossil fuel in addition to the significant contribution in increasing the local pollution levels. The management has pledged to convert the whole resort into a carbon neutral operation within the next two years and into carbon positive operation on the longer term. In order to reduce the electricity production costs and to reduce the local pollution levels, the management has decided to adopt renewable energy technologies in the operation of their resort.

The objective of the project is to construct a 1 MWe solar thermal power plant with cogeneration to partly replace the usage of fossil fuels for electricity generation, heating and cooling. Parabolic trough technology being the more mature and successful technology among the CSP technologies has been chosen for this power plant project.

After careful consideration, the Meteonorm radiation data was chosen with an annual direct normal radiation of 1756 kWh/m²/day. This data was used for the analysis at this stage which is to be checked and refined using the METEOSAT solar data in the next phase of basic engineering. The steam turbine of 1 MW has significantly less net efficiency than ORC turbines. Therefore an ORC turbine with a total efficiency solar to electric of 14.8 % was chosen. The technical parameters are the same as in case 1; 330 °C at 30 bar [35].

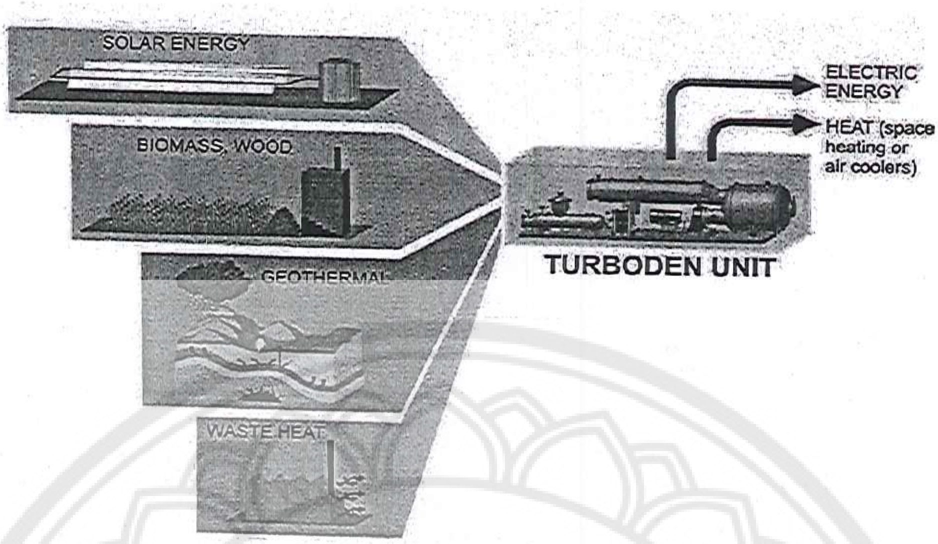

Figure 41 The use of ORC machines in different renewable applications

Source: Turboden Co. Ltda.,2009

The following graph explains the co-generation and its advantages.

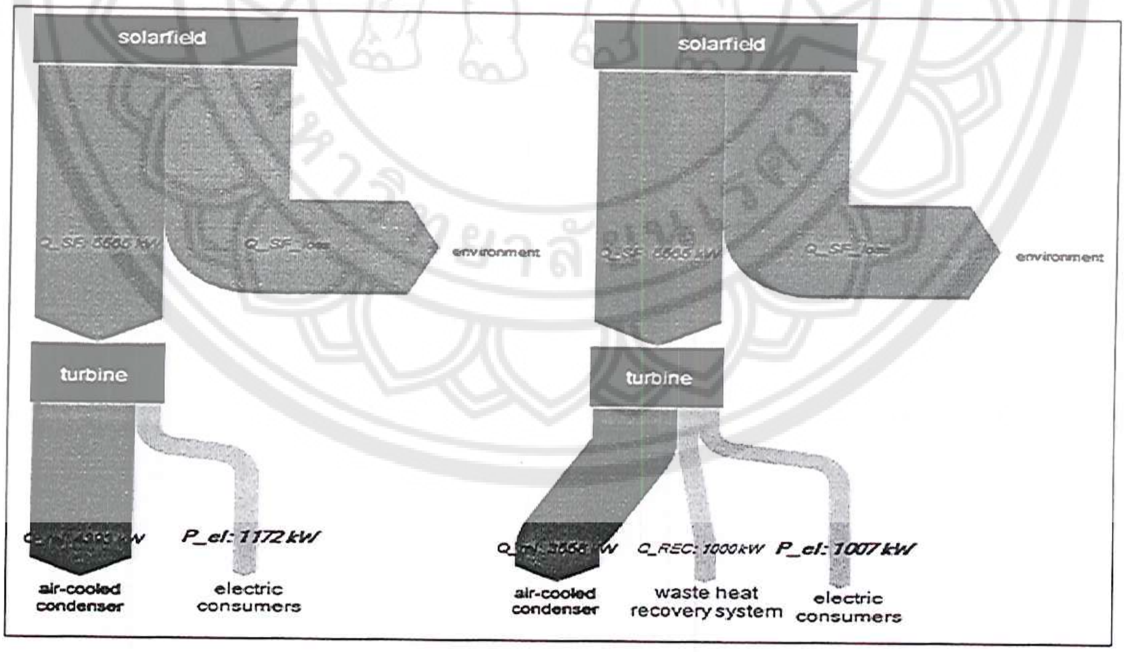

Figure 42 Sankey diagram of the solar energy use

Source: Solarlite GmbH, 2009

Based on the hourly solar radiation and turbine characteristics, a gross solar field area of approximately 29,000 m² was calculated. It is currently foreseen that the solar thermal power plant will have an area of approximately 32,000 m². The solar field thermal output and the amount of electricity produced throughout the year are calculated using the Meteonorm data and turbine part load characteristic data. The technical characteristics of the solar field are the same as in case 1. At the current stage, the solar power plant annual electricity generation is estimated to be 1274 MWhe while the thermal heat available for secondary uses is estimated to be around 9576 MWhth.

Solar attractiveness criteria values for Kho Kood Thailand:

Radiation: 1200 – 1350 kWh/m² = inadequate	> CL = 4
Electrical power: 1.0 MW = class 3	
Price per kW installed: 6,500 €	> I = 1
Solar-electrical efficiency: 14.8 %	> TC = 4
Period Feed-in-tariff: 10 years	> PI = 2

Integrated into the equation gives:

SOLAR A = 4 (* 0.5) + 1 (* 0.25) + 4 (*0.1) + 2 (* 0.15)

SOLAR A = 2 + 0.25 + 0.4 + 0.3

SOLAR A = 2.95

The conclusion of the SOLAR A equation for case study 2 must be, that the project is technically and economically not valuable. It is not recommended to put this project into reality. The following LCOE calculation shall validate this conclusion.

Project Assumptions

The following more detailed information are chosen for the above mentioned LCOE calculation and followed by a comparism of both results.

General assumption

Project lifetime:	20 years
Net Power:	1.0 MW
Subsidy period:	10 years
Investment:	6 mio € or 247 mio THB turnkey

Degradation:	Not considered
Depreciation:	25 years
Revenue assumption	
Operating hours:	4.5 hours average on 300 days per year
Availability:	More than 98%
Turbine Efficiency:	24,7%
Solar-Electric Efficiency:	14,8%
Electrical output:	1,79 GWh per year
O+M cost:	1% of invest per year
Inflation:	Not considered
Tax conditions:	Not considered
Financial assumption	
Equity capital:	30% of invest
Interest rate:	5,0 %

Putting the project details into the LCOE equation leads to the following:

$$LCOE_{plant} = \frac{248mioTHB + 2{,}5mioTHB + 3{,}4mioTHB}{1{,}181mioWhe + 300mioWhe(th)}$$

The LCOE per kWhe is therefore:

$$LCOE_{plant} = 17THB / kWhe$$

The internal rate of return (IRR) in this case is resulting as follows:.

$$NPV_{plant} = 4{,}4\%$$

The detailed LCOE calculation shows higher specific investment per kWe installed as the power block includes numerous installations like in large scale power plants. In addition to that, the project is situated on an island and therefore demands higher transportation costs.

Investments		
Solar field specific cost	333	THB/m²
Solar field investment cost	3.311.194	Euro
power block specific cost	2376	Euro/kWe
Power block investment costs	2.687.492	Euro
Total investment cost	247.867.437	THB
Specific investment per kWe	5.479	€/kWe

Financial results		
Total gross revenues	538.277.838	THB
Toal revenue from CER	16.753.911	THB
Total operating costs	119.365.292	THB
Simple payback period	11,51	year
Payback period with financing (including cost of interest)	18,49	
ROE	10,5%	
IRR	4,4%	
DCSR	0,7	
Levelised cost of electricity	17,18	THB/kWhe

Figure 43 The detailed LCOE calculation shows higher specific investment per kWe installed as the power block includes numerous installations like in large scale power plants. In addition to that, the project is situated on an island and therefore demands higher transportation costs

The business plan shows details as follows:

Financials Solar Trough Power Plant
Kho Kood, Thailand

Investment 247.867.436,85 THB

YEAR	25 years	0	1	2	3	...	25
Revenues Solar Trough							
Power of plant in kWel			1.131,00	1.131,00	1.131,00		1.131,00
Power of plant in kWth			3.275,55	3.275,55	3.275,55		3.275,55
Annual full load operational hours			1.590,06	1.590,06	1.590,06		1.590,06
Electricity Sale in THB	521.523.927,29		20.860.957,09	20.860.957,09	20.860.957,09		20.860.957,09
Heat Sale in THB	0,00		0,00	0,00	0,00		0,00
CO2 Credit / t CO2 Price in THB	14,90						
saved tons CO² per year - electricity	0,61						
saved tons CO² per year - thermal energy							
Total income CO2 Credit in THB	16.753.911,21		670.156,45	670.156,45	670.156,45		670.156,45
Total Revenues in THB	538.277.838,50		21.531.113,54	21.531.113,54	21.531.113,54		21.531.113,54
Operating costs							
Own electricity consumption			2.419.871,02	2.419.871,02	2.419.871,02		2.419.871,02
accrual and equipment			892.322,77	892.322,77	892.322,77		892.322,77
Maintenance and operation			1.090.616,72	1.090.616,72	1.090.616,72		1.090.616,72
administration and insurance			371.801,16	371.801,16	371.801,16		371.801,16
Total operating costs in THB	119.365.291,82		4.774.611,67	4.774.611,67	4.774.611,67		4.774.611,67
EBITDA in THB	418.912.546,68		16.756.501,87	16.756.501,87	16.756.501,87		16.756.501,87
Depreciation in THB			9.914.697,47	9.914.697,47	9.914.697,47		9.914.697,47
EBIT in THB	171.045.109,83		6.841.804,39	6.841.804,39	6.841.804,39		6.841.804,39

Figure 44 The business plan

The cash flow is negative in the depreciation period. An extension of this period may bring the cash flow back into positive values.

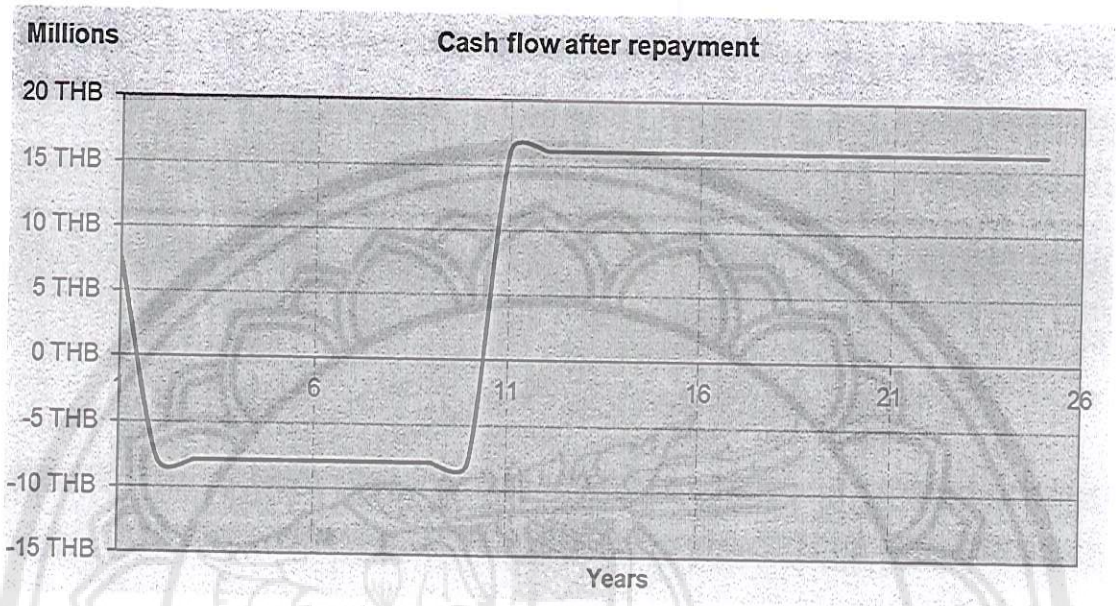

Figure 45 The cash flow is negative in the depreciation period. An extension of this period may bring the cash flow back into positive values

Conclusion

The project is technically and economically not viable. The IRR is reaching a value of 4,3 % only, which is not attractive for investors. The ROE of 9,9 % is too low for a reasonable backflow for equity capital. The simple payback period of 11,51 years is longer than the solar adder period of 10 years and therefore not sufficient. The LCOE is 50 % higher than the amount received by PEA. This analysis result proves that the result of the SOLAR A equation is correct and that this project should not be put into reality as the economic reasons are insufficient.

Case 3: Grid connected station in Spain

The Almeria project consists of several construction phases, each has 50 MW electrical output and a storage device allowing up to 7 hours operation into night time. The solar field has a size of 500,000 m² and uses the parabolic troughs with a span of 5.7 m [36].

The Spanish feed-in tariff allows 25 year grace period and more than 20 €ct fee per kWh. The project is the first of its kind and example for another 10 similar projects. The size of 50 MW is a result of the Spanish regulations; a more economic size of the producer is declared with 125 MW and optimized to the steam turbine.

The radiation in Almeria is comparable to Thailand, but the percentage of direct normal irradiation (DNI) is higher. The radiation quality is also supported by the altitude of the projects site, which is approximately 1000 m.

The project can be described as a typical project under average conditions, but with optimum public impact situation as 25 years are guaranteed by the state and allow enough security for investors at this early stage of the solar technology.

Solar attractiveness criteria values for Almeria Spain:

Radiation: 1701 – 1900 kWh/m² = good > CL = 7

Electrical power: 50 MW = class 4

Price per kW installed: 2,645 € > I = 9

Solar-electrical efficiency: 16.2 % > TC = 5

Period Feed-in-tariff: 25 years > PI = 9

Integrated into the equation gives:

SOLAR A = 7 (* 0.5) + 9 (* 0.25) + 5 (*0.1) + 9 (* 0.15)

SOLAR A = 3.5 + 2.25 + 0.5 + 1.35

SOLAR A = 7.6

The result of the SOLAR A equation for case study 3 must be, that the project is technically and economically viable. It is possible to put this project into reality. The LCOE calculation comes to the following figures:

Project Assumptions

The following details are assumed for the project:

General assumption

Project lifetime:	25 years
Net Power:	50 MW
Subsidy period:	25 years
Investment:	132,2 mio €

Degradation:	Not considered
Depreciation:	25 years
Revenue assumption	
Operating hours:	8.8 hours average on 300 days per year
Availability:	More than 98%
Turbine Efficiency:	31%
Solar-Electric Efficiency:	16.2%
Electrical output:	110 GWh per year
O+M cost:	1% of invest per year
Inflation:	Not considered
Tax conditions:	Not considered
Financial assumption	
Equity capital:	30% of invest
Interest rate:	7,0 %

If the project details are inserted into the LCOE equation, they lead to the following:

$$LCOE_{plant} = \frac{132mio€ + 1{,}1mio€ + 2{,}8mio€}{110{,}628mioWhe}$$

The LCOE per kWhe is therefore:

$$LCOE_{plant} = 0{,}06€ / kWhe$$

The internal rate of return (IRR) in this case is resulting as follows:.

$$NPV_{plant} = 21{,}5\%$$

The project shows lower specific investment per kWe installed as scale effects take place. The efficiency of the turbine also has a positive impact on sizing and economic data.

Investments		
Solar field specific cost	250	€/m²
Solar field investment cost	99.235.550	€
power block specific cost	660	€/kWe
Power block investment costs	32.998.044	€
Total investment cost	132.233.594	€
Specific investment per kWe	2.645	€/kWe

Financial results		
Total gross revenues	587.281.600	€
Toal revenue from CER	0	€
Total operating costs	103.610.885	€
Simple payback period	5,98	
Payback period with financing (including cost of interest)	9,40	
ROE	34,7%	
IRR	21,5%	
DSCR	1,5	
Levelised cost of electricity	0,064	€/kWhe

Figure 46 The project shows lower specific investment per kWe installed as scale effects take place. The efficiency of the turbine also has a positive impact on sizing and economic data

The business plan over 25 years foresees the following values:

Financials Solar Trough Power Plant
Almeria, Spain

Investment 132.233.593,99 €

YEAR	25 years	0	1	2	3	...	25
Revenues Solar Trough							
Power of plant in kWel			50.000,00	50.000,00	50.000,00		50.000,00
Power of plant in kWth			111.290,32	111.290,32	111.290,32		111.290,32
Annual full load operational hours			2.212,57	2.212,57	2.212,57		2.212,57
Electricity Sale in €	587.281.599,92		22.125.732,41	22.235.254,79	22.345.319,30		24.909.474,43
Heat Sale in €	0,00		0,00	0,00	0,00		0,00
Total Revenues in €	587.281.599,92		22.125.732,41	22.235.254,79	22.345.319,30		24.909.474,43
Operating costs							
Own electricity consumption			1.327.543,94	1.340.819,38	1.354.227,58		1.685.628,54
accrual and equipment			595.051,17	595.051,17	595.051,17		595.051,17
Maintenance and operation			727.284,77	727.284,77	727.284,77		727.284,77
administration and insurance			1.322.335,94	1.322.335,94	1.322.335,94		1.322.335,94
Total operating costs in €	103.610.885,48		3.972.215,82	3.985.491,26	3.998.899,46		4.330.300,42
EBITDA in €	483.670.714,45		18.153.516,59	18.249.763,52	18.346.419,84		20.579.174,01
Depreciation in €			5.289.343,76	5.289.343,76	5.289.343,76		5.289.343,76
EBIT in €	351.437.120,45		12.864.172,83	12.960.419,76	13.057.076,08		15.289.830,25

Figure 47 The business plan over 25 years

The cash flow is positive from the beginning. After 12 years of payback time for the loan it increases drastically.

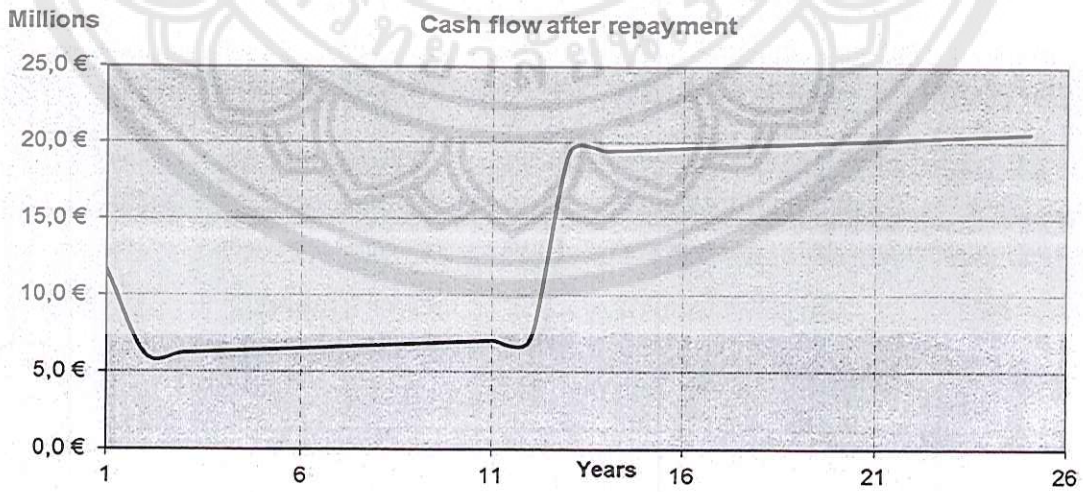

Figure 48 The cash flow is positive from the beginning. After 12 years of payback time for the loan it increases drastically

Conclusion

The project is technically and economically viable. The IRR is reaching a value of 21,5 % and therefore attractive for investors. The ROE of 34,7 % is very reasonable and a good value for return on equity capital. The simple payback period of 5,98 years and describes a short period. The LCOE of 6,3 €Ct is comparable to actual production costs of fossil energy and therefore showing grid parity. This analysis underlines the result of the SOLAR A equation. The project is highly viable and should be put into reality as the economic reasons are sufficient. The LCOE calculations and the SOLAR A equation give the explanation, why this type of technology is used to a large extend in Spain and other countries.

Conclusion and general model

If we take a look at all results of the case studies and the comparism calculation, we come to the conclusion that an estimated value for economical valuable projects may start at a SOLAR A value of approximately 4. Most of the existing projects of today are projected between a SOLAR A value of 5 to 6.

Future projects in more recommendable areas like the Arabian Peninsula or Northern Africa, may reach higher values. Anyhow, an economical approach has been reached already and further improvements will lead to grid parity for solar thermal power plants.

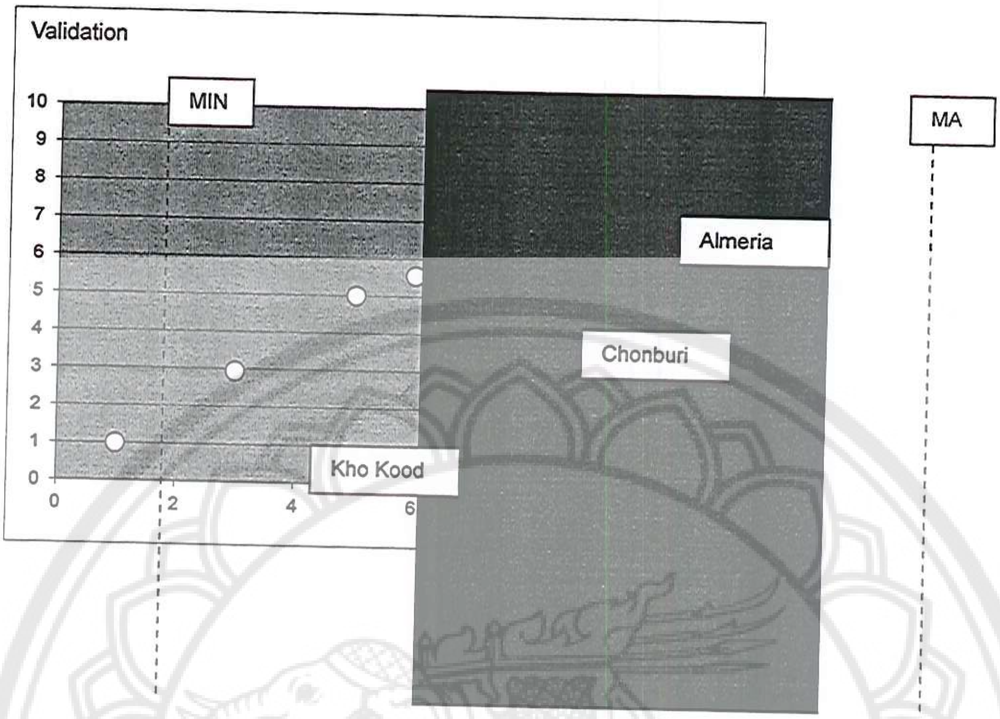

Figure 49 SOLAR A values of several, different solar projects in Thailand and Europe