MSc Program
Renewable Energy in Central & Eastern Europe

Economical comparison of optimally inclined photovoltaic system and horizontal single-axis tracking photovoltaic system in conditions of the Slovak republic

A Master Thesis submitted for the degree of
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supervised by
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Affidavit

I, **Stanislav Kosut** hereby declare

1. that I am the sole author of the present Master Thesis, "Economical comparison of optimally inclined photovoltaic system and horizontal one-axis tracking photovoltaic system in the conditions of the Slovak republic", 90 pages bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

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Abstract

Deployment of photovoltaic technology in Slovakia has been for many years lacking behind its potential, liabilities towards European Union, as well as behind development in the neighboring countries.

Only at the end of year 2009, relevant legislation came into force, which made photovoltaics a feasible way of electricity production in Slovakia. Nevertheless a cap in installed capacity of larger systems was introduced by the National Transmission System Operator shortly afterwards, which again limited the potential contribution of PV to the energy mix of Slovakia.

One of possible ways how to increase the share of electricity produced from photovoltaics on the total electricity production without breaking this cap is to use tracking photovoltaic systems, which are able to produce more electricity per unit of installed capacity.

Objective of this master thesis was to verify, if using tracking photovoltaic systems instead of fixed systems in the conditions of Slovak republic is an economically viable way how to achieve this goal.

This verification was realized by comparing horizontal single-axis tracking system with an optimally inclined fixed system, especially in terms of energy yields, investment costs and economical performance.

The results show that application of single-axis tracking system is capable of increasing the share of renewable electricity on the total electricity production in SR. Moreover, it is indeed an economically attractive option for solar electricity production in every part of Slovak republic, and actually more attractive than application of fixed system, since the key compared criteria – internal rate of return, net present value and simple payback period show better results for the tracking system than for the fixed system.

Nevertheless, application of tracking photovoltaic systems itself will certainly not be enough in order to fulfill the targets set for Slovakia by the European Union with regards to utilization of renewable sources of energy. Only adoption of truly supportive legislation, creation of attractive economical environment for investors and removal of barriers can achieve this goal.

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List of Abbreviations

Institutions
EC – European Commission
EU – European Union
IEA – International Energy Agency
MoE – Ministry of Economy
SNB – Slovak National Bank
SEPS – National Transmission System Operator
URSO – Slovakian Regulatory Office for Network Industries

Units
EUR – Euro
GJ – Giga Joule
GWh – Gigawatt per hour
ha – Hectare
J – Joule
kWh – Kilowatt hour
m – Meter
m2 – Square Meter
m3 – Cubic Meter
Mio. EUR – Million Euros
MWe – Megawatt electric
MWh – Megawatt per hour
PJ – Petajoule
Sk – Slovak Crown

Terms
DSCR – Debt Service Cover Ration
DPP – Discounted Payback Period
DSO – Distribution system operator
EPC – Engineering, Procurement, Construction
FiT – Feed-in tariff
GDP – Gross domestic product
IRR – Internal Rate of Return
LHPP – Large Hydro Power Plant
NPV – Net Present Value
O&M – Operation and maintenance
PP – Payback Period
PV - Photovoltaics
RES – Renewable Energy Source
R&D – Research and Development
SR – Slovak republic
SPF – Seasonal Performance Factor
SPP – Simple payback period
TPEC –Total Primary Energy Consumption

Chemical substances
Si – sillicium

Executive Summary

Low utilization of renewable energy sources in Slovakia has regularly been subject of criticism from domestic and foreign energy experts, environmentalists, sociologists as well as institutions of the European Union. All declarations and attempts of the government to improve this state could so far be interpreted just as a marketing propaganda with little or no results, simply because the real effect of most support mechanisms currently applied is blocked by another "hidden" form of emphraxis, mostly incorporated in the legislation.

Support of Photovoltaics is, unfortunately, no exception to this "rule". After introduction of an attractive feed-in tariff and its fixation for 15 years in august 2009, a two year's cap in installed capacity of photovoltaic power plants has been set up only few months later, moreover, from 1st of May 2010 onwards, all photovoltaic land installations and all roof installations above 100 kW require permission from the National Transmission System Operator - SEPS as well as approval of Ministry of Economy in order to be built.

This, of course, significantly hinders deployment of photovoltaic industry in Slovakia, thus reduces the potential contribution of solar energy to the total energy mix and generally decreases exploitation of renewable energy sources in our country. This master thesis was therefore an attempt to find a practical solution which would allow increase of the share of solar electricity on the total energy mix in Slovakia respecting the current unfavourable legislation.

As one of such solution appears to be utilization of single-axis tracking photovoltaic systems instead of fixed systems, which, naturally depending on location, allows significant increase of the energy yield per unit of installed capacity. Nevertheless, since aim of the author was to make the thesis as practical as possible, it was necessary to ensure that this solution also makes sense from the economical point of view, since otherwise it would never get adopted by investors. Therefore the comparison was especially focused on the economical performance of both systems.

The economical performance of the systems was measured with the most frequently used criterions for evaluation of investments – internal rate of return, net present value and simple payback period. The results show that using horizontal single-axis tracking as well as fixed

substructure as the mounting system for photovoltaic modules are in the conditions of SR clearly attractive investments. This is proven by positive net present value, extremely high internal rate of return (especially when compared to current interest rates offered by banks) as well as very fast simple payback period of both systems assumed in the PV project studied in this thesis – project Buzitka. Moreover, it has been proved that both systems are economically viable even under the worst irradiation values achievable in Slovakia.

When the systems were compared against each other, the energy yields as well as all compared economical criterions speak evidently in favor of the tracking system. However, it is also essential to consider other aspects of both systems, such as acceptance of the systems by banks, O&M or construction intensity.

In general, it is obvious that application of horizontal single-axis tracking system would lead to increase of the share of renewable energy sources on the total energy mix of Slovakia, thus would contribute to fulfillment of the targets set for our country by the European Union. Nevertheless, this contribution is rather negligible and without amending the current legislation and creating a healthy environment for exploitation of solar energy as well as other renewable sources, these targets will never be achieved.

1. Introduction

In this chapter, purpose of this master thesis, its objectives as well as motivation of the author for choosing its subject will be discussed. Furthermore, the key questions, answering of which should lead to achieving the objective of the thesis, as well as its structure and approach will be defined.

1.1 Motivation and objectives

Conducting business in politically dependable environment is a very difficult task, especially if the environment is constantly changing. There is perhaps no better example of such environment than the Slovak renewable energy sector. On one hand, adoption of regulation and laws supporting the RES utilization under the pressure of the EU, on the other hand, adoption of various forms of obstacles that hinder their utilization, under the pressure of nuclear, gas and coal lobby as well as other groups that would not benefit from broader deployment of RES in Slovakia.

Experiencing this environment, specifically the photovoltaic industry, also stood behind the author's choice of the subject of this master thesis. Since the author is actively involved in development, construction and operation of PV power plants in the central and eastern Europe, looking for "creative answers" to the turbulent legislative changes in this field in Slovakia, namely introduction of a cap in installed capacity of PV power plants and requirement of SEPS and Ministry of Economy approval for PV power plants, both introduced only shortly after attractive feed-in tariff guaranteed for 15 years came into force, appeared to be an ideal topic.

One of these "creative answers" could be application of tracking photovoltaic systems allowing higher energy yield per unit of installed capacity, instead of fixed photovoltaic systems, which would result in higher production of solar electricity without breaking the cap of 120 MW introduced for the next 2 years. Nevertheless, since this solution has to be, above all, economically viable, the objective of this master thesis is to verify, if using of tracking photovoltaic systems instead of fixed systems in the conditions of Slovak republic is an economically viable way how to increase the share of solar electricity, thus the share of RES, on the total energy mix of Slovakia.

At the same time, the work should identify the main barriers (theoretical and practical) which negatively influence deployment of PV technology in Slovakia, and suggest concrete action that would help to overcome these barriers.

Finally, accomplishment of the two previous objectives should lead to increased share of PV technology on the energy mix of Slovakia, thus contribute to fulfillment of RES utilization targets set by the EU and the government.

The key questions that should be answered in course of this study are:

- What are the main barriers hindering deployment of PV technology in Slovakia?
- What policies should be employed by the government to improve utilization of PV technology?
- Is production of solar electricity in Slovakia through horizontal single-axis tracking system economically viable?
- Is production of solar electricity in Slovakia through horizontal single-axis tracking system more attractive from the economical point of view than production through a fixed system?
- Is using of tracking photovoltaic systems instead of fixed systems in the conditions of Slovak republic is the right way how to increase the share of solar electricity, thus the share of RES, on the total energy mix of Slovakia?

Answers to these questions will be summarized in the last chapter of this thesis.

1.2 Approach and Structure

This study is based on the information presented and received during the New Energy "Renewable Energy in Central and Eastern Europe" Course (Course program 2007 – 2009), specific literature and internet web sites (see Sources), PV SYST calculations, SolarGIS calculations, Microsoft Excel for economic analysis, interviews with people involved in the PV sector (installers, suppliers, bankers, etc.) and last but not least, author's experience and knowledge gained within his active involvement in the PV sector.

Since the major part of the thesis is comparison of two different photovoltaic systems from the economical point of view, first of all, all relevant legal and economical aspects that influence the economics of photovoltaic power plants in Slovakia and that will be later used in the cash flow calculations will be introduced.

Secondly, the two concrete systems, which will be used in this thesis, will be described in detail. Since the inclination of the modules is especially important when mono or polycrystalline modules are used (due to their lower ability to utilize diffused sun radiation unlike CdT modules for instance), modules produced on this basis will be used in both systems. The rest of the components will also be identical, except for the substructure on which the PV modules will be mounted, to keep the comparison as objective as possible. Here also the price intensity of both systems will be shown (also during operation), based on real price quotations from market suppliers.

Subsequently, the specific location will be introduced, in which installation of these 2 systems will be simulated, the irradiation in the exact location will be thoroughly analysed using various software packages to get the most exact value possible (PV GIS, Meteonorm, SolarGis,...), and also other local conditions will be taken into account (for example those which are important for construction). Furthermore, the irradiation value from the best and worst location in terms of irradiation in Slovakia will be also calculated, so that the comparison of the systems takes into account also the different irradiation conditions.

In the end, data obtained from the previous calculations and analyses will be put into a detailed cash-flow model and the two systems will be compared by the IRR, NPV and SPP.

This should give us a clear answer if using the horizontal single-axis tracing system is an economically viable way how to increase the share of electricity produced from photovoltaics on the total electricity production in Slovakia, or, at least, from which irradiation value it becomes viable.

The last part summarizes the results of this study, answers questions raised in the first chapter and brings conclusions and recommendations that stem from it.

2. Photovoltaics in Slovakia

This chapter will look at the current situation in Slovakia in the photovoltaic industry. This includes analysis of key political, legal and economical factors influencing the industry, current state of the industry in terms of installed capacity and market players, analysis of climate conditions with specific focus on irradiation, but also approximation of the grid situation, and especially grid availability as one of the key barriers of further deployment of photovoltaic technology in Slovakia.

2.1 Political and legal environment

Since RES sector is in most countries, including Slovakia, still heavily depending on subsidies and other forms of support mechanisms, political and legal environment plays a crucial role in terms of development of this sector.

As Slovakia is a member state of EU, legislation of EU has legal preference to the legislation adopted by the national government. European leaders signed up in March 2007 to a binding EU-wide target to source 20% of their energy needs from RES such as biomass, hydro, wind and solar power by 2020. On 23rd of January 2008, the Commission put forward differentiated targets for each EU member state, based on the GDP per capita of each country. Slovakia has binding regulation for increasing the share of renewables from actual 7% (European Commission, 2005) to 14% in 2020.

“The European Commission's new Directive sets out the renewable energy targets and aims to provide a stable and integrated framework for all renewable energy, which is critical to ensure that investors have the confidence needed to make renewables play their envisaged role. At the same time, the framework is sufficiently flexible to take into account the specific situations in Member States and to ensure that they have leeway to meet their targets in a cost-effective manner, including through an improved regime for transfers of guarantees of origin. In addition, the Directive contains specific measures to remove barriers to renewable energy's development such as excessive administrative controls and to encourage greater use of better-performing types of renewable energy”[1].

This sounds ideal from the RES support point of view, nevertheless, the reality is slightly different from “paper statements”, because such wording of the policy, naturally, leaves a lot

[1] European Commision, 2008

of room for own interpretation from the national governments. Also, there are so far no consequences stated in the current EU legislation, in case of situation when a member state doesn't fulfil the binding targets. Furthermore, effects of the "European" legislation can be easily negated by other national laws that at the first sight don't seem to be related.

All these aspects can be observed in the Slovak legislation which is influencing the PV sector. There are more reasons for this vague situation, starting with no activities in Green party, fragmented green business sector to governmental preferences in fossil sources (especially nuclear power) due to strong lobby of companies involved in production of energy from these sources.

2.1.1 Key legislation, programs and concepts in the PV sector

There are several pieces of legislation that into a large extent influence the deployment of the PV industry in Slovakia.

a) Law nr. 309/2009 of the legal code about support of RES[2]

This very long time expected law came into force on the 1st of September 2009 and its aim was to bring the required legal and investment security into the field of RES. Regarding photovoltaics, it introduced the obligation of regional distribution grid operator to:

- preferentially connect every PV facility of any capacity for unlimited period of time to the grid (except for cases when the facility doesn't fulfill technical requirements, or if its connection to the grid would jeopardize security or reliability of the grid network)
- purchase the electricity produced by PV facility at the price of electricity for losses for the lifetime of the facility
- pay the owner of a PV facility connected to the grid the difference between the price of electricity for losses and the price stated by the Regulatory office[3] for electricity produced by PV facilities for the period of 15 years
- take over the responsibility for deviation in the delivery of electricity for PV facilities with installed capacity up to 4 MW

Besides this, the law also contains clauses guaranteeing that the FiT for PV facility must not decrease for 15 years following the year of connection of the facility to the grid, clauses that

[2] Zákon č. 309/2009 Z. z. o podpore obnoviteľných zdrojov energie a vysoko účinnej kombinovanej výroby a o zmene a doplnení niektorých zákonov
[3] Regulatory office – URSO (Úrad pre reguláciu sieťových odvetví)

give the Regulatory office an option to increase the FiT by the core inflation or similar coefficient, clauses according to which the Regulatory office cannot decrease the FiT for the next regulation period below level of 90% of the level in the current period[4] clauses preventing duplicating of support mechanisms (if by the contraction of the PV facility a subsidy from the national budget or structural fund of the EU was granted, the FiT is reduced according to the extent of such subsidy).

b) Law nr. 656/2004 of the legal code about energetics[5]

This is the basic law regulating the Slovak energy market, especially the conditions of conducting business in this market, conditions of entering this market, defines measures for safety of service delivery as well as measures for securing a functional market, rights and liabilities of the market participants, role of state institutions and state control.

Regarding photovoltaics, this law above all clarifies conditions under which a PV facility can be built in Slovakia. Currently, the law states that all land installations and roof installations above 100 kW require an approval of Ministry of Economy about conformity of the investment plan with the long-term conception of Energy policy of SR, and without this approval a building permission for a PV facility cannot be issued.

There is a number of data which have to be submitted to the Ministry of Economy in order to have the approval granted, most important of which is the positive statement of the SEPS regarding construction of the facility.

c) Law nr. 276/2001 of the legal code about regulation in the network industries[6]

Through this law, the Office for Regulation of Network Industries[7] was founded, which plays an important role in the energy sector of Slovakia. This role will be explained in the further text.

d) Decree of the regulatory office nr. 2/2008, in the statutory text of decree nr. 7/2009

This decree regulates prices in the electro-energy field, including prices of electricity that comes from RES – so called feed-in tariffs.

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[4] The length of this period is regulated by the Regulatory office and currently cannot be above 3 years.
[5] Zákon č. 656/2004 Z. z. o energetike a o zmene niektorých zákonov
[6] Zákon č. 276/2001 Z.z. o regulácii v sieťochých odvetviach
[7] ÚRSO

FiT schemes for PV are based on a direct payment per kWh for the PV energy produced. FiT schemes therefore have the great advantage that the quality of the PV systems is intrinsically monitored, as the FiT payment directly depends on it.

Tariffs vary in height and duration. The general rule is that the tariff should be calculated to enable an internal rate of return (IRR) for PV power plant operator that is equal to the IRR on investments with similar duration and risk. The FiT for PV in Slovakia have been set up as stated in the following table.

Table 1: Tariffs for PV in Slovakia

Operation period	Feed-in-tariff
Till 2004	398,- EUR/MWh
From 2005 till 2008	425,- EUR/MWh
From 2009	448,- EUR/MWh
From 2010 *Up to 100 kW* *Above 100 kW*	 430,72 EUR/MWh 425,12 EUR/MWh
From 2011 *Up to 100 kW* *Above 100 kW* *Between 100 kW and 1 MW* *Between 1 MW and 4 MW* *Above 4 MW*	 387,65 EUR/MWh 387,65 EUR/MWh 382,61 EUR/MWh 382,61 EUR/MWh 382,61 EUR/MWh

Source: URSO

e) Conception of RES utilization

This conception, which was adopted by the government in April 2003, was the first document which truly opened the subject of RES in Slovakia. It was focused on analysis of the state of utilization of RES and led to conclusion that activities focused on support of RES were insufficient and that if this situation wouldn't change, it would be impossible to fulfill our international liabilities in this field.

f) Strategy for higher utilization of RES

Strategy of higher utilization of RES was adopted in year 2007. It defines potential of individual RES as well as their expected contribution to the future electricity production.

The largest total potential of RES in Slovakia (54,038 Two / 194,537 PJ) refers to solar energy. The technically utilizable potential of solar energy was set by the Ministry of

Economy at 9,450 GWh / 34,000 TJ per year. However, ambitions for PV utilization are very low and far out of line with the ambitions for other RES. The expected goal for PV utilization for 2030 is only 0,6 % of the usable potential, whereas the ambitions for the other RES range from 60% for small hydropower to 100% for biomass. This is in great contrast with the rest of Europe, where PV is expected to play a serious roll in the long term.

g) Strategy of energy security of Slovak republic

This document analyses all sources of energy used in Slovakia and estimates their future deployment. “The basic aims and scopes of power engineering development in long-term perspective are determined by energy policy of the Slovak Republic and it states, that maximal economy growth in conditions of perpetually sustainable developing is conditioned by reliability of energy supply with optimal costs and adequate protection of environment”.[8]

One chapter of the document is focused on utilization of RES and introduces an optimistic and conservative scenario. The following table shows these scenarios for PV:

Table 2: Scenarios for PV utilization according to Strategy of energy security of SR

Year	2010	2015	2020	2025	2030
Optimistic scenario (TJ)	300	3000	12000	22000	37000
Conservative scenario (TJ)	300	1000	6000	14000	20000

Source: Strategy of energy security of SR

h) Law nr. 595/2003 of the legal code in the statutory text of amending acts nr. 204/2009 and 563/2009

This law influences economics of PV facilities, above all, in two areas – corporate taxes and depreciation. According to this law, all enterprises in Slovakia pay corporate taxes of 19 %, regarding depreciation, most components of a PV power plant fall within 3rd depreciation group, which means, that the value of the power plant is depreciated equally over period of 12 years.

i) Other relevant legislation

[8] A. Mészáros: Ekonomická a environmentálna efektívnosť v podmienkach liberalizovaného trhu s elektrinou. In: Elektroenergetika 2005, Zborník z 3. medzinárodného vedeckého sympózia, 21.-23. 9. 2005, Stará Lesná, Slovensko. Technická univerzita v Košiciach, 2005, s. 16. ISBN 80-8073-305-8.

- Law nr. 220/2004 of the legal code about protection and utilization of agricultural land, which is setting rules for utilization of agricultural land for other purposes.
- Decree of the government nr. 376/2008 of the legal code, which defines fee for extraction of land from agricultural land fund.
- Methodical regulation of the Ministry of Agriculture nr. 3384/2009-430 from September 2009, regarding appraisal of application for using agricultural land for the purpose of construction of PV facilities.
- Law nr. 50/1976 of the legal code about zoning and building regulation, in the statutory text of further amendments.

2.1.2 Key government institutions in the PV sector

a) Government

Government is the utmost body of executive power. It is named by the president and it reports to the parliament. Its relevance to the PV sector consists in its authority to propose legislation to the parliament as well as in its ability to adopt decrees and other regulation.

It has to be said that the last government was doing very little to create a stable environment for deployment of photovoltaics in Slovakia, and if it wasn't for our membership in the EU, the situation would most likely be even much worse. Clear preference was given to fossil energy sources, which is, considering that 90 % of our primary energy sources come from export (mainly Russia), a very dangerous strategy which is jeopardizing our energy as well as political security and independence. Since the new government was set up only few months ago, it is very difficult to predict its attitude towards RES sector. Nevertheless, since the new government, unlike the last one, consists of right wing parties, certain changes can be expected.

b) Parliament

Parliament is the only constitutional and lawmaking body in the SR. Its role is to make decisions about legislative proposals of the government and individual members of parliament.

Since generally the majority in the parliament is represented by the same political parties as the government, its activities in the PV field (and RES field generally) could be described in the same way as activities of the government.

c) Regulatory Office for Network Industries (ÚRSO)

"The role of the Regulatory Office is, within the fields with no competition, to create environment related to competition for monopolies, i.e. producers and suppliers of electricity, gas, heat and water. However, it has to follow protection of both consumers´ and investors´ interests. It is common thing that an investor would not conduct business in this field if there were not any profit. The Office has to create such a climate so that the investor would have good conditions for investments, but, on the other side, so that a consumer would not be negatively affected, or in other words, so that the prices would be fair for both parties."[9]

The most important role of the office regarding photovoltaics is the competence to regulate prices of electricity, thus set up the feed-in tariff. Other important activities are regulation of prices of connection to the grid, transmission and distribution of electricity, which the grid operators subsequently reflect in their prices.

d) National Transmission System Operator (SEPS)

"The main role of SEPS is to operate the transmission system reliably, ensure dispatching control of the system, its maintenance and development so that to guarantee reliable and quality electricity supply, and parallel operation with neighbouring systems in line with ENTSO-E recommendations while respecting non-discriminating and transparent principle approaches to the grids with minimum environmental impacts."[10]

SEPS is responsible for transmission of electricity on the whole territory of Slovakia from power plants to the distribution network and major customers connected to the 220 kV and 400 kV grids.

Nevertheless, SEPS is also responsible for including the wind and photovoltaics among so called "unpredictable RES". This means that all land based PV power plants and all roof based installations above 100 kW require a positive statement of the SEPS about their impact on the grid, which is a key attachment of the application for approval of the MoE.

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[9] http://www.urso.gov.sk/en/about-us
[10] http://www.sepsas.sk/seps/en_ProfilZaklUdaje.asp?Kod=99

This measure would not be such a problem if the decision process was based upon relevant facts (such as outcome of grid impact study), which is unfortunately not the case. In December 2009, SEPS has issued positive statement for 120 MW of projects between 1 and 4 MW for the next 2 years (after a very sudden announcement and on the “first come, first served” basis, which was also subject of criticism from the EC). Where did this number of 120 MW come from is so far not clear, however, it certainly wasn’t based upon any expertise or relevant study and is significantly lower than recommendations often presented by experts from the Slovak and international RES field.

Since SEPS is under direct control of MoE, thus the government, its last actions only confirm that the governmental promotion of RES utilization is had so far more to do with political marketing and effort to feignedly satisfy the requirements of the EU rather than real interest to support this field.

e) Ministry of Economy

Ministry of Economy is one of the organs of the government and among other industries, is also responsible for the energy sector, thus proposals of all legislation relevant to this field. It has considerable influence on the PV industry, since it directly controls the SEPS and issues approval about conformity of the investment plan with the long-term conception of Energy policy of SR.

2.2 Economical environment

Economical environment is very closely related to the political and legal environment, since it’s regulated by laws which are adopted by the parliament. Therefore, most of the factors influencing the economics of photovoltaic power plants were already discussed in the previous chapter. Factors which are not directly influenced by legislation and still have influence on the economical viability of PV power plants in Slovakia are mainly inflation, average level of salaries, unemployment rate, prices of land, as well as insurance and banking sector. Especially banking sector is extremely important and will therefore be discussed separately.

Furthermore, the Slovak economy is very much linked to the global economy, especially economy of the EU, thus changes occurring in these economies, are reflected also on the

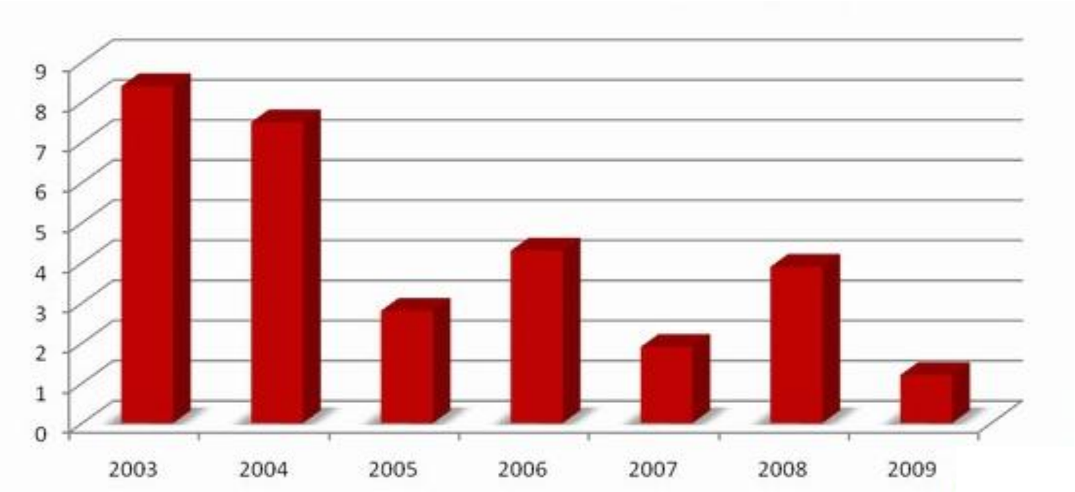
Slovak economy. Without doubts, the most important event that has had an impact on the global as well as Slovak economy in the last period is the financial crisis.

The financial crisis has resulted in significant drop in prices of commodities, including energy, steal, aluminium, as well as speeded up the long-term decrease of PV modules and inverters (due to difficulties in financing of many large projects related to lack of finance in banks). Nevertheless, the situation has started to change and prices of commodities starting to rise again and decrease in prices of PV modules slows down, prices of inverters are even rising due to their lack on the market.

a) Inflation

Inflation represents the inter-yearly growth in level of customer prices. It is an important variable which must be incorporated in cash-flow calculations, because upon its value is predicted the growth in operational cost of PV facility.

Figure 1: Inflation in Slovakia in years 200-2009 in %



Source: Statistical Office of the SR

The above figure shows the level of inflation in Slovakia in the last 6 years. Based on the figure as well as long term values from other economies, the normal level of inflation should be somewhere around 2-3 %, which is also a value that will be used in this case study.

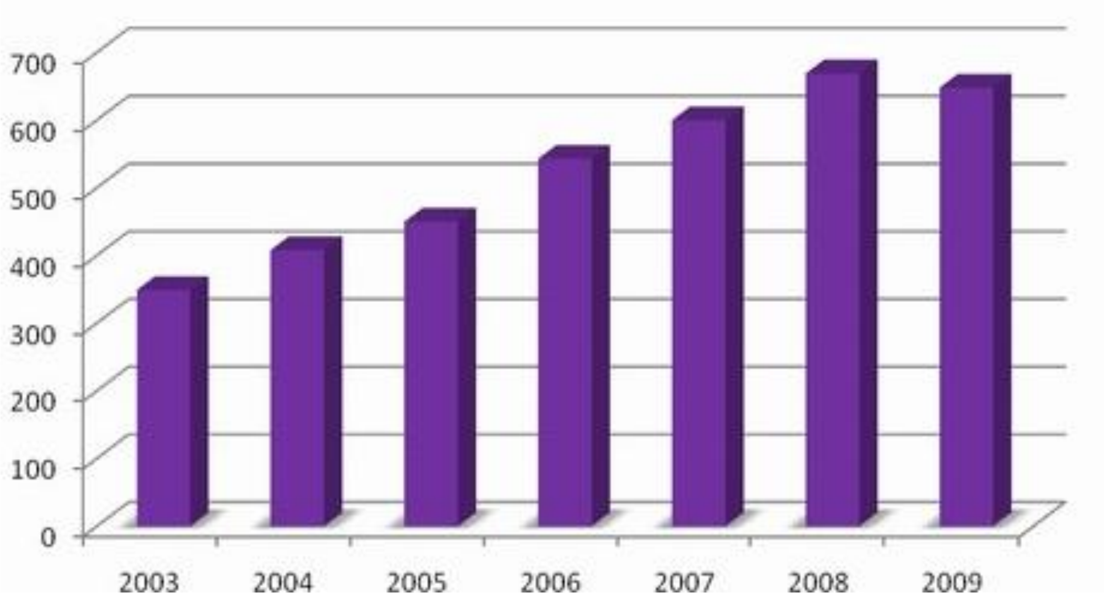
b) Average salary & unemployment rate

Level of salaries, which is very closely linked to unemployment rate (supply/demand/price concept) plays important role in the value of EPC and O&M costs. Although average salary in

Slovakia has been growing in the last years (except for the last year, when the average salaries have actually decreased due to the financial crisis), the level of salaries in Slovakia is still very low when compared to the currently main PV markets such as Germany, Spain or Italy.

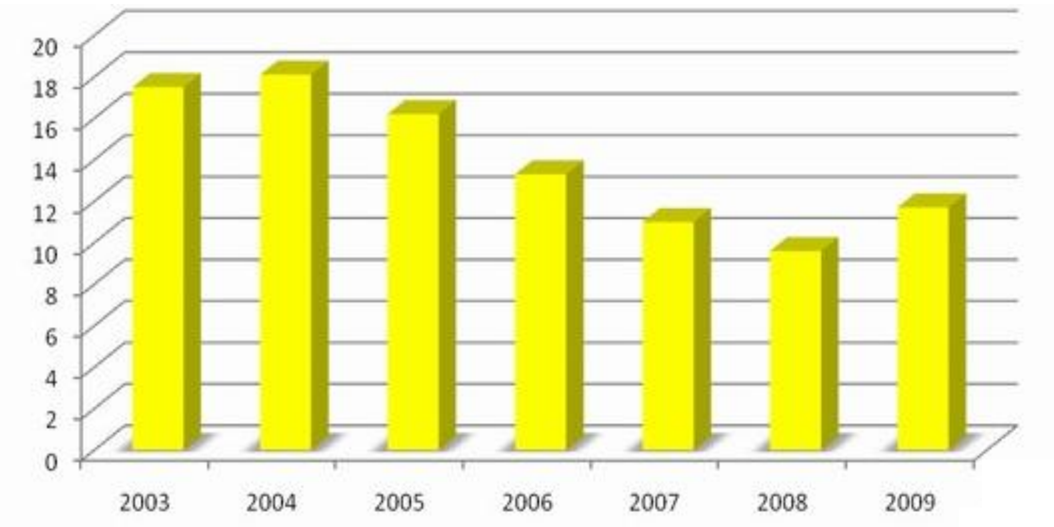
Therefore, also the cost of EPC and O&M in Slovakia can be lower than in those markets, even though the price of components (especially PV modules) is, naturally, more important.

Figure 2: Average monthly (nominal) salary in Slovakia in years 2003-2009 in EUR



Source: Ministry of Finance of Slovak Republic

Figure 3: Unemployment rate in Slovakia in years 2003-2009 in %



Source: Statistical Office of the SR

As it can be seen from the above figure, there is a clear correlation between the level of salaries and unemployment rate (when unemployment rate is decreasing, level of salaries is rising).

c) Price of land

PV facilities are land intensive (1,5 – 3,5 ha/MWp, depending on the chosen technology), therefore price of land is an important factor that influences economics of PV. Naturally, price of land hugely depends on its location, therefore, from the economical point of view, it doesn't make sense to built PV facilities near larger cities or generally in locations where land is expensive. Prices of land in Slovakia are still relatively low, especially when compared with economically more developed countries.

From the cash-flow point of view, it is much more favourable to lease land rather than buy it (since the requirement for the equity at the beginning is lower), although it naturally depends on the price of each solution. In this study, lease of land will also be assumed, based on the experience of the author of this thesis, the price of land lease in Slovakia for the purpose of installation of a PV facility oscillates between 0,1 and 0,5 EUR/m^2/year (naturally, only when the land was agricultural at the beginning of the development, otherwise the price would be significantly higher).

d) Insurance

In order to be able to obtain financing for a PV project, it is necessary to have it insured according to the requirements of financing bank. This includes insurance against natural catastrophes, theft, damage, as well as interruption in production of energy.

The insurance sector in Slovakia doesn't differ from the insurance sector in other PV markets, thus the cost of insurance products is very similar. Based on experience of the author of the thesis and quotations of insurance companies, the insurance cost are in the range of 1,5-2 % of the annual revenues.

2.1.2 Banking sector

Access to banking financing and conditions under which a loan can be granted are crucial for economics of a power plant. Due to the current financial crisis and lack of capital on the market, banks are extremely careful in terms of offering loans for project financing. On the other hand, RES sector is because of state guaranteed income one of the very few fields into which the banks are still willing to invest. At the same time, in order to help to overcome the financial crisis, European Central Bank has decreased margins at which it is landing capital to commercial banks, which resulted in lower interest rates for loans.

Table 3: Key loan conditions for financing PV projects in Slovakia

Criterion \ Bank	DEXIA Bank	KB Slovakia	UNICREDIT Bank
Required share of equity (%)	25	20	20
Interest margin (%)	3,5	2,65	3,00
Loan Maturity (years)	13	13	14
Administration fee (%)	0,5	1	0,8

Source: Indicative term sheets from the mentioned banks

Important role in the overall cost of loan plays the value of EURIBOR. "**Euribor®** is the rate at which Euro interbank term deposits are offered by one prime bank to another prime bank within the EMU zone, and is published at 11:00 a.m. (CET) for spot value (T+2). It is sponsored by the European Banking Federation (EBF), which represents the interests of some 5,000 European banks, and by the Financial Markets Association (ACI). Euribor® was first published on 30 December 1998 for value 4 January 1999."[11]

The interest rate table below shows the latest Euribor interest rates. These Euribor rates are updated on a daily basis.

Table 4: Example of Euribor interest rates

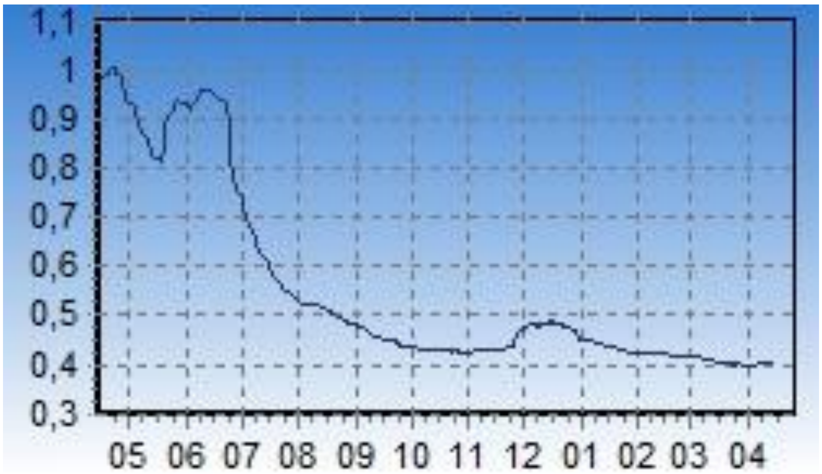
	04-16-2010	04-15-2010	04-14-2010	04-13-2010	04-12-2010
Euribor - 1 week	0.347%	0.345%	0.346%	0.346%	0.344%
Euribor - 1 month	0.405%	0.404%	0.404%	0.404%	0.403%
Euribor - 6 months	0.954%	0.954%	0.954%	0.953%	0.953%
Euribor - 12 months	1.224%	1.225%	1.226%	1.226%	1.224%

Source: http://www.euribor-rates.eu/current-euribor-rates.asp

As can be seen from the below figure, the Euribor rate (1-month rate in this case, but similar scenario can be observed in all other Euribor rates) has dropped significantly over the last year. This is caused by the financial crisis and subsequent effort of the governments to bring more funds to the economy through making the funds more affordable.

[11] http://www.euribor.org/html/content/euribor_about.html

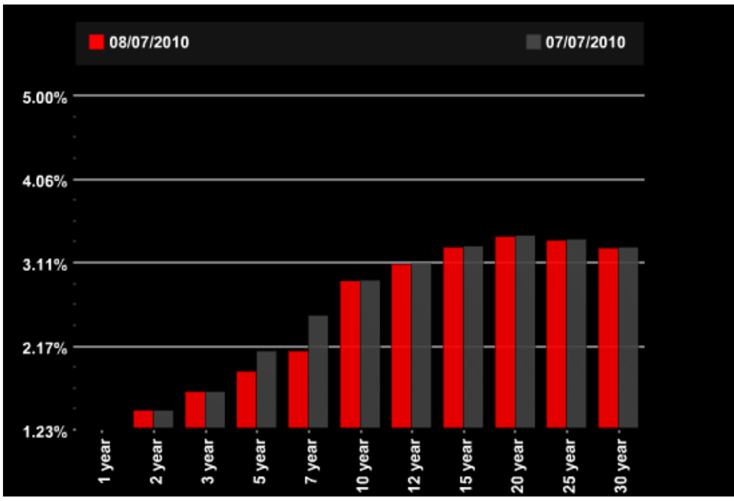
Figure 4: 1-month EURIBOR, may 2009 – april 2010



Source: http://www.euribor-rates.eu/euribor-charts.asp

Nevertheless, for loans, which last for a long period of time (such as loans for PV projects), most of banks require to have the EURIBOR rate fixed for certain period of time, depending on the duration of the loan. This is achieved by a so called interest swap. The below figure shows the current rates valid for fixing Euribor for a longer period of time (above 1 year). Regarding photovoltaic projects in Slovakia, most banks currently require fixation of Euribor for a period of 10 years (2,9 % as of 7th of August), which is a value that will be used in this case study.

Figure 5: Current values of Euribor fixed for a longer period of time



Year	08/07/2010	07/07/2010
1 year	1.24%	1.24%
2 year	1.44%	1.44%
3 year	1.65%	1.65%
5 year	1.88%	2.11%
7 year	2.11%	2.51%
10 year	2.90%	2.91%
12 year	3.09%	3.10%
15 year	3.28%	3.29%
20 year	3.40%	3.41%
25 year	3.36%	3.37%
30 year	3.27%	3.28%

Source: http://swapratesonline.com/current-euro-fixed-interest-swap-rates.html

Naturally, these are not the only conditions which need to be considered when a loan is being evaluated. Important factors are also reserve accounts and their level, minimum level of DSCR[12], repayment schedule, commitment fee, free cash withdrawal and many others. Nevertheless, for purpose of this case study, the criterions in the above table are crucial and sufficient.

2.3 Market & irradiation situation

Photovoltaics in Slovakia has rather zero share on the market of renewable energies when compared to small hydro power plants or geothermal energy (just for heat production). The total installed capacity of PV facilities in Slovakia is currently only approximately 10 000 kWp, 213 kWp was according to the DSOs connected to the grid in year 2009[13], 445 kWp power plant in southern Slovakia was opened only in march 2010[14], thus until end of year 2008, the installed capacity of PV was absolutely negligible. This was primarily a consequence of the fact that PV was seen as an expensive and if at all a very long term option, and therefore not included in the Slovak energy policy, thus not reflected in the relevant support mechanisms.

Naturally, after introduction of the necessary legislation the situation started to change dramatically. Since the FiT was set-up at a rather high level for years 2009 and 2010, as soon as the FiT became guaranteed for period of 15 years, the market began booming.

Unfortunately, instead of creation of a sustainable PV industry and attracting long-term business oriented and experienced system integrators, developers, EPC and component suppliers, the attractive economical conditions, combined with specific Slovakian “business environment”, resulted in a massive, chaotic and non-transparent trade with grid capacities, since they are one of the basic and main requirements for realization of PV projects. For what in Germany or Spain years were needed, in Slovakia only took months and very shortly after the introduction of the 15 years validity of the FiT, capacities in the volume of several thousand MWp were reserved for new PV power plants.

Such situation obviously couldn’t last for long and had a very dramatic and damaging impact on the whole industry, which could be summarized in the following points:

- blockage of grid capacities which were needed for real PV projects, by opportunists with “fictional” projects that could never be realized, who were just trying to sell the capacities at highest price possible

[12] Debt service cover ratio

[13] http://byvanie.pravda.sk/slnecne-elektrarne-na-slovensku-zatial-tak-pre-stovku-domov-prz-/sk-bpeniaze.asp?c=A100123_132528_sk-bpeniaze_p01

[14] http://www.zive.sk/v-klucovci-spustili-novu-fotovoltaicku-elektraren/sc-4-a-287241/default.aspx

- overwhelming of grid operators with applications for grid capacities for unreal projects, which dramatically prolonged the process of the applications processing

- subsequent unwillingness of the grid operators to cooperate on preparation of PV projects

- introduction of a cap in installed capacity of larger systems by the the SEPS

- change of the Energy law resulting in complicated permissioning process

- very negative perception of the whole PV industry by the public

- overall, a very unclear and uncertain future of the PV industry in Slovakia

However, not all the negative trends can be appointed just to the high FiT. Since electricity production from PV is not quite predictable, it requires higher level of management from the side of grid operators, thus higher costs involved in balancing of the grid. Therefore, obstacles that were created in the PV power plants permissioning by the grid operators also stem from their effort not to increase their operational cost. Moreover, instead of investing into development of the grid (smart grids[15], etc.), the operators preferred to complain about the impact of PV power plants on the grid and increased costs of electricity for the public, which, of course, turned the opinion of the public against PV.

At the same time, the introduction of the cap by the SEPS (which is under control of the government) also doesn't have its origin only in the situation that followed the adoption of the rather high FiT for 15 years. Subsidies involved in support of renewable energy have also impact on the state budget, which, in a year when elections take place is extremely high in terms of cost (effort of the government to "buy" votes by giving various subsidies and other form of presents to municipalities), thus any additional cost in the budget reduces the possibility of the government to spend those money on, from their point of view, more important subjects. From the steps of the current government, it is also quite clear that if it wasn't' for the European legislation and pressure, support mechanisms for RES would most likely never get adopted.

[15] Electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.

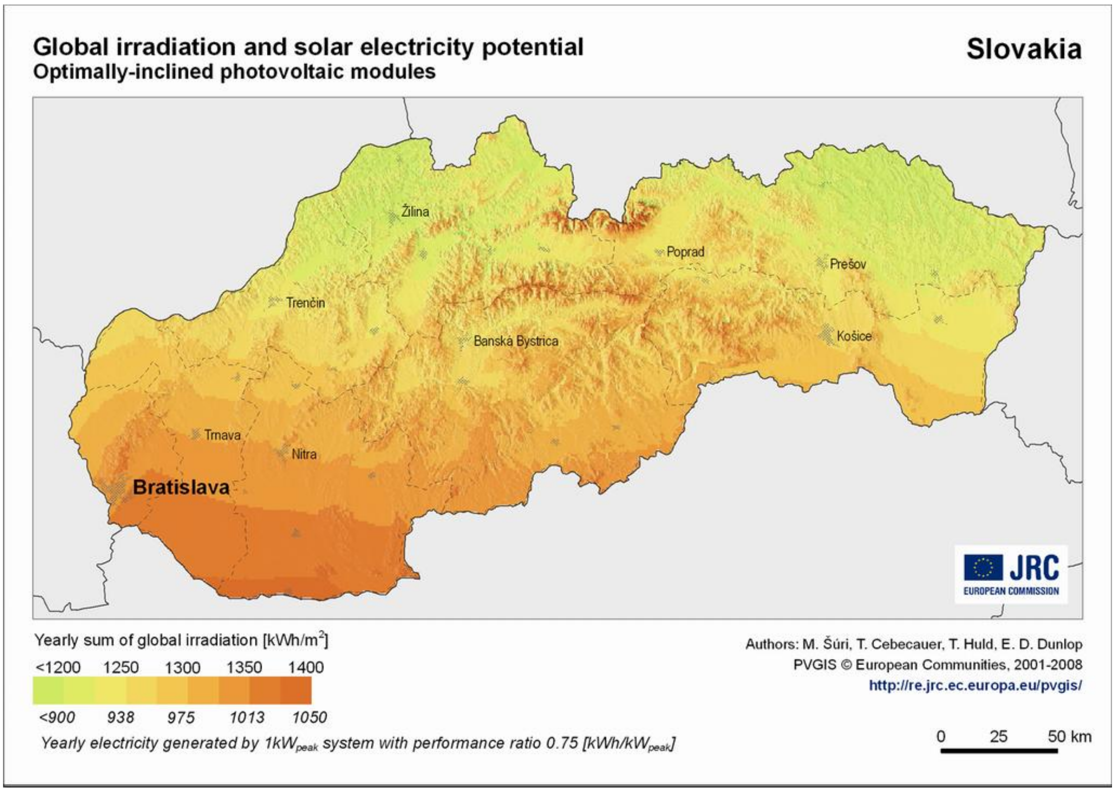
Furthermore, higher utilization of RES in Slovakia doesn't really suit certain industries, especially industries which are dealing with fossil sources. Naturally, companies involved in these industries are mostly large corporate structures with a strong position within the economy, thus they are capable of influencing (through lobbying) the government.

Last but not least, it cannot be forgotten that majority of our primary energy sources is currently being imported from Russia, which, into a large extent, makes our economy politically dependent upon Russia. Naturally, higher utilization of RES would result in decreasing of this dependence and this is something that the last government, which had close relationships with Russia and benefited from those relationships, would explain to their Russian "partner" only with difficulties.

Climate conditions

Slovakia has a very good potential in terms of utilizing solar energy. There is a large excess of solar gains, with low density influenced by seasonal and daily varieties and weather conditions. Most of the PV technologies receive indirect sun radiation, therefore optimal inclination and orientation of the PV modules is crucial.

Figure 6: Irradiation map of Slovakia with optimal tilt



Source: http://re.jrc.ec.europa.eu/pvgis

Table 5: Solar irradiation in Slovakia, G- Global irrad. in kWh/m², E- potential of energy output kWh/1kWp

	PV installation							
	Horizontal		**Vertical**		**Optimal tilt**		**Tracking system**	
	G	E	G	E	G	E	G	E
Minimal	1015	760	780	585	1160	870	1450	1090
Average	1120	840	880	660	1280	960	1615	1210
Maximal	1205	905	940	705	1370	1030	1760	1320

Source: http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm

Table 5 (based on the PV GIS database that was later replaced by updated and more accurate SolarGIS, data of which are also used in the economical calculations) offers an overview of solar energy production on horizontal and optimal inclination as well as energy potential in Slovakia. The optimized tilt depends on latitude which is from 34º to 37º oriented to south. As shown in the Global irradiation map (Figure 6), region below Bratislava has the most valuable conditions in Slovakia. In contrary, the most northern regions are rather poor for solar irradiation.

Consequently, the best economic result from the PV modules is coming from the power plant located in the south, which has more than 20% higher sun gains than the same technology in the north. Subsequently, the most frequent Application forms for connecting PV power plant to grid operators come for areas near the borders with Hungary.

3. Currently used tracking PV systems

Getting the most energy production (maximizing capacity factor) from a photovoltaic system within a set geographic area depends on its exposure to direct sunlight. Key factors for this are avoiding shade and exposing the panels to the most direct sun for the longest period of time. This can be achieved by installing a PV system at the most appropriate tilt and azimuth possible. The tilt of the array is the angle of inclination from horizontal (0° = horizontal, 90° = vertical). Very generally, installers aim for a tilt equal to the geographic latitude minus 15 degrees in order to achieve yearly maximum output of power. An increased tilt will improve power output in the winter months, which is often desired for solar water heating (thus not that suitable for PV), and a decreased tilt will favour power output in summer months. There are several types of substructures that are used for holding PV modules, but the most general types are fixed, one-axis and two-axis tracking ground systems. Each system has different aspects which should be meet with various situations containing the irradiation values, electric rates, magnitude, latitude, weather, atmosphere constraints as well as economical expectations of an investor.

3.1 Single-axis trackers

As it can be derived from their name, single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is usually aligned along a true North meridian. However, it is possible to align them in any cardinal direction with advanced tracking algorithms.

There are several variations of single axis trackers, including Horizontal Single Axis Trackers, Vertical Single Axis Trackers, and Tilted Single Axis Trackers. The orientation of the module with respect to the tracker axis is extremely important when modelling the overall performance of the PV System.

Horizontal Single-axis tracker

Single axis horizontal trackers allow the PV panels to track the sun east to west. This tracking system is able to increase productivity of the modules by up to 35% or more dependent upon the latitude of the installation.

In these systems, a long horizontal tube is supported on bearings mounted upon pylons or frames. The axis of the tube is on a North-South line and horizontal with respect to the ground. Panels are mounted upon the tube, and the tube will rotate on its axis to track the apparent motion of the sun through the day. The posts at either end of the axis of rotation of a Horizontal Single Axis Tracker can be shared between trackers to lower the installation cost.

Figure 7: Example of horizontal single-axis tracking system

Source: http://en.wikipedia.org/wiki/File:RayTracker_Utility_Scale_Solar_Tracker_Installation.JPG

Field layouts with Horizontal Single Axis Trackers are very easy to prepare. The simple geometry means that keeping all axis of rotation parallel to one another is actually all that is needed for correct positioning of the trackers with respect to one another. In addition, with backtracking function, they can be installed at any density without shading, although, naturally, angle of the modules is then not always optimal.

Vertical Single Axis Tracker

Second type of single axis tracking systems is the vertical single axis system. The axis of rotation for Vertical Single Axis Trackers is vertical with respect to the ground and these trackers rotate from East to West over the course of the day.

Similarly to the previous tracker type, field layouts must consider shading to avoid unnecessary energy losses and to optimize land utilization. Nevertheless, optimization for dense packing is limited due to the nature of the shading over the course of a year, thus application of this tracker type is rather limited. Interesting example of utilization of this system can be seen on the following picture.

Figure 8: Example of vertical single-axis tracking system

Source: http://solardecathlon.cca.edu/wp-content/uploads/2008/03/gemini-house-2001.jpg

The face of the module is oriented at an optimal, seasonally adjusted angle (15, 25, 35, 45, 55, or 65 degrees.) relative to the axis of rotation; therefore, a cone is swept at an angle to the ground.

Tilted Single Axis Tracker

All trackers with axes of rotation between horizontal and vertical are considered Tilted Single Axis Trackers. Tracker tilt angles are often limited to reduce the wind profile and decrease the elevated end's height off the ground.

With backtracking function, they can be installed without shading perpendicular to their axis of rotation at any density, however, installation parallel to their axis of rotation is limited by the tilt angle and the latitude.

Figure 9: Example tilted single-axis tracking system

Source: http://www.nellis.af.mil/photos/media_search.asp?q=solar&btnG.x=0&btnG.y=0

One scientifically interesting variation of a Tilted Single Axis Tracker is a Polar Aligned Single Axis Trackers (PASAT). In this particular implementation of a Tilted Single Axis Tracker the tilt angle is equal to the latitude of the installation. This aligns the tracker axis of rotation with the earth's axis of rotation. These types of trackers are rarely deployed because of their high wind profile.

3. 2 Dual-axis trackers

Dual axis trackers are capable of rotating independently about two axes. Dual axis trackers have a primary axis that is fixed relative to the ground with a secondary axis normal to the primary. Installation of a Dual-axis Solar Tracker (Azimuth Dual Axis Tracker) removes the need to adjust the array monthly or seasonally to optimize solar performance from morning to evening.

There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two most common implementations are Tip - Tilt trackers and Azimuth-Altitude trackers.

The orientation of the module with respect to the tracker axis is important when modelling performance. Dual Axis Trackers typically have modules oriented parallel to the secondary axis of rotation.

Figure 10: Example of 2-axis tracking system

Source: http://www.heliotechniki.com/images/bg6.jpg

Tip – Tilt Dual Axis Tracker

A Tip – Tilt Dual Axis Tracker has its primary axis horizontal to the ground. The secondary axis is then typically normal to the primary axis. The posts at either end of the primary axis of rotation of a Tip – Tilt Dual Axis Tracker can be shared between trackers to lower installation costs.

The axes of rotation of Tip – Tilt Dual Axis Trackers are typically aligned either along a true North meridian or an east west line of latitude. It is possible to align them in any cardinal direction with advanced tracking algorithms.

Azimuth-Altitude Dual Axis Tracker

An Azimuth – Altitude Dual Axis Tracker has its primary axis vertical to the ground and the secondary axis is then typically normal to the primary axis.

„This mount is used as a large telescope mount owing to its structure and dimensions. One axis is a vertical pivot shaft or horizontal ring mount that allows the device to be swung to a compass point. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. By using combinations of the two axes, any location in the upward hemisphere may be pointed. Such systems may be operated under computer control according to the expected solar orientation, or may use a tracking sensor to control motor drives that orient the panels toward the sun. This type of mount is also used to orient parabolic reflectors that mount a Stirling engine to produce electricity at the device.“ [16]

[16] http://en.wikipedia.org/wiki/Solar_tracker

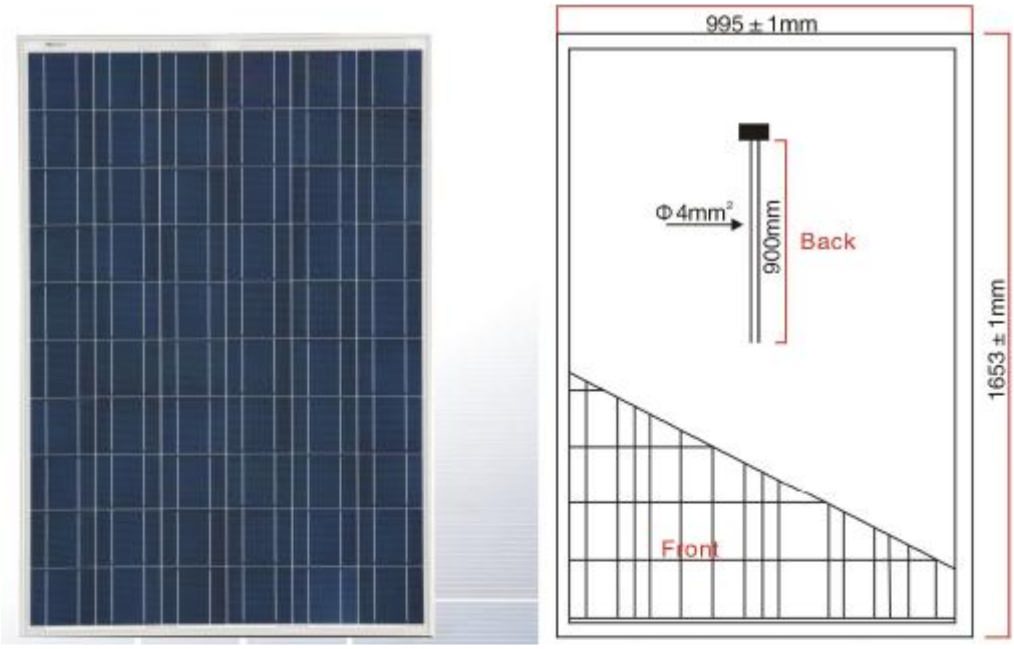
4. Specification of components of the compared PV systems

Following the description of the currently used tracking system in the previous chapter, this chapter will contain a detailed description of the two photovoltaic systems compared in this study. This description will be broken down into the following parts: PV modules, substructure, and inverters.

4.1 PV modules

In this case study, PV modules TW 230(28) P from company TIANWEI NEW ENERGY will be used. The modules consist of 60 pieces of 156 x 156 mm multicrystalline silicon PV cells, which are hot laminated and sealed with high transparency tempered glass, anti-aging EVA, weather resistant backsheet and good quality anodized aluminium alloy frame.

Figure 11: Visual specification of the modules



Source: Module datasheet

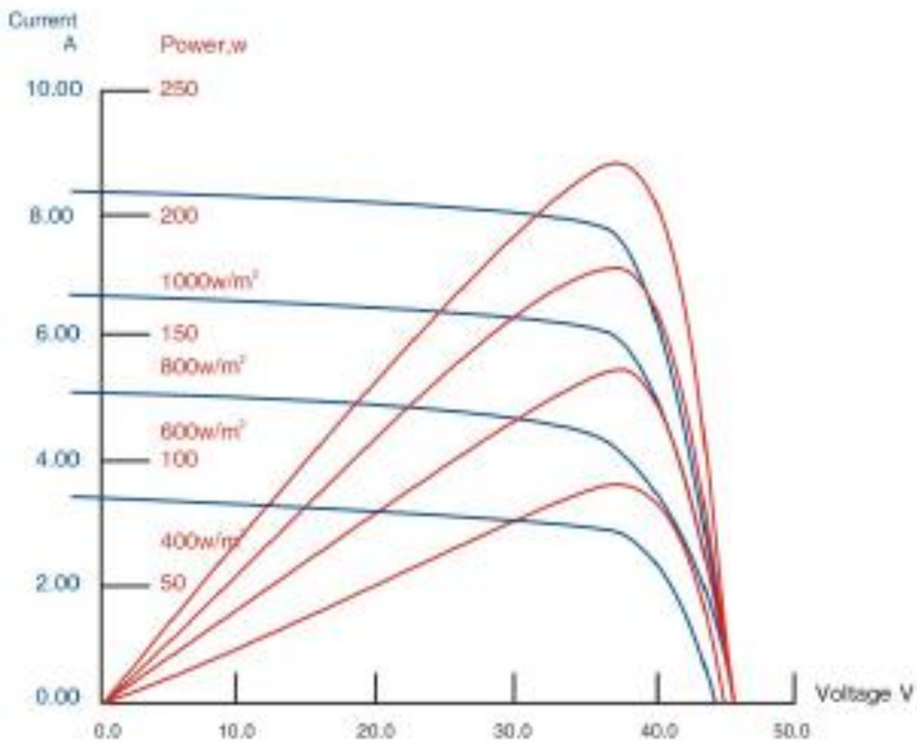
The modules have high efficiency, long usable life and easy installation and meet all relevant norms and standards. The modules have output power guarantee which guarantees that the modules will not lose more than 10 % of their performance in the first 10 years of their operation and not more than 20 % of their performance in the 25 years of their operation.

Table 6: Technical specification of the modules

Parameter	Unit	Value
Maximum power	*Pm(W)*	*230*
Maximum operating voltage	*Vmp(V)*	*29,7*
Maximum operating current	*Imp(A)*	*7,74*
Short circuit current	*Isc(A)*	*8,72*
Open circuit voltage	*Voc(V)*	*36,7*
Maximum system voltage	*(V)*	*DC 1000V (TUV); 600V (UL)*
Power tolerance	*%*	*+/- 3*
Weight	*Kg*	*20*

Source: Modules datasheet

Figure 12: Modules IV curves



Source: Modules datasheet

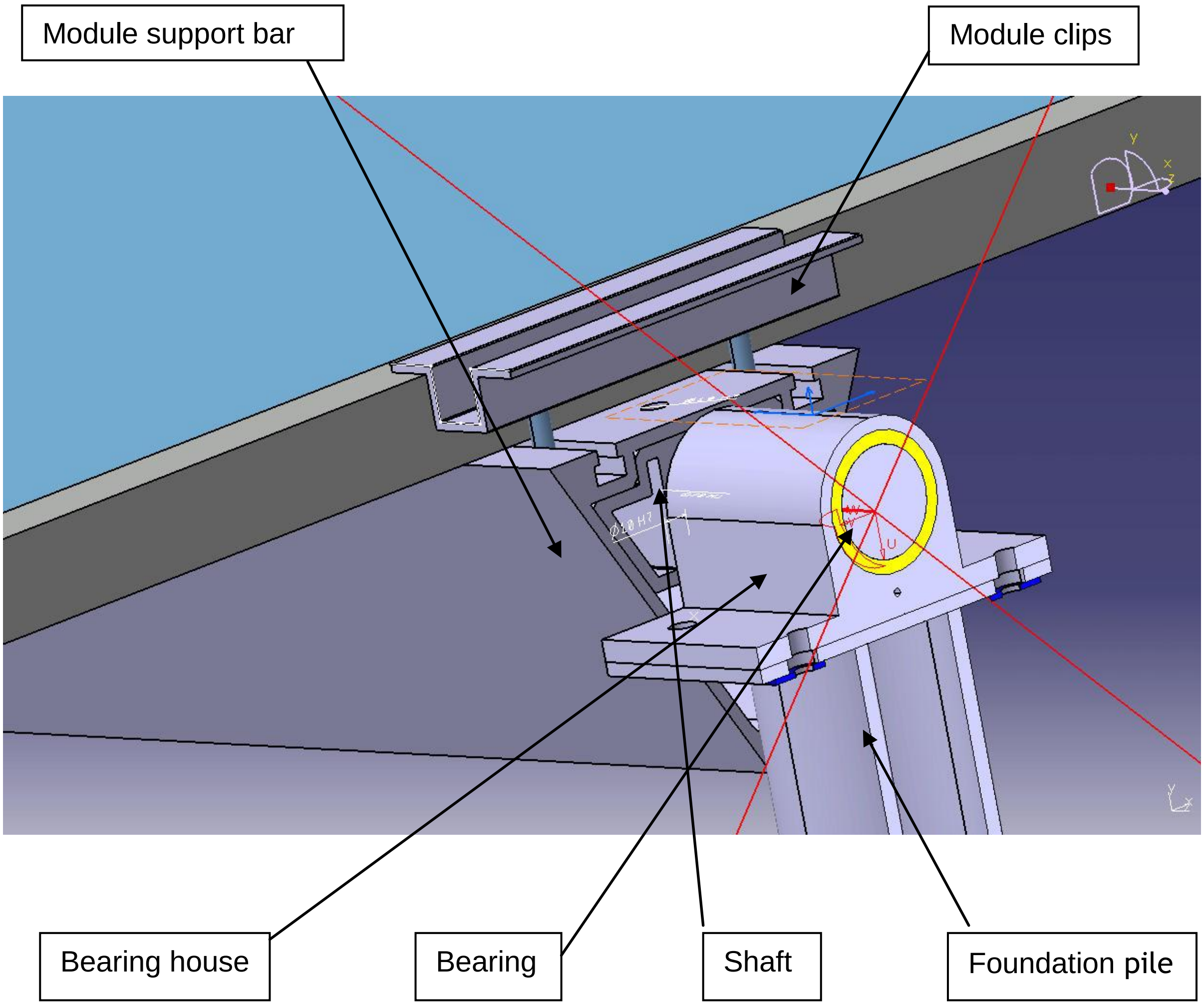
4.2 Substructure

The substructure is pretty much the only part which will differ in the 2 compared systems. Since the more intricate of the 2 substructures is, naturally, the horizontal single-axis tracking system, it will be described in much more detail than the optimally inclined fixed system that is rather simple in its function.

4.2.1 Horizontal single-axis tracking structure

This mounting system is a one row substructure for free field photovoltaic systems in optimised form for crystalline modules and based on tried and tested ram pile technology (pile grid 6190 mm, deviating in the first and last pile). With predetermined connection points and a low number of screw connections, rapid, simple and secure installation is guaranteed. Due to the uniform surface coating of the individual components, the structure is highly resistant to corrosion. The module clamp also ensures rapid mounting of the solar modules.

Figure 13: Overview of the mounting structure



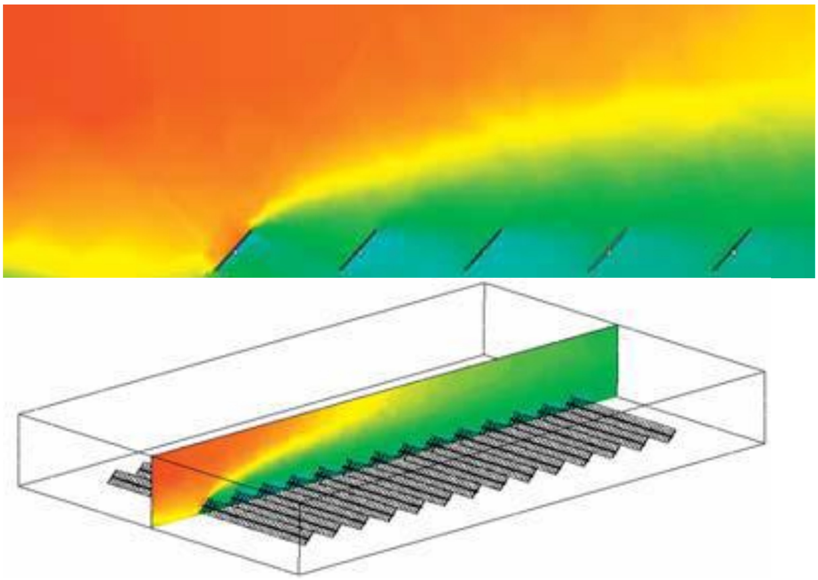
System was designed by CATIA software in 3D modelling. All components are subjected to Finite Element Method (Gauss R6) analyses during development, for the purposes of structure optimization, operating stability analysis and mechanical load evaluation.

Table 7: Specification of the studied tracking system

Tracking type	1-axis tracking (with backtracking algorithm)
Tilt angle	0 degrees
Tracking angle	+/- 60^0 East-West
Drive type	Linear actuator
kW/Drive	up to 300 kW
Controller	astrology based PLC, without light sensors
Wind resistance	up to 50 m/s
Energy gain vs. optimally inclined fixed system	13 - 17% (in Germany, Czech, Slovakia)
Area required	1,6 - 2,5 ha/MW

With using aluminium parts in the structure, stresses between the module frame and the support bar are avoided. Aluminium also helps to prevent the structure from corrosion in the 25 years of operation phase. The aluminium has also advantages in the recycling at the end of the lifecycle of the product.

Figure 14: Wind resistance tests of the system



Source: CATIA Software package

The profiles of the framework foundations can be selected from a broad product range, such as Sigma 100, IPE 100, C 100, C125, IPE 120, HEA 120. The basic profile for the tracking system is the hot dip galvanized steel Sigma 100.

Figure 15: Actual visualisation of the studied tracking system

Source: Own database

Drive and Control

Central linear actuator moves the module rows in the exact position. The drive comes with up to 10 years of factory guarantee. The tracker uses a 100 kN trust power drive, with a 1,5 kW AC 4 pole motor. The actuator can move on 1500mm way.

The drive is controlled by PLC logics. The positioning of the system is based on an astrological algorithm and not on light sensors. Based on the GPS coordinates of the location, the logics calculates the exact position of the sun and turn the module surface in every 12 minutes. The PLC control helps to avoid the unnecessary movements. The control is programmed with a backtracking algorithm. At low sun angles, the tracker employs its backtracking feature to prevent shading and to optimize energy production. Wind and snow sensors are monitoring the weather conditions and command the system to move to the vertical position in case of high wind (over 25 m/s), or to move to the snow drop-off position. The system can be operated manually, with local or remote controls. With this feature the module surface can turn to the service position, or any kind of other positions, to avoid weather disasters, like hail storm.

The tracker actuators are moving every 12 minutes for 6-10 sec. The exact angle of the movement is changed day by day, according to the current day lengths, so it cannot be specified. The maximum angle is +/- 60 degrees. The consumption is 180-220 kWh/year, depending on the weather conditions (snow towing, wind protection).

Figure 16: Engine and drive for the tracking system

Source: Own database

The turning movement is on the same time as the rows are connected to each other, but the individual actuators will be not synchronized to each other so there can be delays, but only few 10 seconds. So every 12 minutes the system will move for 6-10 seconds, depending on the day length. At the end of the day, when the modules starting to shade each other, the actuators will move them backwards, to avoid the shading. After the sunset the system is moving to the morning starting position. If there is too high wind (basic setup is 80 km/h) the system automatically standing to the horizontal position. If there is too big snow (weight sensor shows more than 0,3 kN/m2), the system is moving to the snow towing 60 degree position (once for +60 degree, next time -60 degree, to avoid too much snow on one side). The third position is the manual kept position when the operator sets an angle to the system which he desires, this is for cleaning, reparation works etc.

The flow-optimized design of the tracker supports a large module area per drive. This minimizes the frequency of service calls and reduces the overall maintenance requirements. In case of need for replacement, all major components of the system are easily accessible. Central linear actuator moves the module rows in the exact position. The drive comes with up to 10 years of factory guarantee. The tracker uses a 100 kN trust power drive, with a 1,5 kW AC 4 pole motor. The actuator can move on 1500mm way.

The drive is controlled by PLC logics. The positioning of the system is based on an astrological algorithm and not on light sensors. Based on the GPS coordinates of the location, the logics calculates the exact position of the sun and turn the module surface in every 12 minutes. The PLC control helps to avoid the unnecessary movements. The control is programmed with a backtracking algorithm. At low sun angles, the tracker employs its backtracking feature to prevent shading and to optimize energy production. Wind and snow sensors are monitoring the weather conditions and command the system to move to the vertical position in case of high wind (over 25 m/s), or to move to the snow drop-off position. The system can be operated manually, with local or remote controls. With this feature the module surface can turn to the service position, or any kind of other positions, to avoid weather disasters, like hail storm.

The flow-optimized design of tracker supports a large module area per drive. This minimizes the frequency of service calls and reduces the overall maintenance requirements. In case of need for replacement, all major components of the system are easily accessible.

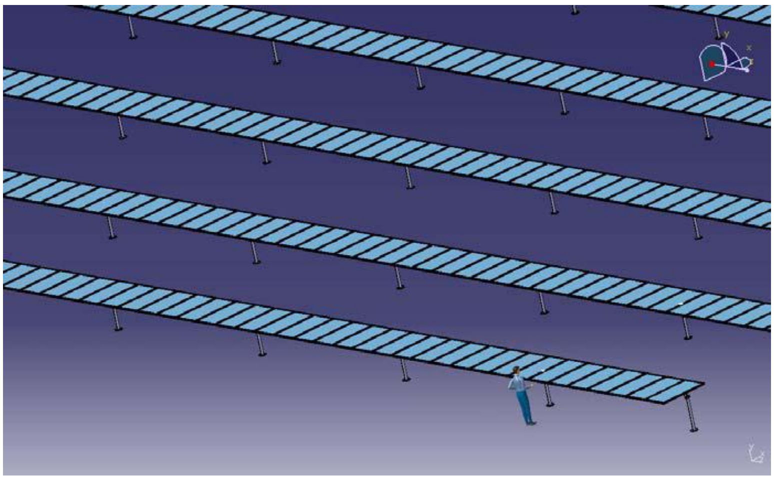
Areal Requirements

The substructure has the following areal requirements[17]:

Distance between poles	*max. 6.6 m*
Distance between rows	*3m – 6m*
Maximal lengths of the rows	*66 m*
Area required per MWp	*1,6 - 2,5 ha*

.

Figure 17: Visualisation of areal placement of the system

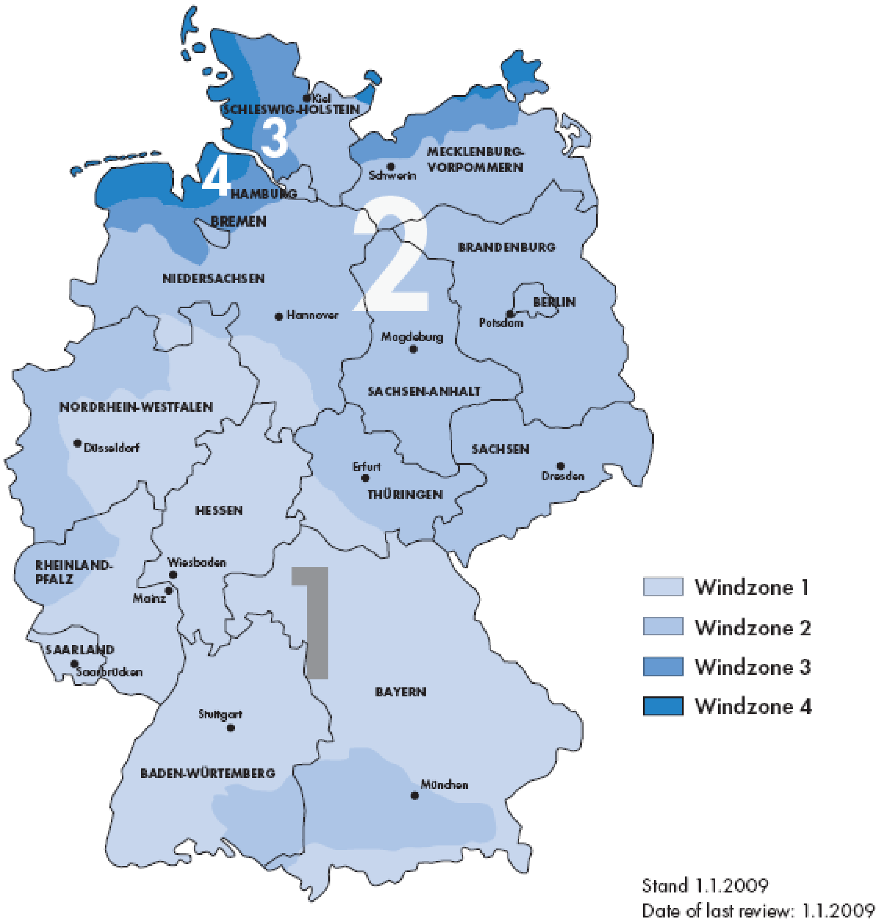


[17] The area data are valid for crystalline modules only

Wind zones

DIN 1055, Part 4 applies for the calculation of the assumed wind loads. The wind zone map for the Federal Republic of Germany is used to determine the wind zone for the location of the planned photovoltaic system. The wind loads apply for inland mounting under regular conditions. For coastal locations or exposed locations (hilltop, troughs) larger wind loads must be taken into consideration. In the case of doubt it is recommended to consult a qualified structural engineer.

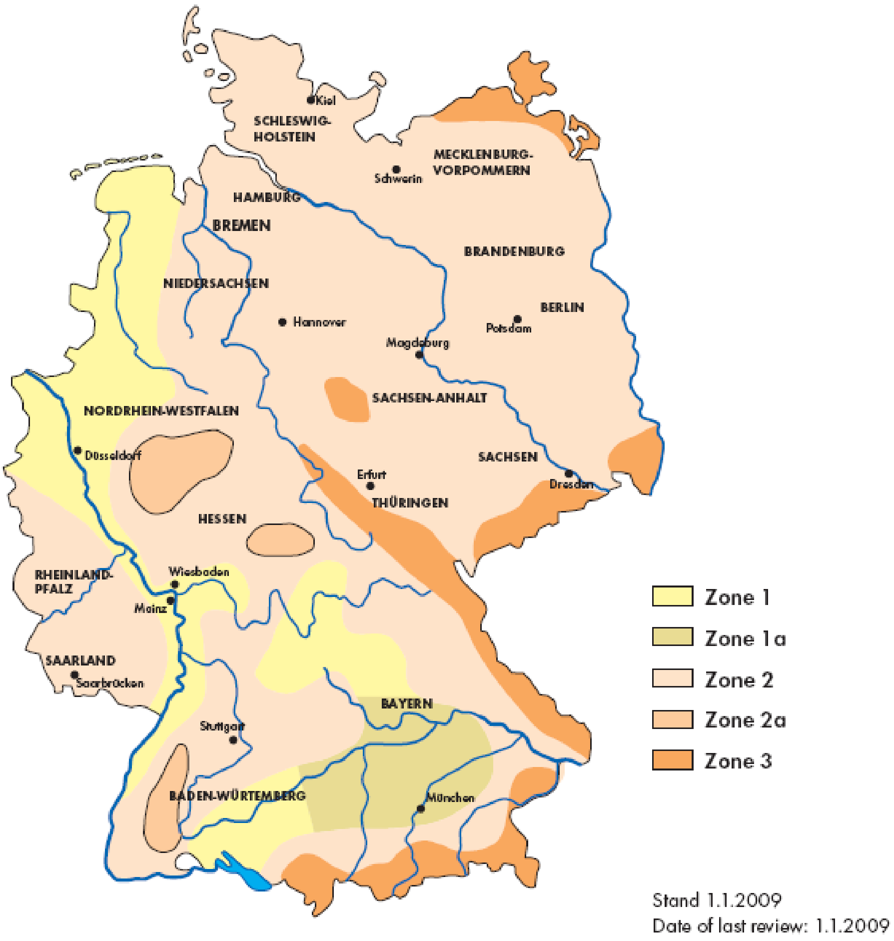
Figure 18: Example of Windzones in Germany



Snow zones

DIN 1055 Part 5 shall serve as the basis for the calculation of the snow load. It is determined for the location of the planned photovoltaic system from the snow load map for the Federal Republic of Germany. The characteristic snow load on the ground is then calculated depending on the snow load zone and the altitude above sea level.

Figure 19: Example of Snowzones - Germany



Loads for the substructure

With the aid of the following table, the suitability of the substructure for the planned installation location can be roughly assessed taking into account wind and snow loads in accordance with DIN 1055.

Table 8: Suitability of the substructure according to Wind and Snow zone level

Wind zone	Snow zone	Max. altitude
1	3	530 m
1	2a	600 m
1	2	700 m
1	1a	950 m
1	1	1.090 m
2	3	500 m
2	2a	570 m
2	2	660 m
2	1a	900 m
2	1	1.040 m

3	3	480 m
3	2a	550 m
3	2	640 m
3	1a	880 m
3	1	1.010 m

4.2.2 Optimally inclined fixed structure

Fixed systems as the less difficult substructure are widely used in greenfield power plants. The main used material is the aluminium, because of the water resistance and long life, but hot-dip galvanized steel can be used. The ideal angle in Europe is $29^0 – 35^0$ and the modules are facing to the South direction. A typical fixed system cost is 30 Eur/m^2, that means 210 Eur/kW_p for crystalline modules and around 450 Eur/kW_p for thin film modules. Only small price reduction can be expected in the following years, because the producers have to take into consideration the valid standards and this makes possible only limited reduction of the materials.

4.3 Inverters

The Xantrex GT500E is a grid tie three-phase Inverter based on a reliable platform that is used in grid-connect photovoltaic and wind turbine applications in North America and Europe. Easy to install and operate, the GT500E automates start up, and shut down. It incorporates advanced Maximum Power Point Tracking Technology to maximize the energy harvested from a PV array. To minimize power losses during the conversion process, the inverter's switching technology uses insulated gate bi-polar transistors. Multiple inverters can be paralleled for large power installations. Designed for European PV installations, the GT500E meets all applicable CE requirements.

Table 9: Technical specification of the GT500E inverter

Nominal power rating (AC)	500 kW
Nominal AC voltage	315 V
Nominal AC frequency	50 Hz (optional 60 Hz)
Line power factor	> 0,99 above 20% rated power
AC current distortion	< 3% THD at rated power
Max AC line current	920 A
Stand-by tare losses	< 100 W
Night consumption	< 100 W

Min DC voltage for feed-in	450 V
Suggested PV power	560 kWp
Max DC current	1120 A
Max open circuit voltage	880 V
Power Tracking window range	450 V - 800 V
Max efficiency	98,10%
European efficiency	97,30%
Ambient temperature range	−10º - 45ºC
Weight	1770 kg
Dimensions (H x W x D)	211,2 x 240,6 x 60,5 cm
Altitude	up to 1500 m without de-rating

Source: Inverter datasheet

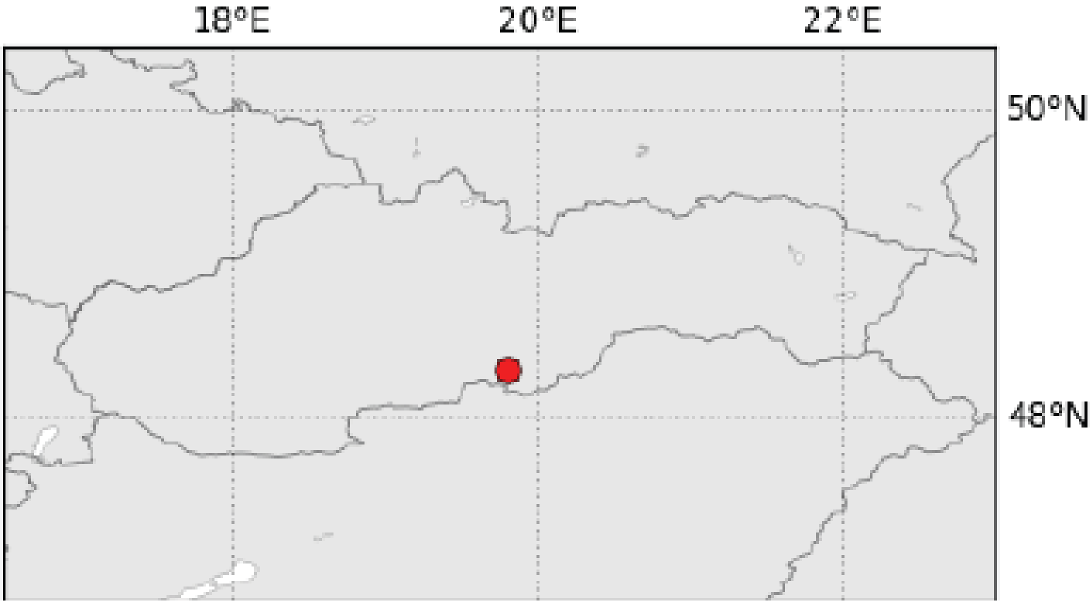
5. Characteristics of the studied site

In this chapter, the location chosen for the case study will be analysed in terms of its suitability for construction of a PV facility. Irradiation, shading, protection zones, zoning status, proximity of grid connection and similar factors will be taken into account.

The selected plot is located in the commune of Buzitka, district Lucenec, which is one of the sunniest areas of Slovakia, the nearest larger city is Lucenec. The global horizontal irradiation in this location is 1 192,6 kWh/m^2/year[18]. The size of the plot is approximately 113 000 m^2 (it consists of 2 individual plots), which is sufficient for installation of 4 MWp of PV modules by using most of the currently used systems and technologies, including the 2 possible solution proposed and discussed in this case study. The plot is in ownership of the local municipality, which is willing to lease it out for the required period of 25 years (predicted life-time of the power plant) at the price of 0,3 EUR/m^2/year.

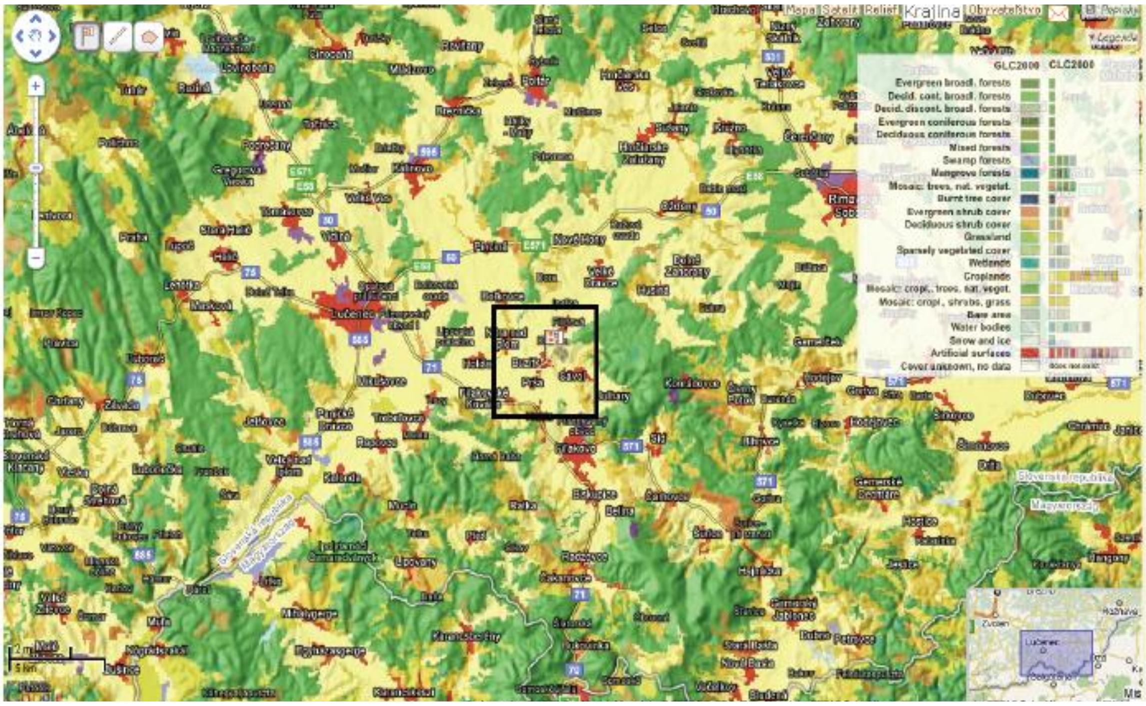
Geographical coordinates: **48° 18' 18", 19° 48' 14"**
Elevation above sea level: **approx. 191 - 198 m**
Slope inclination: **approx 1° - 2°**
Slope azimuth: **South – Southeast**

Figure 20: Geographical coordinates of the plot



[18] PV SYST database

Figure 21: Geographical position of the site in the region



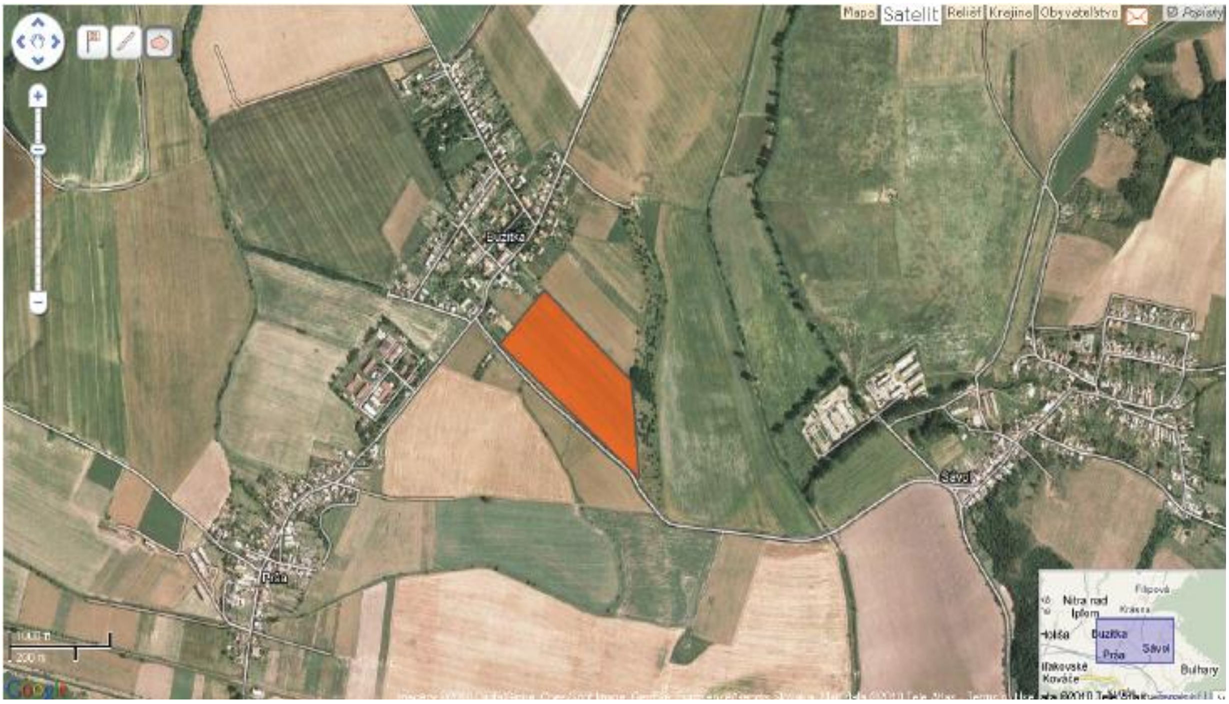
Source: www.googlemaps.com

A high voltage grid (22 kV) is located on the plot. The capacity of the grid has been pre-discussed with a relevant person from the grid operator (SSE) with a positive feedback, nevertheless, for a guaranteed and binding information a “connectivity study” would be required.

The plot is almost flat, with a moderate inclination to south, which is ideal. There are no objects causing shading located on the plot, very little shading comes from the neighbouring plots (trees located at the eastern side), even this will be, however, avoided by increasing the distance between the borders of the plot and the first row of installed panels. Moreover, no protection zones limiting the usable area (except for the grid line) are present on the plot.

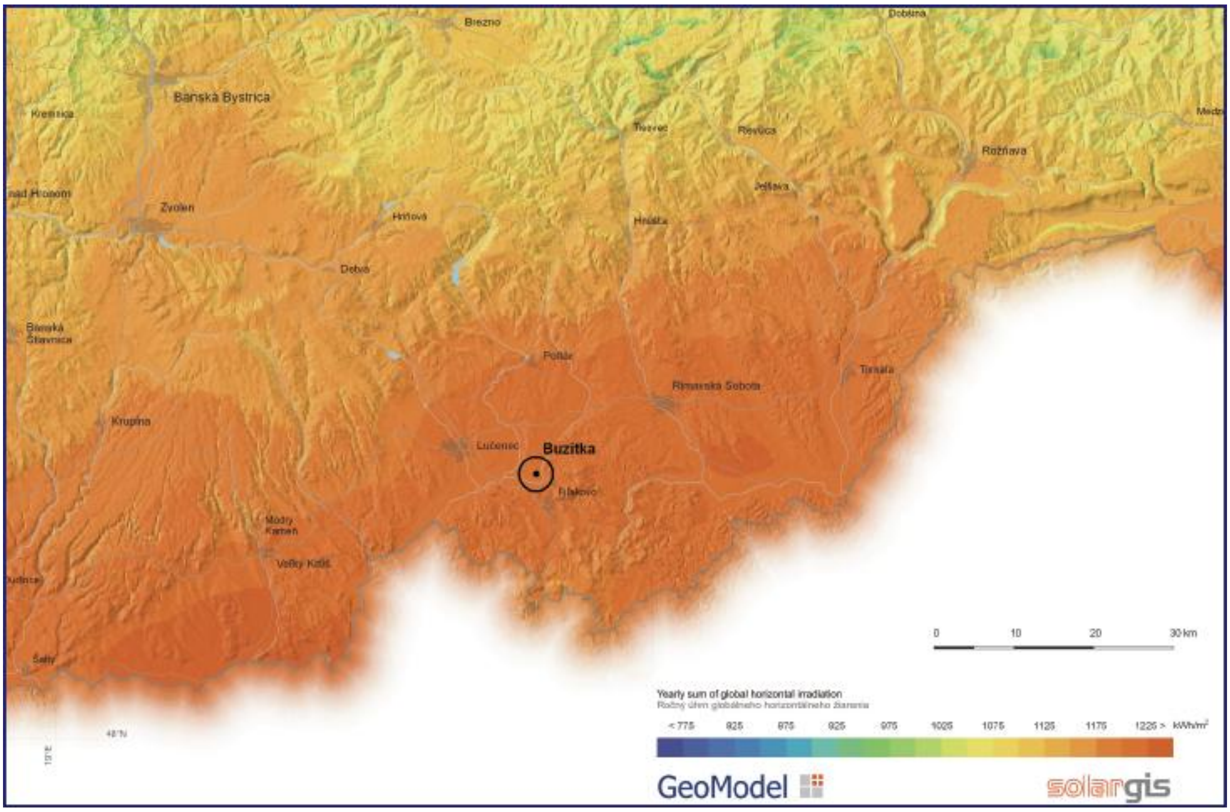
The plot is defined in general city plan of Buzitka as a part of industrial zone Buzitka-South, suitable for this kind of utilization; change of the status of the land will be done within Area management pursuant to official request to State land fund. The local municipality has no objection to the presence of the power plant in their cadastral area; on the contrary, they welcome it due to the financial income resulting from leasing out the plot, as well as due to positive publicity and potential increase of tourism.

Figure 22: Visualization of the area assumed for construction of the PV power plant Buzitka



Source: www.googlemaps.com

Figure 23: Yearly sum of global horizontal irradiation in the chosen location



Source: SolarGIS v 1.3 - GeoModel

The below figure shows change of the day length and solar zenith angle during a year. The local day length (time when sun is above the horizon) is negligibly shorter compared to astronomical day length, due to small obstructions from the local terrain horizon.

Figure 24: Day length and minimum solar zenith angle

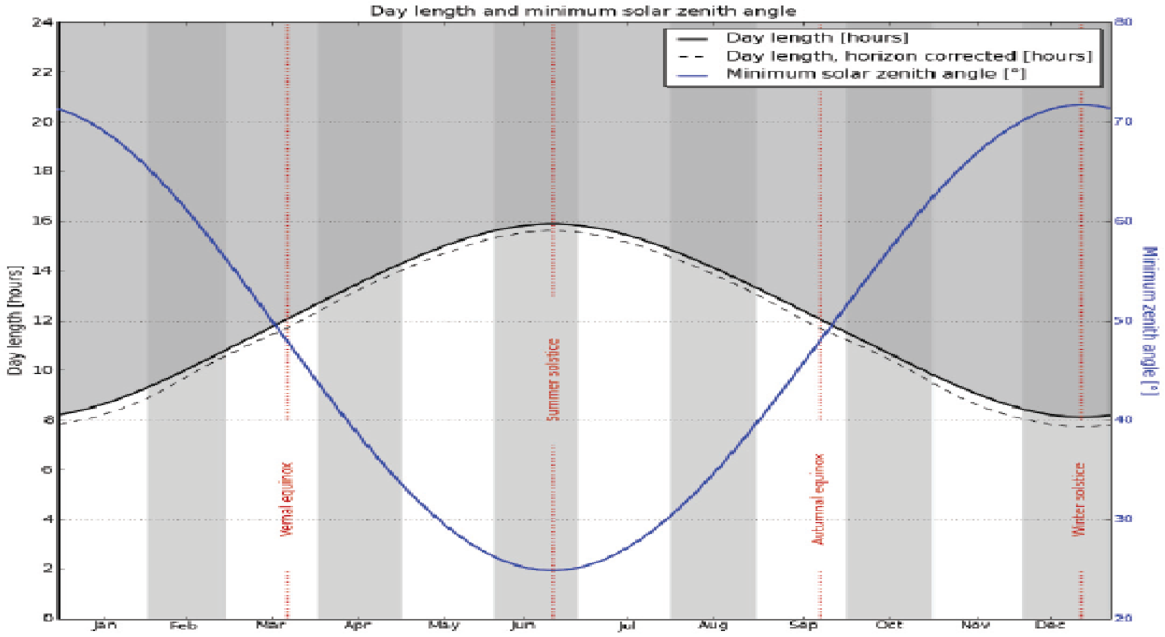
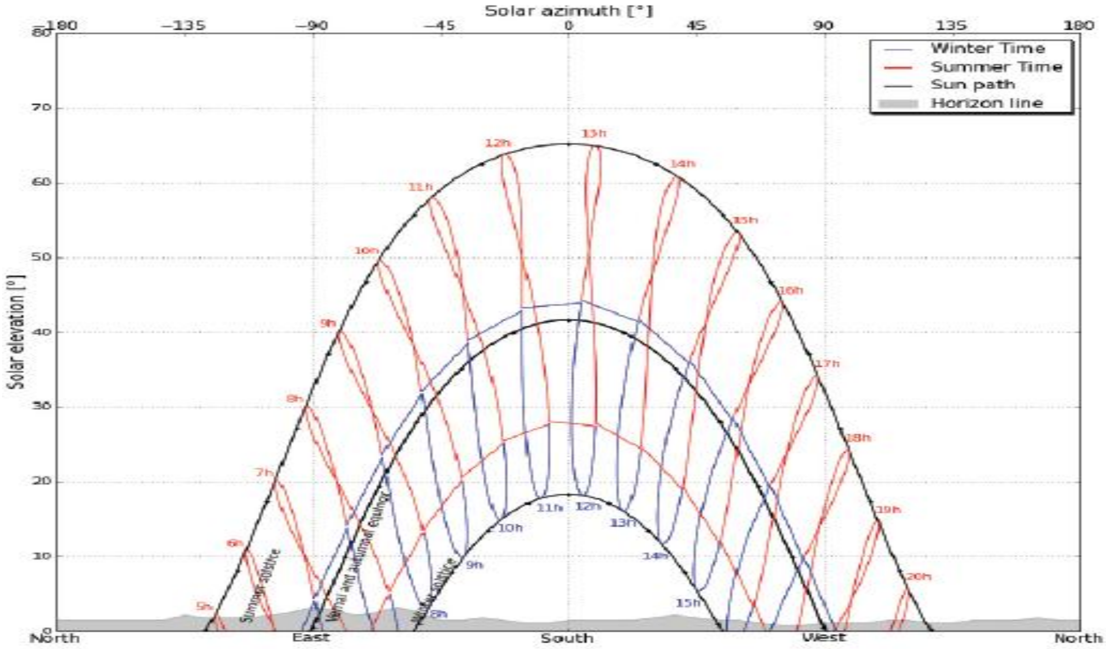
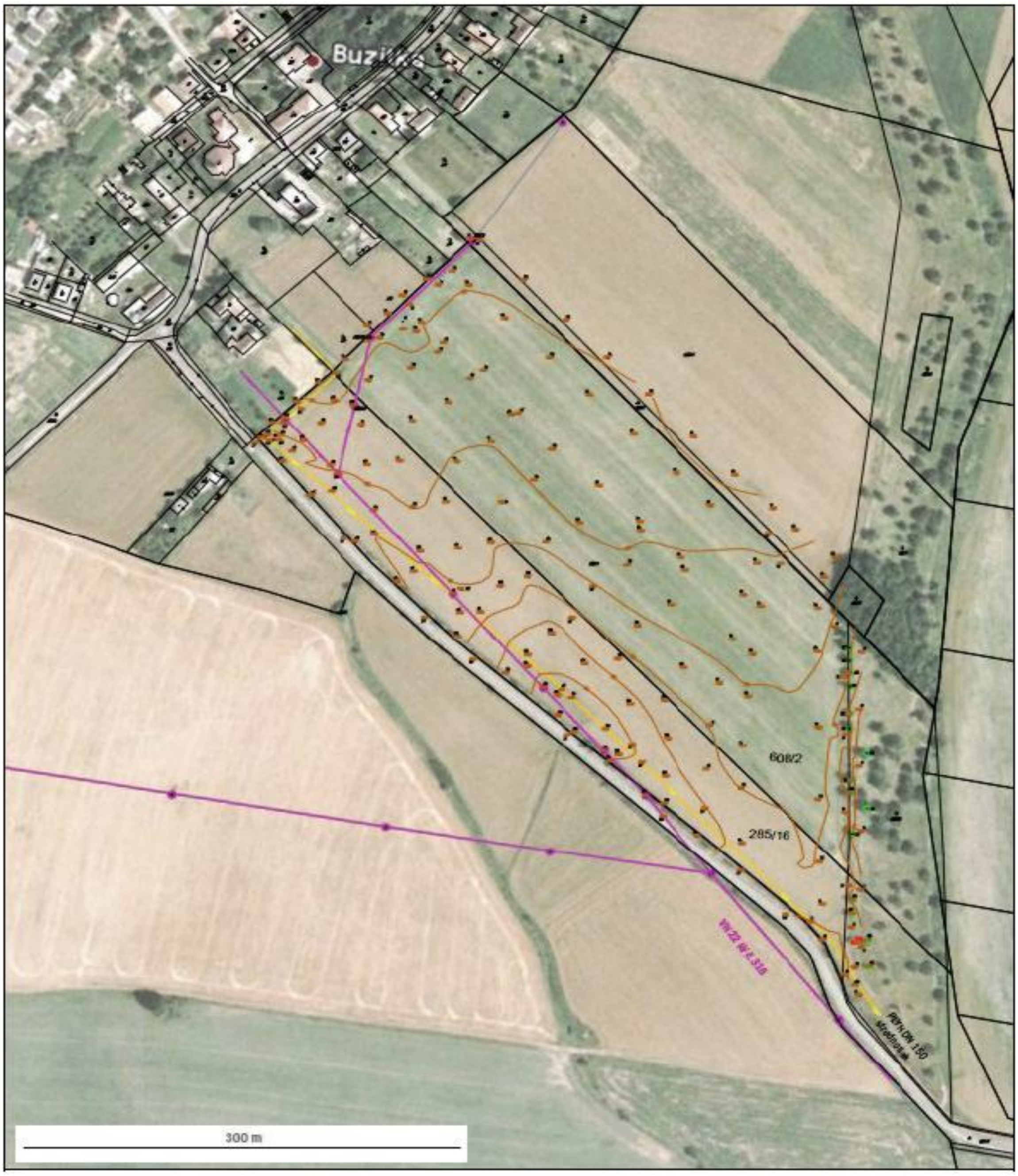


Figure 25: Sunpath and terrain horizon



The above figure shows change of the sunpath over a year. Terrain horizon is drawn in grey colour and has insignificant shadowing effect on solar radiation. Black dots show hours in True Solar Time. Red labels on the top of the curves indicate Local Clock Time in summer (UTC + 1 hour + 1 hour summer time shift). Local Clock Time in winter (blue labels) is without 1 hour summer time shift.

Figure 26: Detailed view of the plot in Buzitka assumed for construction of the PV facility



6. Energy yield assessment

Energy yield is, together with the level of feed-in tariff, the most important factor influencing economics of a PV facility. In this chapter, a simplified form of an energy audit will be performed, which will determine the energy yield based on the specification of the location as well as specification of the compared systems.

6.1 Data, methods and assumptions

Two sources of data have been used in the calculation:

SolarGIS v1.3 – high-resolution climate database developed by GeoModel, with geographical extent covering Europe, North Africa and Middle East. Primary data layers include solar radiation, air temperature, and terrain data (elevation, horizon).

Satel-Light - solar database developed within the EU project Satel-Light from Meteosat MFG satellite data. The database is maintained by ENTPE, France.

Table 10: Data description and sources

Air temperature:	SolarGIS v1.3 (GeoModel)
Primary parameters:	Air Temperature at 2 metres height
Data description:	High-resolution database is derived from ECMWF ERA Re-analysis data (© ECMWF) by algorithms developed by GeoModel and Digital Elevation Model (DEM) SRTM-3. Original temporal resolution is 6 hours.
Period covered by data:	01/1991 up to 12/2009 (19 years)
Data resolution:	Time resolution is interpolated to 15-minute, spatial resolution is 1 km
Solar radiation 1:	SolarGIS v1.3 (GeoModel)
Primary parameters:	Global Horizontal Irradiance and Direct Normal Irradiance
Data description:	Database is derived from Meteosat Second Generation satellite data (© EUMETSAT) and atmospheric data using in-house computing infrastructure and high performance algorithms
Period covered by data (in this report):	04/2004-03/2009 (5 years)
Data resolution:	time resolution of 15-minute, original spatial resolution of ~5 km is disaggregated to ~80 metres for the studied site

	using high resolution Digital Elevation Model SRTM-3
Average quality in Europe:	The overall relative mean bias difference for global horizontal irradiance is -1.4%, and relative root mean square difference is 20.0%, 10.7% and 4.7% for hourly, daily and monthly data, respectively; 99.4% data coverage.
Solar radiation 2:	Satel-Light (ENTPE)
Primary parameters:	Global Horizontal Irradiance and Direct Horizontal
Data description:	Database is derived from Meteosat First Generation satellite data and Linke atmospheric turbidity
Period covered by data:	01/1996-12/2000 (5 years)
Data resolution:	time resolution of 30-minute, spatial resolution of ~5 km
Average quality in Europe:	Mean Bias -1%, Root Mean Square Deviation 20% for hourly values;

Simulation methods, assumptions and uncertainties

Photovoltaic power production has been calculated using numerical models developed or implemented by GeoModel. 15-minute time series of solar radiation and air temperature data are used as inputs to the simulation of PV power production. Data and model quality is checked according to recommendation of IEA SHC Task 36 and the MESoR standards using measurements from 41 ground stations over Europe and critical cross-comparison with other available data sources.

Step 1: Global irradiation on in-plane surface

Global irradiation impinging on a tilted plane of PV modules is calculated from Global Horizontal Irradiance (G_h), Direct Normal Irradiance (DNI), the shadowing effects from the horizon determined using Digital Elevation Model (SRTM-3) with ~80 m resolution (H_{SHAD}), terrain albedo, and instantaneous sun position within 15 minutes time interval (SPOS): $G_{INCLINED}=f_{DIFF}$ (G_h, DNI, H_{SHAD}, Albedo, S_{POS}). The P(90) uncertainty of this estimate may vary in a range of a few percent.

Step 2: Losses due to terrain shadowing

Shadowing by terrain features is calculated by disaggregation using SRTM-3 DEM and horizon height. Shadowing of local features such as from nearby building, structures or vegetation is not considered: $G_{INCLINED-SHAD} = f_{SHAD}(G_{INCLINED}, S_{POS}, \text{Horizon})$. For open space systems the uncertainty of this estimate is very low due to high resolution of DEM. For urban areas, where shadowing is mainly influenced by buildings, an additional analysis must be undertaken to consider the detailed surface model.

Step 3: Losses due to angular reflectivity

The resulting irradiation is subjected to losses from angular reflectivity (angle of incidence effects) on the surface of PV modules, and the magnitude of effects depends on relative position of the sun and plane of the module: $G_{ANGULAR} = f_{ANGULAR} (G_{INCLINED-SHAD}, SPOS)$. The accuracy of calculations of angular reflectivity losses depends on cleanness and specific properties of the module surface (antireflection coating, texture, etc.). In this study a typical low iron float glass and "average" effect of dust are assumed. The uncertainty of this step is low, below ±1% in majority of cases.

Step 4: Losses due to performance of PV module outside of STC conditions

Global irradiation ($G_{ANGULAR}$) reaching modules of the given type (M_{TYPE}) along with the air temperature (T_{AIR}) are the input parameters to the PV performance model: $PV_{DC} = f_{PV}(G_{ANGULAR}, T_{AIR}, M_{TYPE})$. The conversion efficiency is non-linear and depends on the distribution of pair of values of irradiance and temperature. Spectral effects in outdoors conditions are not fully understood due to missing experimental data. Relative change of produced energy from this stage of conversion depends on modules technology and mounting type. Typically loss at this step is higher for crystalline silicone modules than thin films due to higher negative thermal power coefficient of crystalline silicon and better behaviour of thin film at low light levels. Another significant source of uncertainty is variation in nominal power specified by the module manufacturer.

The "label value" of module nominal power is given with certain tolerance and real power of the module may deviate from the nominal power. Tianwei New Energy specifies tolerance as a symmetrical deviation from the nominal value of ±3%. This may imply that for a large number of modules statistically the average value of nominal power of modules should be close to the one stated on the label. However this assumption may not be always tenable. The uncertainty in this stage is for crystalline silicon around ±2 due to stable behaviour of crystalline silicon modules.

Step 5: Other DC losses

A number of effects cause DC power losses (DCLOSS), such as mismatch due to different MPP operating point of modules connected into an inverter, heat losses in interconnections and cables; these losses depend on the design and components of the PV power plant. Other effects are dirt and dust, snow, icing, soiling, bird droppings, and self-shadowing. While self-shadowing is a factor to be controlled in the design stage, the rest depends on the environmental factors and maintenance during the power plant lifetime. Although it is assumed that the module pollution will be weak, its long-term effects are not satisfactorily known.

The total magnitude of DC losses can be estimated at around 7.0% with and uncertainty of ±2.0%, however it is stressed that due to limited information about the power plant and natural effects, this assumption may suffer from imprecision when compared to the estimated at other stages of simulation.

Step 6: Inverter losses from conversion of DC to AC

Although power efficiency of inverter has improved, each type of inverter has its own efficiency function (dependence of the inverter efficiency on the inverter load and inverter input voltage) $f_{INVERTER}$. $PV_{AC}= f_{INVERTER} (PV_{DC}, DC_{LOSS})$, losses due to performance of inverters can be estimated using inverter power curve with 15-minute pairs of DC data once the inverter type is chosen. In this step we assume choice of an inverter with conversion losses 2.4% and the uncertainty of ±0.5%.

Step 7: AC and transformer losses

The inverter output is connected to the grid through the transformer. The additional AC side losses reduce the final system output by a combination of cabling (AC_{LOSS}) and transformer losses (TR_{LOSSES}): $PV_{OUT}=f_{AC}(AC_{LOSS}, TR_{LOSSES})$. These losses are estimated to 1% with ±0.5% uncertainty.

Step 8: Availability

This empirical parameter quantifies effect of downtime of a PV power plant or its sections/components due to maintenance or failures. We assume that 0.5% of yearly PV power production may be lost due to various disruptive events with an uncertainty of about ±0.5%.

Step 9: Long term degradation

Many years of operation of PV power plants is the ultimate test for all components, placing the module encapsulants, cell interconnections, junction boxes, cabling, and inverters under stress during weather cycles. Currently produced modules and system components represent a mature technology, and very low level of degradation can be assumed. Many module manufacturers currently give a double power warranty for their products (including the modules proposed in this study), typically 90% of the initial maximum power for first 10 years and 80% of the original maximum power for the next 15 years which corresponds to the maximum of 1% or 0.67% linear annual degradation as a worst case scenario.

Although it has been observed in different studies that the degradation rate is higher at the beginning of the exposure (initial degradation), and then stabilizes at a lower level, an assumption of linear annual degradation rate might be the first approximation for the payback time of the investment costs.

Based on the field experiments and experience with c-Si technology, a degradation rate smaller than 0.7% should be taken into consideration, but for different types of thin film modules the degradation mechanisms are not so well understood. In order to avoid unfair technology benchmark a warranty value of degradation, given by the manufacturers, is used in the calculation presented in Section 5.4.

6. 2 Local climate

In Fig. 27 and Tab. 11, two types of monthly-averaged air temperature are shown:

- ***diurnal*** represents 24-hour (full day) average, see the black line in the graph. For diurnal air temperature, the vertical bars show variability of monthly averages (thick vertical line with horizontal tick marks) and variability of daily averages (thin vertical line with horizontal tick marks).

- ***daytime*** is a temperature average calculated only for a period of daylight (from sunrise to sunset), see the blue line in the graph. The variability represents 80% occurrence (average ±40%) for each month over the period from 1991 to 2008. It is calculated as ±1.28155 * standard deviation assuming normal distribution of values. The remaining 20% of values represent either minimum or maximum extremes that have occurred within the considered period of18 years.

Figure 27: Daytime and diurnal air temperature – monthly averages (^{0}C)

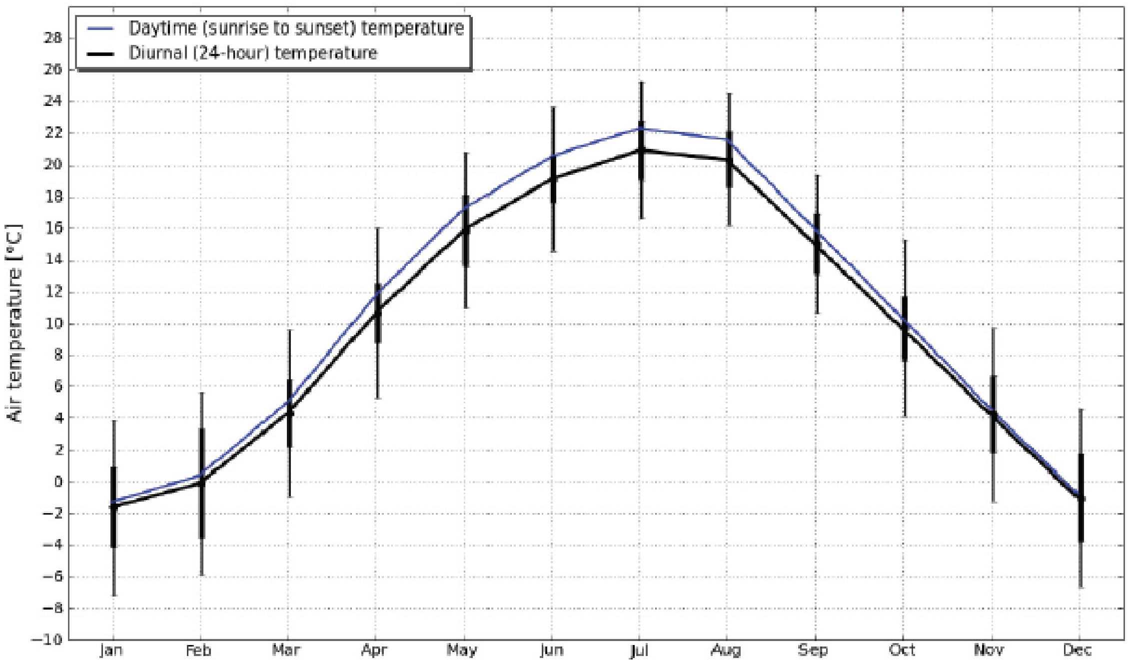


Table 11: Daytime and diurnal air temperature – monthly averages (^{0}C)

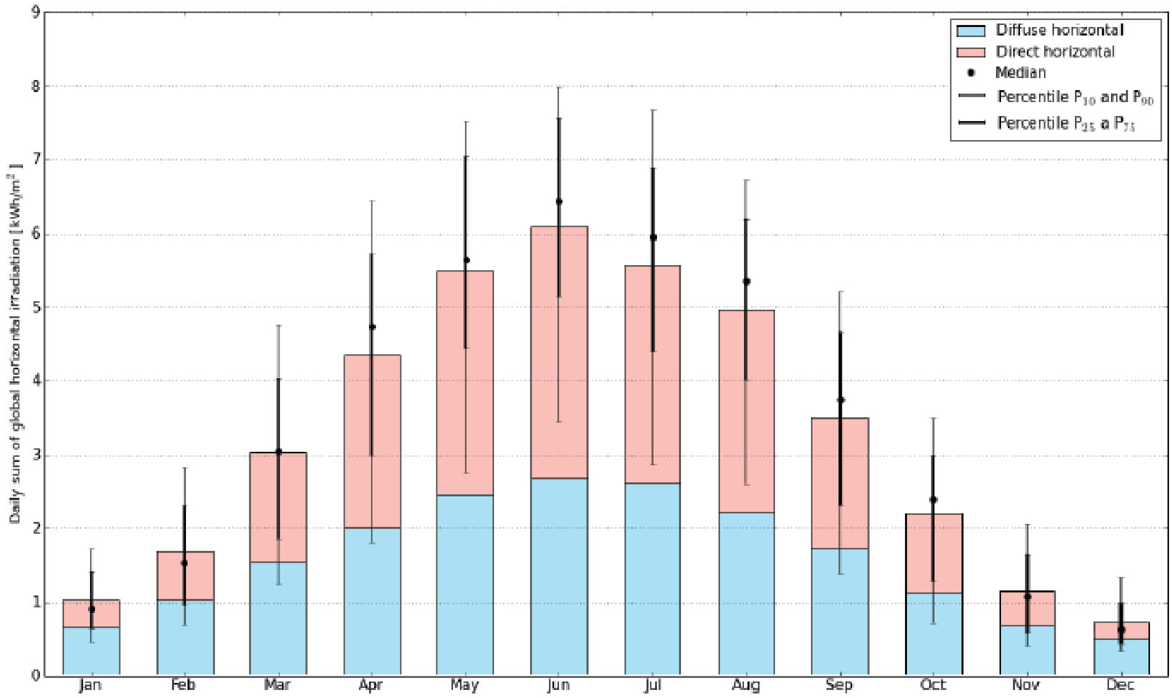
	Daytime average [°C]	Diurnal (24-hour) temperature [°C]		
		Average	Variability of monthly averages	Variability of daily averages
Jan	-1.3	-1.7	-4.2 to 0.9	-7.2 to 3.9
Feb	0.4	-0.1	-3.6 to 3.3	-5.9 to 5.7
Mar	5.0	4.3	2.1 to 6.4	-1.0 to 9.6
Apr	11.8	10.6	8.8 to 12.5	5.3 to 16.0
May	17.2	15.9	13.6 to 18.1	10.9 to 20.8
Jun	20.5	19.1	17.6 to 20.6	14.6 to 23.6
Jul	22.3	20.9	19.0 to 22.8	16.6 to 25.3
Aug	21.6	20.3	18.6 to 22.1	16.1 to 24.5
Sep	16.0	15.0	13.1 to 16.9	10.6 to 19.4
Oct	10.3	9.7	7.6 to 11.7	4.1 to 15.3
Nov	4.6	4.2	1.8 to 6.6	-1.3 to 9.7
Dec	-0.8	-1.1	-3.9 to 1.7	-6.7 to 4.5
Year	**10.6**	**9.8**		

Global horizontal irradiation (*Gh*) – solar radiation reference

Fig. 28 and Tab. 12 show for each month daily sums of global horizontal irradiation. In Fig. 28 the direct and diffuse components are also shown. The average daily sums are complemented by variability indicators: median, and 10th, 25th, 75th, and 90th percentiles

(P10, P25, P75, and P90 respectively). The percentiles P10 and P90 show 80% range of occurrence of daily values within a month or year (column P90 – P10), while percentiles P25 and P75 show 50% range of occurrence (column P75 – P25). The **percentile P90** indicates a value of daily sum of global horizontal irradiation which is exceeded for 90% of days within the particular month (or year). In analogy, the similar interpretation applies to P10, P25, and P75.

Figure 28: Global horizontal irradiation – monthly values



The **interannual variability** is calculated from standard deviation of Gh over ten years, considering, in the long-term, the normal distribution of monthly and yearly sums. The values in Tab. 12 represent interannual variability at 80% probability which is here calculated as ±1.28155 * standard deviation). The monthly values of interannual variability indicate year-by-year instability for each month in the studied period. The yearly values give an idea of weather fluctuation when comparing yearly Gh daily sums.

The interannual variability of Gh yearly sums expressed by 80% probability has the following statistical interpretation: it is expected that for about 80% of years the yearly sum will deviate from the long-term average (1212 kWh/m2) in the range of less than ±5.0%, i.e. within 1151 to 1273 kWh/m2. In other words, it is statistically expected that with 90% probability P(90) the yearly sum of *Gh* will exceed 1151 kWh/m2, and with 10% probability P(10) the yearly *Gh* will exceed 1273 kWh/m2. As can be seen in Tab. 10, monthly sums in a particular year may deviate, with 80% probability, from the long-term average values in the range of ±6.1% to ±22.7%.

Table 12: Global horizontal irradiation –monthly values

	Daily sum [kWh/m²]					Monthly sum		
	Average		Variability					
	Global	Diffuse	Median	P_{75} - P_{25}	P_{90} - P_{10}	Average [kWh/m²]	Monthly share [%]	Interannual variability [%]
Jan	1.02	0.65	0.91	0.64 – 1.41	0.46 – 1.73	32	2.6	6.1
Feb	1.69	1.02	1.54	0.96 – 2.31	0.69 – 2.82	48	3.9	22.7
Mar	3.03	1.53	3.05	1.86 – 4.02	1.24 – 4.75	94	7.7	15.0
Apr	4.34	2.00	4.72	2.99 – 5.72	1.80 – 6.44	130	10.8	14.6
May	5.48	2.46	5.64	4.43 – 7.04	2.75 – 7.52	170	14.0	10.1
Jun	6.08	2.66	6.43	5.15 – 7.55	3.44 – 7.99	183	15.1	7.5
Jul	5.56	2.60	5.95	4.41 – 6.89	2.86 – 7.67	173	14.2	11.4
Aug	4.97	2.21	5.35	4.01 – 6.19	2.59 – 6.72	154	12.7	14.0
Sep	3.50	1.73	3.74	2.31 – 4.67	1.38 – 5.21	105	8.7	20.0
Oct	2.19	1.13	2.39	1.27 – 2.99	0.71 – 3.49	67	5.6	18.0
Nov	1.15	0.69	1.08	0.58 – 1.65	0.40 – 2.05	34	2.8	14.6
Dec	0.73	0.51	0.62	0.44 – 0.99	0.33 – 1.33	23	1.9	14.4
YEAR	**3.32**	**1.60**	**2.85**	**1.24 - 5.22**	**0.63 - 6.70**	**1212**	**100.0**	**5.0**

Tab. 12 shows in addition also the share of monthly sums relative to the yearly sum of *Gh* – in four summer months (May, June, July, and August), more than 56% of yearly solar radiation is received by the horizontal surface.

Table 13: Uncertainty of the estimate of long-term yearly average of global horizontal irradiation and comparison of the combined SolarGIS and Satel-light estimate used in this report to other three data sources

Data source	Gh (kWh/m²)
PVGIS	1146
Meteonorm	1214
NASA SSE	1146
Satellight	1183
SolarGIS	1241
Overall average	**1186**
P(90) uncertainty	**4.5%**

Global horizontal irradiation used in this report (calculated from SolarGIS and Satel-Light data) was compared to three other data sources with different temporal and spatial resolution, and time coverage (Tab. 13). This comparison shows that the uncertainty of the estimate of long-term average of yearly sum of global horizontal irradiation for this site at P(90) level is about 4.5%.

6.3 Electricity production by the power plant

The values in Fig. 29, 30 and Tab. 14, 15 show global in-plane irradiation received by PV modules. In addition to global irradiation, also average daily sums of direct and diffuse components are shown. The monthly averages of *Gi* are complemented by median, and 10th, 25th, 75th, and 90th percentiles (P10, P25, P75, and P90 respectively).

The percentiles P10 and P90 show 80% range of occurrence of daily values within a month or year (column P90 – P10), while percentiles P25 and P75 show 50% range of occurrence (column P75 – P25). The percentile P90 indicates a value of daily sum of global horizontal irradiation which is exceeded for 90% of days within the particular month (or year). In analogy, the similar interpretation applies to P10, P25, and P75. Interannual variability is described by P(90) values and it shows year-by-year weather fluctuation compared to long-term averages.

Figure 29: Global in-plane irradiation received by optimally inclined polycrystalline modules

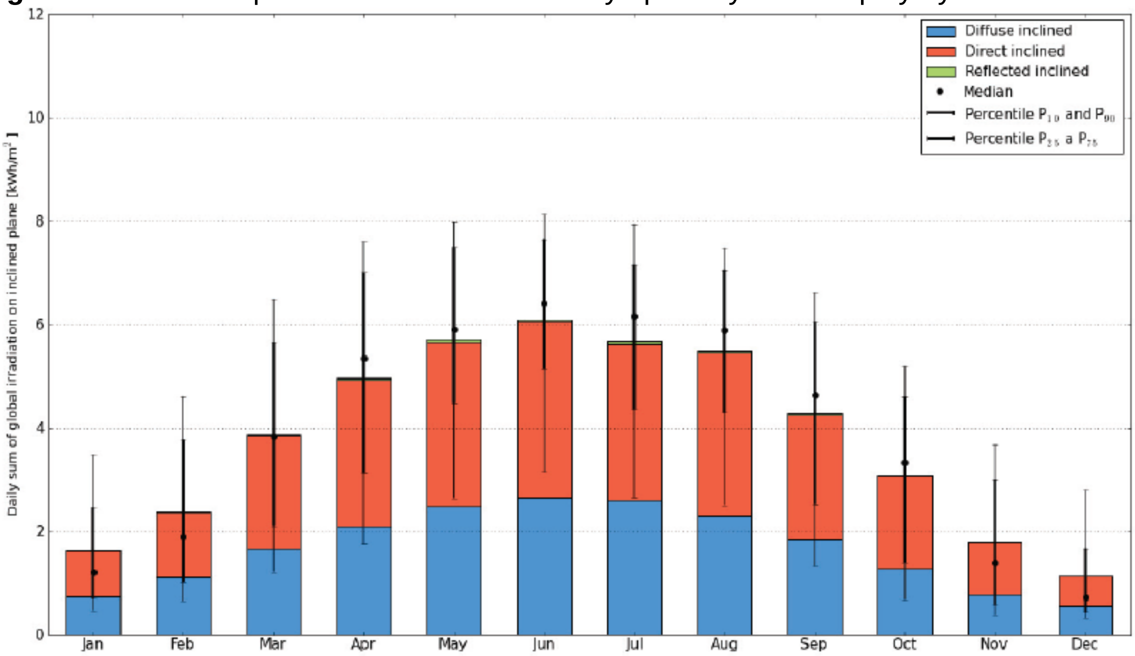


Fig. 29 and Tab. 14 present the values of global irradiation received by PV modules inclined southwards at an **angle of 30°**, the inclination chosen for **Variant 1** with **c-Si modules**.

Table 14: Global in-plane irradiation received by polycrystalline modules mounted on a fixed system

	Daily sum [kWh/m²]						Monthly sum		
	Average			Variability			Average [kWh/m²]	Monthly share [%]	Interannual variability [%]
	Global	Diffuse	Reflected	Median	P_{75} - P_{25}	P_{90} - P_{10}			
Jan	1.63	0.75	0.01	1.20	0.70 - 2.45	0.47 - 3.48	50	3.6	10.7
Feb	2.39	1.13	0.01	1.91	1.02 - 3.77	0.65 - 4.61	68	4.8	32.0
Mar	3.88	1.66	0.03	3.84	2.10 - 5.66	1.22 - 6.50	120	8.5	19.2
Apr	4.96	2.10	0.04	5.34	3.14 - 7.01	1.76 - 7.60	149	10.6	16.8
May	5.71	2.49	0.05	5.90	4.49 - 7.51	2.64 - 7.98	177	12.6	11.1
Jun	6.10	2.66	0.05	6.40	5.14 - 7.65	3.15 - 8.13	183	13.0	7.8
Jul	5.68	2.61	0.05	6.16	4.36 - 7.16	2.65 - 7.94	176	12.5	12.2
Aug	5.49	2.31	0.04	5.88	4.30 - 7.06	2.50 - 7.49	170	12.1	15.3
Sep	4.28	1.86	0.03	4.63	2.52 - 6.05	1.33 - 6.63	128	9.1	23.1
Oct	3.09	1.27	0.02	3.33	1.40 - 4.60	0.68 - 5.21	95	6.8	22.3
Nov	1.80	0.78	0.01	1.40	0.58 - 3.00	0.38 - 3.67	54	3.8	22.6
Dec	1.15	0.57	0.01	0.73	0.44 - 1.67	0.32 - 2.81	36	2.5	26.5
YEAR	**3.85**	**1.68**	**0.03**	**3.66**	**1.56 - 5.97**	**0.66 - 7.36**	**1406**	**100.0**	**6.1**

Interannual variability of the yearly sum of global in-plane irradiation for 30° is ±6.1%. Uncertainty of the estimate of the long-term average of yearly sum of global irradiation on the surface inclined at 30° at P(90) level is 5.1%. Interannual variability of the yearly sum of global in-plane irradiation for 25° is ±5.9%. Uncertainty of the estimate of the long-term average of yearly sum of global irradiation on the surface inclined at 25° at P(90) level is 4.9%.

Figure 30: Global in-plane irradiation received by c-Si PV modules mounted on single-axis horizontal tracker (monthly values)

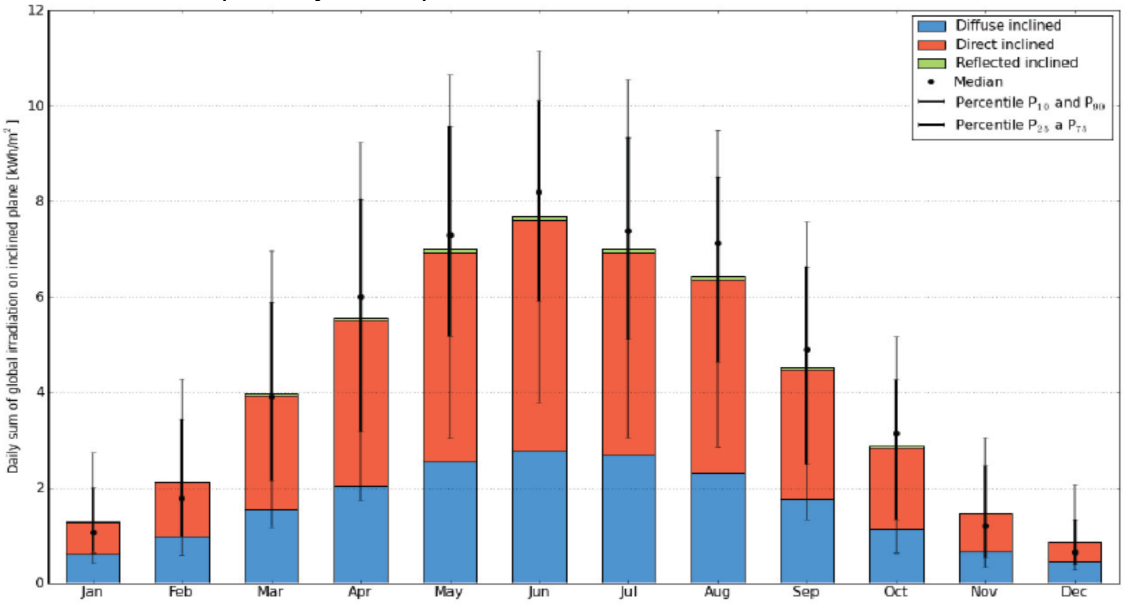


Fig. 30 and Tab. 15 present the values of global irradiation received by PV modules installed on single-axis tracker with North-South horizontal axis - **Variant 2** with **c-Si modules**.

Table 15: Global in-plane irradiation received by polycrystalline modules mounted on a single-axis horizontal tracker

	Daily sum [kWh/m^2]						Monthly sum		
	Average			Variability			Average [kWh/m^2]	Monthly share [%]	Interannual variability [%]
	Global	Diffuse	Reflected	Median	P_{75} - P_{25}	P_{90} - P_{10}			
Jan	1.36	0.62	0.02	1.08	0.64 - 2.01	0.43 - 2.73	42	2.6	9.2
Feb	2.21	0.98	0.03	1.78	0.97 - 3.44	0.60 - 4.28	63	3.9	32.5
Mar	4.06	1.54	0.04	3.90	2.16 - 5.88	1.18 - 6.96	126	8.0	18.8
Apr	5.67	2.05	0.06	6.01	3.18 - 8.05	1.74 - 9.24	170	10.7	19.0
May	7.13	2.55	0.07	7.30	5.18 - 9.58	3.03 - 10.65	221	13.9	12.8
Jun	7.83	2.78	0.07	8.19	5.91 - 10.12	3.79 - 11.15	235	14.8	9.5
Jul	7.13	2.68	0.07	7.38	5.11 - 9.33	3.04 - 10.55	221	14.0	13.3
Aug	6.55	2.31	0.06	7.11	4.63 - 8.52	2.87 - 9.48	203	12.8	17.8
Sep	4.63	1.76	0.05	4.89	2.50 - 6.64	1.35 - 7.58	139	8.8	24.4
Oct	2.96	1.13	0.03	3.14	1.35 - 4.27	0.63 - 5.17	91	5.7	22.1
Nov	1.53	0.66	0.02	1.21	0.54 - 2.45	0.34 - 3.04	46	2.9	21.7
Dec	0.91	0.46	0.01	0.65	0.39 - 1.35	0.28 - 2.08	28	1.8	24.5
YEAR	**4.34**	**1.63**	**0.05**	**3.67**	**1.42 - 6.92**	**0.61 - 9.20**	**1584**	**100.0**	**6.0**

Interannual variability of the yearly sum of global in-plane irradiation for a tracker is ±6.0%. Uncertainty of the estimate of the long-term average of yearly sum of global irradiation on the surface of the modules mounted on a tracker at P(90) level is 6.5%.

Estimation of system losses and performance ratio

In Tab. 16 and 17 the conversion steps and system losses are outlined for 1 kWp of installed nominal power for variants 1 and 2.

Initially, the 100% conversion efficiency at STC conditions is assumed, starting with production of 1406 kWh/kWp for Variant 1 and 1585 kWh/kWp for Variant 2. In each step, the conversion losses and decrease of efficiency are simulated.

Table 16: Conversion stages, energy losses and performance ration at the level of the PV system and its components for the fixed system

Energy conversion stage	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	[%]	Uncertainty [%]	Performance ratio Partial [%]	Cumul. [%]
Global irradiation - inclined plane (input)	1406			5.1	100.0	100.0
Global irradiation (reduced by terrain shadowing)	1406	-0	-0.0	0.1	100.0	100.0
Global irradiation (reduced by angular reflectivity)	1362	-43	-3.1	0.3	96.9	96.9
Conversion to DC in the modules (effect of irradiation and module temperature)	1267	-95	-7.0	2.0	93.0	90.1
Other losses (DC cabling, mismatch, dirt, snow, self-shadowing)	1178	-89	-7.0	2.0	93.0	83.8
Inverters (DC/AC conversion)	1150	-28	-2.4	0.5	97.6	81.8
Transformer and AC cabling losses	1139	-12	-1.0	0.5	99.0	81.0
Availability	1133	-6	-0.5	0.5	99.5	80.6
Total system performance	**1133**	**-273**	-	**5.9**	-	**80.6**

Table 17: Conversion stages, energy losses and performance ration at the level of the PV system and its components for the tracking system

Energy conversion stage	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	[%]	Uncertainty [%]	Performance ratio Partial [%]	Cumul. [%]
Global irradiation - inclined plane (input)	1585			6.5	100.0	100.0
Global irradiation (reduced by terrain shadowing)	1584	-1	-0.0	0.1	100.0	100.0
Global irradiation (reduced by angular reflectivity)	1549	-35	-2.2	0.3	97.8	97.7
Conversion to DC in the modules (effect of irradiation and module temperature)	1448	-101	-6.5	2.0	93.5	91.3
Other losses (DC cabling, mismatch, dirt, snow, self-shadowing)	1346	-101	-7.0	2.0	93.0	84.9
Inverters (DC/AC conversion)	1314	-32	-2.4	0.5	97.6	82.9
Transformer and AC cabling losses	1301	-13	-1.0	0.5	99.0	82.1
Availability	1294	-7	0.5	0.5	99.5	81.7
Total system performance	**1294**	**-291**	-	**7.1**	-	**81.7**

The other losses (DC losses on the modules and cables) are considered to be 7.0%, as explained in Section 3.2. However, this value will very depend on a final design of the power plant and a difference in the range of ±1% or more can be expected. In each conversion step the uncertainty is considered. The resulting combined uncertainty of ±5.9% (c-Si modules) and ±7.1% (c-Si modules on the tracker) is calculated using error propagation formula.

PV power production in the first year

The values shown in Fig. 31, Fig. 32 and in Tab. 18 and 19 represent expected monthly solar electricity production from a PV system for Variants 1 and 2 in kilowatt-hours per 1 kWp. The monthly averages of daily sums of PV electricity are complemented by median and 10th, 25th, 75th, and 90th percentiles (P10, P25, P75, and P90 respectively).

Figure 31: Daily electricity production from 1 kWp for each month for the fixed system

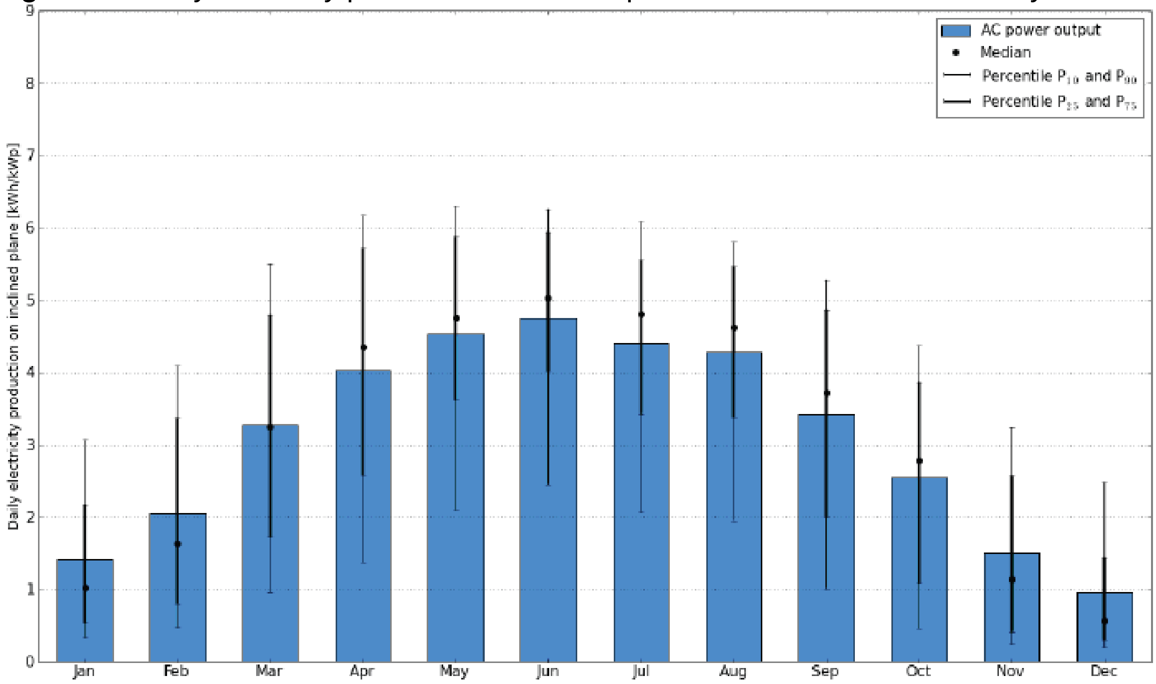


Table 18: PV electricity production from 1 kWp – monthly values for fixed system

	Daily sum [kWh/kWp]				Monthly sum		
		Variability					
	Average	Median	P_{75} - P_{25}	P_{90} - P_{10}	Average [kWh/kWp]	Monthly share [%]	Minimum*
Jan	1.41	1.03	0.54 – 2.17	0.33 – 3.07	44	3.8	39
Feb	2.05	1.64	0.80 – 3.37	0.47 – 4.10	58	5.1	39
Mar	3.28	3.25	1.72 – 4.80	0.96 – 5.50	102	9.0	81
Apr	4.03	4.35	2.58 – 5.72	1.37 – 6.17	121	10.7	101
May	4.53	4.76	3.62 – 5.88	2.10 – 6.30	140	12.4	126
Jun	4.76	5.03	4.02 – 5.95	2.45 – 6.26	143	12.6	132
Jul	4.40	4.81	3.43 – 5.56	2.06 – 6.09	136	12.0	121
Aug	4.28	4.63	3.38 – 5.47	1.96 – 5.81	133	11.7	113
Sep	3.43	3.72	2.00 – 4.86	1.02 – 5.28	103	9.1	79
Oct	2.55	2.78	1.09 – 3.87	0.46 – 4.37	78	6.9	60
Nov	1.51	1.15	0.42 – 2.58	0.24 – 3.24	45	4.0	34
Dec	0.96	0.56	0.31 – 1.44	0.20 – 2.49	30	2.6	21
YEAR	**3.11**	**3.10**	**1.28 - 4.79**	**0.49 - 5.78**	**1133**	**100.0**	**1066**

Figure 32: PV electricity production from 1 kWp for each month for tracking system

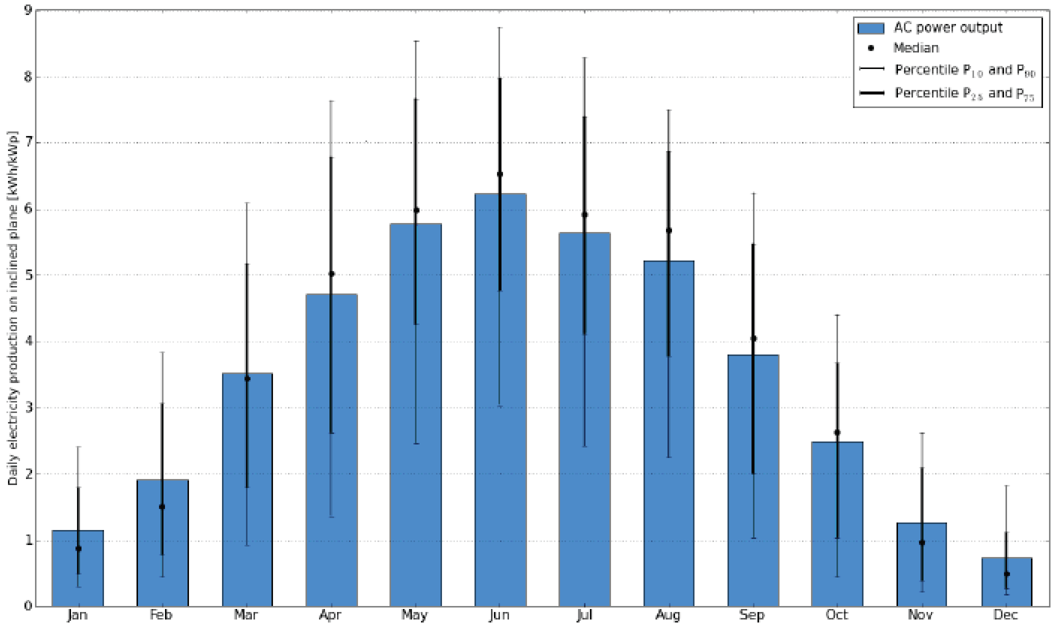


Table 19: PV electricity production from 1 kWp – monthly values for tracking system

	Daily sum [kWh/kWp]				Monthly sum		
		Variability					
	Average	Median	P_{75} - P_{25}	P_{90} - P_{10}	Average [kWh/kWp]	Monthly share [%]	Minimum*
Jan	1.15	0.88	0.49 – 1.79	0.29 – 2.41	36	2.8	32
Feb	1.91	1.51	0.78 – 3.05	0.43 – 3.83	54	4.2	36
Mar	3.52	3.44	1.79 – 5.17	0.93 – 6.08	109	8.4	88
Apr	4.72	5.02	2.62 – 6.78	1.37 – 7.64	141	10.9	115
May	5.77	5.97	4.26 – 7.67	2.46 – 8.53	179	13.8	157
Jun	6.23	6.53	4.76 – 7.97	3.04 – 8.74	187	14.4	169
Jul	5.64	5.92	4.12 – 7.39	2.42 – 8.28	175	13.5	153
Aug	5.23	5.69	3.78 – 6.87	2.24 – 7.50	162	12.5	133
Sep	3.80	4.06	2.00 – 5.47	1.04 – 6.25	114	8.8	86
Oct	2.48	2.62	1.04 – 3.67	0.43 – 4.41	76	5.9	59
Nov	1.27	0.97	0.38 – 2.10	0.21 – 2.62	38	2.9	29
Dec	0.74	0.49	0.27 – 1.12	0.18 – 1.83	23	1.8	17
YEAR	**3.55**	**3.13**	**1.17 – 5.69**	**0.44 – 7.42**	**1294**	**100.0**	**1221**

Outline of PV electricity production from the PV power plant over 15 years

The estimated average specific electricity output is 1133 kWh/kWp and 1294 kWh/kWp for variants 1 and 2. For the planned 3999 kWp PV power plant this represents an average yield of 4531 and 5175 MWh per year for each selected variant respectively under a theoretical assumption that no degradation occurs with PV module conversion efficiency.

The indicative prediction of energy production for the next 15 years can be based only on a simplified assumption of linear degradation (ageing) of nominal power of PV modules. For calculating the expected yield of PV power plant the worst case scenario of degradation rate guaranteed by the manufacturer is assumed - maximum degradation equal to 10% for the first 10 years of operation and total degradation of 20% after 25 years.

In other words the manufacturer warranty can be expressed as expected steeper loss of power during first 10 years (linear degradation of 1% per year) and flatter degradation after 10 years (about 0.67% per year).

Identical assumptions are taken into account for the 2 variants. Results of simplified calculation are presented in Tabs. 20 and 21. Assuming conservative scenario values of the performance degradation (ageing) of the modules provided in the warranty over 15 years long-term average annual yield of 4184 and 4778 MWh of electricity is estimated for Variants 1 and 2.

Table 20: Prediction of the yearly electricity production from the 3999 kWp optimally inclined fixed PV system during the lifecycle of 15 years

No.	End of year	Specific yield [kWh/kWp]	Expected yield [MWh]	Performance ratio [%]	Degradation rate [%]	Total degrad. [%]
1	2011	1122	4485.6	79.8	1.00	99.0%
2	2012	1110	4440.2	79.0	1.00	
3	2013	1099	4394.9	78.2	1.00	
4	2014	1088	4349.6	77.4	1.00	
5	**2015**	**1076**	**4304.3**	**76.6**	**1.00**	**95.00%**
6	2016	1065	4259.0	75.8	1.00	
7	2017	1054	4213.7	75.0	1.00	
8	2018	1042	4168.4	74.2	1.00	
9	2019	1031	4123.1	73.3	1.00	
10	**2020**	**1020**	**4077.8**	**72.5**	**1.00**	**90.00%**
11	2021	1012	4047.6	72.0	0.67	
12	2022	1005	4017.4	71.5	0.67	
13	2023	997	3987.2	70.9	0.67	
14	2024	989	3957.0	70.4	0.67	
15	**2025**	**982**	**3926.8**	**69.9**	**0.67**	**86.67%**
	Total	**15692**	**62753.0**			
	Average	1046	4183.5	74.4		

Table 21: Prediction of the yearly electricity production from the 3999 kWp horizontal single-axis tracking PV system during the lifecycle of 15 years

No.	End of year	Specific yield [kWh/kWp]	Expected yield [MWh]	Performance ratio [%]	Degradation rate [%]	Total degrad. [%]
1	2011	1281	5123.0	80.9	1.00	99.0%
2	2012	1268	5071.2	80.1	1.00	
3	2013	1255	5019.5	79.2	1.00	
4	2014	1242	4967.7	78.4	1.00	
5	**2015**	**1229**	**4916.0**	**77.6**	**1.00**	**95.00%**
6	2016	1216	4864.2	76.8	1.00	
7	2017	1203	4812.5	76.0	1.00	
8	2018	1190	4760.7	75.2	1.00	
9	2019	1178	4709.0	74.3	1.00	
10	**2020**	**1165**	**4657.2**	**73.5**	**1.00**	**90.00%**
11	2021	1156	4622.7	73.0	0.67	
12	2022	1147	4588.2	72.4	0.67	
13	2023	1139	4553.7	71.9	0.67	
14	2024	1130	4519.2	71.4	0.67	
15	**2025**	**1121**	**4484.7**	**70.8**	**0.67**	**86.67%**
	Total	**17920**	**71669.0**			
	Average	1194	4777.9	75.4		

Row spacing

The loss in performance at partially shaded c-Si photovoltaic modules in the rows can be nearly proportional to the loss at the most shaded cell for PV cells connected in series within the module. As a consequence the cells near the ground can reduce the performance of the whole module considerably when shaded. The module shading can be partially balanced by bypass diodes incorporated within module structure and topology of modules interconnections. The losses of electrical energy in racks with c-Si modules may come closer to the value of maximum losses.

Monitoring

The behaviour of all components of the PV power plant, as well as natural and accelerated changes in their performance may only be better understood by implementation of the active monitoring and automatic performance check. This service is based on the numerical analysis of the monitored production data with simulations of the expected (reference) performance based on real-time satellite and meteorological observations. It enables fast identification of failures, and supports operation, control, and maintenance. Re-analysis of both monitored and simulated data time series over longer period (several years) provides means for improved understanding of the degradation effects and in-depth statistical appraisal of the technology performance.

6.4 Electricity production by the power plant – minimal and maximal for SR

In order to make the comparison of the two systems as objective as possible, it was necessary to compare their performance also under the best and worst irradiation conditions in Slovakia.

For this purpose, municipality Becherov in the northern part of Slovakia and municipality of Komarno in the southern part of Slovakia were chosen for this comparison. Based on analysis of these locations, the following data have been acquired (detailed calculations of these data can be found among the attachments).

Value	Komarno	Becherov
Energy output – fixed system	1165 kWh/kWp	961 kWh/kWp
Energy output – 1axis system	1487 kWh/kWp	1196 kWh/kWp

These data will subsequently be used in the economical calculations in the following chapter.

7. Economical comparison of the studied systems

This is the core chapter of this master thesis and will compare the two analysed systems in terms of their economical performance. The economical performance of the two systems will be calculated in a detailed cash-flow model, as the decisive criterions, internal rate of return, net present value and simple payback period will be used, which are the most frequently used measures for evaluation of investments. All economical calculations will be based upon real data gathered from financial institutions, module suppliers and EPC contractors.

Besides comparison of economical performance of both systems in the location “Buzitka”, the two systems will also be compared in the area with best and worst irradiation area in Slovakia.

Before the inputs for calculations will be summarized, it is necessary to explain meaning of the investment criterions that will be used for comparison of the 2 systems.

Simple payback period

“Payback period in business and economics refers to the period of time required for the return on an investment to "repay" the sum of the original investment. It intuitively measures how long something takes to "pay for itself." All else being equal, shorter payback periods are preferable to longer payback periods. Payback period is widely used due to its ease of use despite recognized limitations, described below.”[19]

Net present value

“NPV compares the value of money today to the value of that same money in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should probably be rejected because cash flows will also be negative.”[20]

Internal rate of return

“The rate of return that would make the present value of future cash flows plus the final market value of an investment or business opportunity equal the current market price of the investment or opportunity. The internal rate of return is an important calculation used frequently to determine if a given investment is worthwhile. An investment is generally

[19] http://en.wikipedia.org/wiki/Payback_period
[20] http://www.investopedia.com/terms/n/npv.asp

considered worthwhile if the internal rate of return is greater than the return of an average similar investment opportunity, or if it is greater than the cost of capital of the opportunity."[21]

7.1 Cash-flow inputs and assumptions

Table 22: Cash-flow inputs and assumptions for fixed and tracking system[22]

Parameter	Unit	Fixed system	Tracking system
		Value	
BASIC INPUTS			
Installed capacity	kW	3999	3999
Energy yield adjusted (plot in Buzitka)	kWh/kWp	1133	1294
Energy yield adjusted (plot in Becherov)	kWh/kWp	961	1196
Energy yield adjusted (plot in Komárno)	kWh/kWp	1165	1487
Annual production (plot in Buzitka)	kWh/year	4 530 867	5 174 706
Annual production (plot in Becherov)	kWh/year	3 843 039	4 782 804
Annual production (plot in Komárno)	kWh/year	4 658 835	5 946 513
Annual production adjustment (first 10 years)	%/year	-1	-1
Annual production adjustment (10 - 25 years)	%/year	**- 0,67**	**- 0,67**
Total Investment costs	€	**11 463 043**	**12 547 708**
Required plot size	m2	80 000	104 000
Land lease	€/m2	0,3	0,3
Type of the PV panels	-	polycrystalline	polycrystalline
Substructure / Carrying system	-	optimally fixed	single-axis tracking
Current feed-in tariff	€/kWh	0,425	0,425
Feed-in tariff after 15 years - prediction	€/kWh	0,1781	0,1781
Duration of the feed-in tariff	years	15	15
Feed-in Tariff annual adjustment	%/year	0	0
Equity requirement	%	20,00%	20,00%
Bank loan maturity (incl. grace period)	years	13	13
Interest rate on bank loan	%/pa	5,9	5,9
EURIBOR fixed for 10 years	%/pa	2,9	2,9
Bank margin	%/pa	3	3
Depreciation over 12 years	€/year	955 253,6	1 045 625,7
OPERATION & MAINTENANCE COST			
Land lease	€/year	24 000	31 200
Insurance	€/year	22 006	23 495
Security costs	€/year	10 000	10 000
Maintenance	€/year	77 022	117 477

[21] http://www.investorwords.com/2564/Internal_Rate_of_Return.html
[22] Energy output calculations for the worst and best irradiation area in Slovakia can be found among attachements

Administrative costs	€/year	25 000	25 000
Own energy consumption	€/year	5 000	10 000
Annual payment to municipality	€/year	13 197	13 197
Annual O&M costs adjustment	%/year	3	3
ENGINEERING, PROCUREMENT & CONSTRUCTION			
PV modules - TUV, IEC61215 certification	€	5 998 500	5 998 500
Substructure / tracing	€	1 199 700	1 799 550
Inverters	€	799 800	799 800
Roads, construction work and baseplates	€	119 970	119 970
Fencing and security measures	€	239 940	319 920
Assembly	€	1 399 650	1 799 550
Mid-kV line due to connection to the grid	€	19 995	19 995
FINANCIAL COSTS			
Bank Fee	€	69 972	74 707
Due Diligence	€	14 916	14 916
OTHER COSTS			
Licence from the ÚRSO	€	1 000	1 000
Project acquisition costs	€	1 599 600	1 599 600

Based on these inputs, a cash flow calculations have been performed, their results are presented in the below tables (some values are only shown for the first year, the full cash flow calculations are among attachments). First table presents the results of the cash-flow calculation for the location "Buzitka", the 2 subsequent tables present results for the minimal and maximal irradiation value in Slovakia.

Table 23: Results of the cash-flow calculation for the location "Buzitka"

Values	Fixed system		Tracking system	
Year	2 010	2 011	2 010	2 011
Operational Income		**1 925 618**		**2 199 250**
TOTAL OPERATION COSTS (€)		180 364		239 967
EBITDA		1 745 254		1 959 283
Depreciation		955 254		1 045 626
EBIT		790 001		913 658
Interest expenses		541 056		592 242
Gross profit		248 945		321 415
Tax		52 278		67 497
Net profit		196 667		253 918
Principal repayment		488 795		535 038
EBITDA – Tax		1 692 976		1 891 786
CF **BEFORE** repayment of instalments	-2 292 609	1 151 920	-2 509 502	1 299 544
CF **AFTER** repayment of instalments	-2 292 609	663 125	-2 509 502	764 506
Cumulated Cash Flow	-2 292 609	-1 629 483	-2 509 502	-1 744 996
IRR	**25,65%**		**26,87%**	
NPV	**€ 3 326 540**		**€ 3 779 249**	

SPP Equity	3,63		3,43	

Table 24: Results of the cash-flow calculation for the location Becherov

Values	Fixed system		Tracking system	
Year	2 010	2 011	2 010	2 011
Operational Income		**1 633 292**		**2 032 692**
TOTAL OPERATION COSTS (€)		180 364		239 967
EBITDA		1 452 927		1 792 725
Depreciation		955 254		1 045 626
EBIT		497 674		747 099
Interest expenses		541 056		592 242
Gross profit		-43 382		154 857
Tax		0		32 520
Net profit		-43 382		122 337
Principal repayment		488 795		535 038
EBITDA – Tax		1 452 927		1 760 205
CF **BEFORE** repayment of instalments	-2 292 609	911 872	-2 509 502	1 167 963
CF **AFTER** repayment of instalments	-2 292 609	423 077	-2 509 502	632 925
Cumulated Cash Flow	-2 292 609	-1 869 532	-2 509 502	-1 876 577
IRR	**15,14%**		**21,36%**	
NPV	**€ 1 375 020**		**€ 2 677 418**	
SPP Equity	**5,95**		**4,20**	

Table 25: Results of the cash-flow calculation for the location Komárno

Values	Fixed system		Tracking system	
Year	2 010	2 011	2 010	2 011
Operational Income		**1 980 005**		**2 527 268**
TOTAL OPERATION COSTS (€)		180 364		239 967
EBITDA		1 799 641		2 287 301
Depreciation		955 254		1 045 626
EBIT		844 387		1 241 676
Interest expenses		541 056		592 242
Gross profit		303 332		649 433
Tax		63 700		136 381
Net profit		239 632		513 052
Principal repayment		488 795		535 038
EBITDA – Tax		1 735 941		2 150 920
CF **BEFORE** repayment of instalments	-2 292 609	1 194 886	-2 509 502	1 558 678
CF **AFTER** repayment of instalments	-2 292 609	706 091	-2 509 502	1 023 640
Cumulated Cash Flow	-2 292 609	-1 586 518	-2 509 502	-1 485 861
IRR	**27,60%**		**37,67%**	
NPV	**€ 3 686 321**		**€ 5 949 181**	
SPP Equity	**3,38**		**2,51**	

Upon the last three indicators in each table, the two systems will be, in the following chapter, analysed and compared, and recommendations and conclusions will be derived.

8. Results, recommendations and conclusions

This chapter will summarize the results of the analyses and comparisons performed in the previous chapters. It should give answers to the key questions raised at the beginning of this work and prove that the objective of this thesis has been achieved.

Moreover, outcome of this chapter should suit as a kind of advice for investors who consider investing into the photovoltaic industry in the Slovak republic.

The key questions raised at the beginning of this study were:

- **What are the main barriers hindering deployment of PV technology in Slovakia?**

Without any doubts, it can be said that there are indeed more barriers to the deployment of PV in Slovakia than support mechanisms. Most of them (the main ones) have been described within the previous chapters, thus only a list of them without further details will be provided here:

- Negative attitude of SEPS towards solar energy and its subsequent actions
- Negative attitude of the previous government towards RES and its subsequent actions
- Fossil sources industry lobby
- Speculative blocking of grid capacities
- Unwillingness of grid operators to integrate RES into the grid
- Still relatively high price of the PV technology
- Negative public perception of the PV sector

- **What policies should be employed by the government to improve utilization of PV technology?**

Based on the previous points, is it quite easy to identify policies that should be employed in order to improve the PV technology exploitation in Slovakia. Generally speaking, the most important measurement that needs to be taken is an actual revision and consolidation of the government's attitude towards the PV technology.

Nevertheless, this revision and consolidation shouldn't be performed within a group of government officers, a much wider and broader debate is necessary to take place, where also representatives of the PV sector, European Union, National Transmission System Operator, local grid operators, authorities and specialists in the energy field, environmentalists as well as sociologists should be able to present their opinion.

Subsequently and based on the outcome of such debate (outcome of which, the author is convinced, would lead to further support of the PV technology), the current legislation needs to be audited, to identify and amend the problematic pieces of legislation which are in contradiction with the proclaimed support of PV technology.

Furthermore, it is necessary to start closely monitoring activities of the local grid operators, to make sure that they obey the legislation and don't create any other obstacles via their internal policies. It would also be very helpful to make the process of reserving a grid capacity much more strict, to make sure only companies or individuals with real ability (professional, financial, etc.) to actually complete the intended project upon which the capacity gets blocked are able to reserve the capacity.

Last but not least, it is essential to invest into public promotion of the PV technology, to improve its currently negative and non-deserved reputation. Best way to do this would certainly lead through education as well as through governmental PV projects, e.g. roof of German parliament being covered with PV modules.

- **Is production of solar electricity in Slovakia through horizontal single-axis tracking system economically viable?**

Based on the NPV of project used as the case study in this thesis, but also on the NPV of similar project assumed in the worst and best irradiation area in Slovakia, as well as based on a simple comparison of the achieved IRR of the same project(s) with currently achievable bank deposits interest rates, the economical viability of the horizontal single-axis tracking system in Slovakia is absolutely obvious and actually represents a very attractive investment opportunity.

- **Is production of solar electricity in Slovakia through horizontal single-axis tracking system more attractive from the economical point of view than production through a fixed system?**

Considering the three main investment criterions (NPV, IRR, SPP) that were analysed and subsequently compared in course of this study, it is clear that from the economical point of view, production of solar electricity based on PV systems with horizontal single-axis tracking substructure is more attractive option than production of solar electricity based on PV systems with optimally inclined fixed substructure.

- **Is using of tracking photovoltaic systems instead of fixed systems in the conditions of Slovak republic is the right way how to increase the share of solar electricity, thus the share of RES, on the total energy mix of Slovakia?**

Answer to this question is not as simple and explicit as answer to the two previous questions. On one hand, using tracking PV systems instead of fixed systems indeed leads to increase of the production of the solar electricity, thus increase of the share of RES on the total energy mix of Slovakia.

However, if we consider the total installed capacity of all PV installations that are expected to be built in the near future, and subsequently count the potential additional solar electricity produced because of using tracking substructure instead of a fixed one (regardless weather all the installations would be built in the best or worst irradiation area of Slovakia), it is clear that the real contribution of this measure would be rather insignificant.

At the same time, if the installed capacity of Photovoltaics in Slovakia increases significantly in the future (which is the expected scenario throughout the world, once grid parity has been achieved), the contribution of tracking systems in terms of produced energy will be much more important and valued.

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[1] Adobe acrobat creator
[2] Microsoft Excel
[3] Microsoft Word
[4] PV SYST
[5] PV Planner

Websites

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[2] http://en.wikipedia.org/wiki/File:RayTracker_Utility_Scale_Solar_Tracker_Installation.JPG
[3] http://en.wikipedia.org/wiki/Payback_period
[4] http://en.wikipedia.org/wiki/Solar_cell
[5] http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm
[6] http://solardecathlon.cca.edu/wp-content/uploads/2008/03/gemini-house-2001.jpg
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[8] http://re.jrc.ec.europa.eu/pvgis/cmaps/eur.htm
[9] http://www.euribor-rates.eu/euribor-charts.asp
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[15] http://www.sepsas.sk/seps/en_ProfilZaklUdaje.asp?Kod=99
[16] http://www.smartgrids.eu
[17] http://www.solarfocus.com/images
[18] http://www.solarpowerfast.com/
[19] http://www.urso.gov.sk/en/about-us
[20] http://www.zive.sk/v-klucovci-spustili-novu-fotovoltaicku-elektraren/sc-4-a-287241/default.aspx

Interviews

[1] Inverview with Mr. Jacmenik – head of municipality Buzitka
[2I Interview with Mr. Krupanzsky – managing director of Raabvill (construction company)
[3] Interview with Mr. Ondrejkovic – technical manager of SSE (Slovak grid operator)
[4] Interview with Mr. Lehocky – credit manager of Unicredit bank
[5] Interview with Mr. Czienege – managing director of HiTech-Electro (electro-installation company)

Legal documents

[1] Stratégia energetickej bezpečnosti SR
[2I Zákon č. 276/2001 Z.z. o regulácii v sieťochých odvetviach
[3] Zákon č. 309/2009 Z. z. o podpore obnoviteľných zdrojov energie a vysoko účinnej kombinovanej výroby a o zmene a doplnení niektorých zákonov
[4] Zákon č. 656/2004 Z. z. o energetike a o zmene niektorých zákonov

Appendix

Appendix 1: Energy output calculation of 1-axis tracking system located Becherov

1. Site info

Site name: **Becherov, Prešovský kraj**
Slovenská republika

Coordinates: **49° 25' 10.26" N, 21° 18' 40.91" E**
Elevation a.s.l.: 409 m
Slope inclination: 4°
Slope azimuth: 141° (SE)

Annual global in-plane irradiation: **1471 kWh/m²**
Annual air temperature at 2 m: **8.2 °C**

2. PV system info

Installed power: **1.0 kWp**
Type of modules: crystalline silicon (c-Si)
Mounting system: **1-axis tracking, inclined axis**
Inclination: **35°**
Inverter Euro eff.: 97.5%
DC / AC losses: 5.5% / 1.5%
Availability: 99.0%

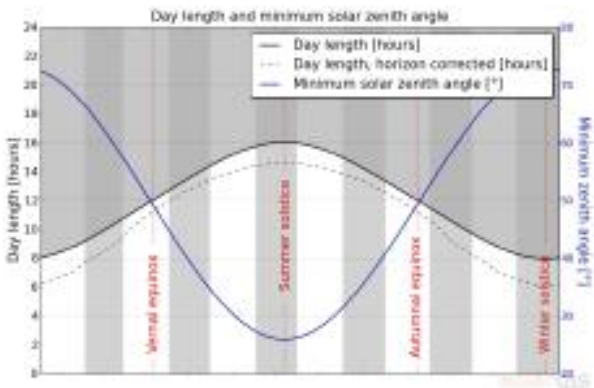
Annual average electricity production: **1196 kWh**
Average performance ratio: **79.9%**

Location on the map: http://solargis.info/imaps/#lat=49.419517&lon=21.311364

3. Geographic position

solargis.info © 2010 GeoModel, s.r.o.; Google Maps © 2010 Google

4. Terrain horizon and day length

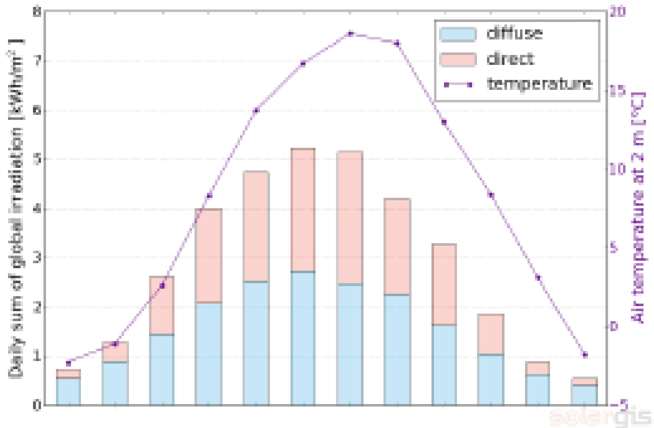


Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Red and blue labels show Local Clock Time in summer and winter, respectively.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	23	0.74	0.55	-2.3
Feb	36	1.29	0.89	-1.1
Mar	81	2.61	1.45	2.6
Apr	120	4.00	2.07	8.3
May	147	4.74	2.52	13.7
Jun	157	5.23	2.73	16.7
Jul	160	5.16	2.48	18.6
Aug	130	4.19	2.26	18.0
Sep	98	3.27	1.63	13.0
Oct	58	1.87	1.03	8.4
Nov	26	0.87	0.63	3.1
Dec	17	0.55	0.42	-1.8
YEAR	**1053**	**2.88**	**1.56**	**8.2**



Long-term monthly averages:

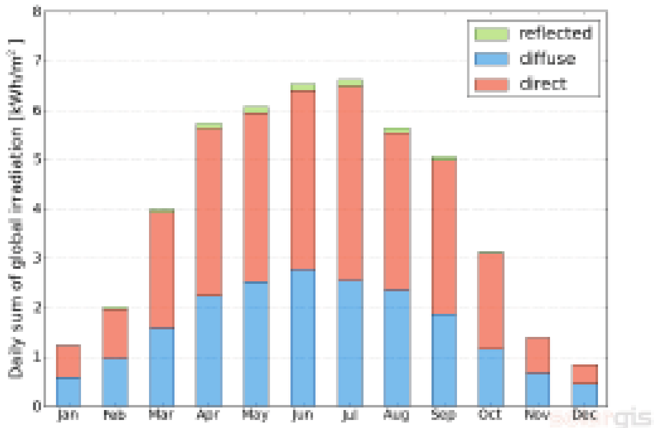
Gh_m Monthly sum of global irradiation [kWh/m²]
Gh_d Daily sum of global irradiation [kWh/m²]
Dh_d Daily sum of diffuse irradiation [kWh/m²]
T_{24} Daily (diurnal) air temperature [°C]

Interannual variability of annual global horizontal irradiation at P(90): **5.3%**

6. Global in-plane irradiation

1 axis tracking surface, incl. 35°

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	38	1.23	0.58	0.00	7.1
Feb	56	2.00	0.96	0.04	3.4
Mar	124	3.99	1.58	0.06	1.6
Apr	172	5.73	2.23	0.10	0.6
May	188	6.07	2.52	0.13	1.1
Jun	196	6.53	2.77	0.13	1.0
Jul	205	6.62	2.55	0.13	1.4
Aug	175	5.64	2.35	0.10	0.6
Sep	152	5.07	1.87	0.07	0.0
Oct	97	3.13	1.16	0.03	3.0
Nov	42	1.40	0.67	0.00	4.4
Dec	26	0.84	0.45	0.00	7.1
YEAR	**1471**	**4.03**	**1.64**	**0.07**	**2.6**



Long-term monthly averages:

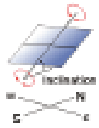
Gi_m Monthly sum of global irradiation [kWh/m²]
Gi_d Daily sum of global irradiation [kWh/m²]
Di_d Daily sum of diffuse irradiation [kWh/m²]
Ri_d Daily sum of reflected irradiation [kWh/m²]

Sh_{loss} Losses of global irradiation by terrain shading [%]

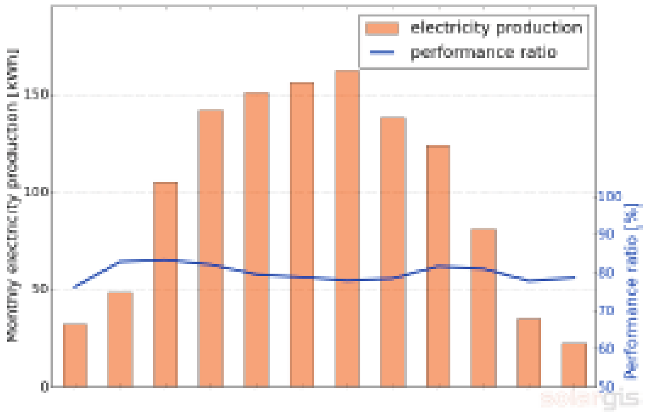
Average yearly sum of global irradiation for different types of surface:

	kWh/m²	relative to optimally inclined
Horizontal	1053	93.4%
Optimally inclined (10°)	1128	100.0%
2-axis tracking	1499	132.9%
Your option (see Section 6 subtitle)	**1473**	**130.6%**

7. PV electricity production in the start-up



Month	Es_m	Es_d	Et_m	E_{share}	PR
Jan	32	1.03	32	2.7	76.2
Feb	48	1.71	48	4.0	82.8
Mar	105	3.39	105	8.8	83.3
Apr	142	4.73	142	11.9	82.1
May	151	4.87	151	12.6	79.5
Jun	156	5.20	156	13.0	78.8
Jul	162	5.23	162	13.5	77.9
Aug	138	4.45	138	11.5	78.4
Sep	124	4.13	124	10.4	81.6
Oct	81	2.61	81	6.8	81.0
Nov	35	1.17	35	2.9	77.8
Dec	22	0.71	22	1.8	78.6
YEAR	**1196**	**3.28**	**1196**	**100.0**	**79.9**



Long-term monthly averages:

Es_m Monthly sum of specific electricity prod. [kWh/kWp]
Es_d Daily sum of specific electricity prod. [kWh/kWp]
Et_m Monthly sum of total electricity prod. [kWh]
E_{share} Percentual share of monthly electricity prod. [%]
PR Performance ratio [%]

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1496	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1473	-23	-1.5	98.5	98.5
3. Global irradiation reduced by reflectivity	1443	-30	-2.0	98.0	96.5
4. Conversion to DC in the modules	1331	-112	-7.8	92.2	89.0
5. Other DC losses	1258	-73	-5.5	94.5	84.1
6. Inverters (DC/AC conversion)	1226	-31	-2.5	97.5	82.0
7. Transformer and AC cabling losses	1208	-18	-1.5	98.5	80.7
8. Reduced availability	1196	-12	-1.0	99.0	79.9
Total system performance	**1196**	**-300**	**-20.1**	**-**	**79.9**

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at http://solargis.info/doc/pvplanner/.

Appendix 2: Energy output calculation of fixed system located in Becherov

1. Site info

Site name:	**Becherov, Prešovský kraj** Slovenská republika
Coordinates:	**49° 25' 10.26" N, 21° 18' 40.91" E**
Elevation a.s.l.:	409 m
Slope inclination:	4°
Slope azimuth:	141° (SE)

Annual global in-plane irradiation: **1196 kWh/m²**
Annual air temperature at 2 m: **8.2 °C**

2. PV system info

Installed power:	**1.0 kWp**
Type of modules:	**crystalline silicon (c-Si)**
Mounting system:	**fixed mounting, free standing**
Azimuth/inclination:	**180° (S) / 33°**
Inverter Euro eff.:	97.5%
DC / AC losses:	5.5% / 1.5%
Availability:	99.0%

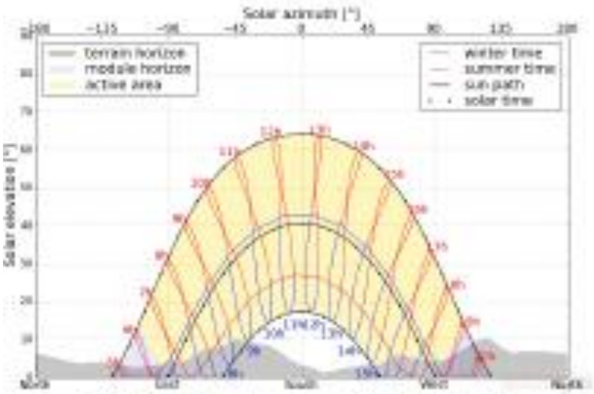
Annual average electricity production: **961 kWh**
Average performance ratio: **80.0%**

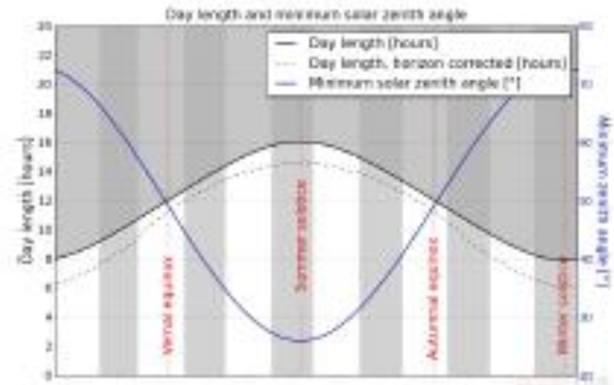
Location on the map: http://solargis.info/imaps/#lat=49.419517&lon=21.311364

3. Geographic position

solargis.info © 2010 GeoModel, s.r.o.; Google Maps © 2010 Google

4. Terrain horizon and day length



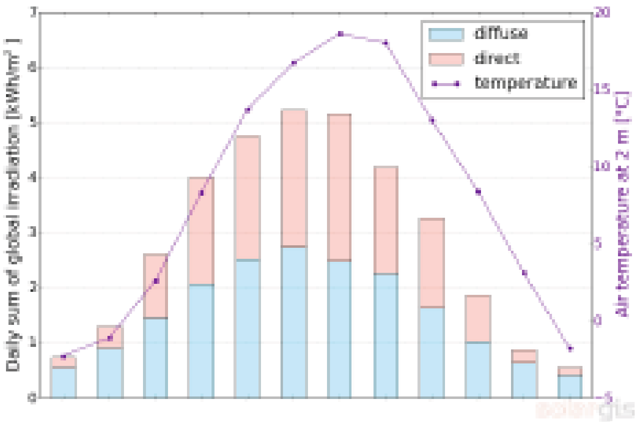


Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Red and blue labels show Local Clock Time in summer and winter, respectively.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	23	0.74	0.55	-2.3
Feb	36	1.29	0.89	-1.1
Mar	81	2.61	1.45	2.6
Apr	120	4.00	2.07	8.3
May	147	4.74	2.52	13.7
Jun	157	5.23	2.73	16.7
Jul	160	5.16	2.48	18.6
Aug	130	4.19	2.26	18.0
Sep	98	3.27	1.63	13.0
Oct	58	1.87	1.03	8.4
Nov	26	0.87	0.63	3.1
Dec	17	0.55	0.42	-1.8
YEAR	**1053**	**2.88**	**1.56**	**8.2**



Long-term monthly averages:

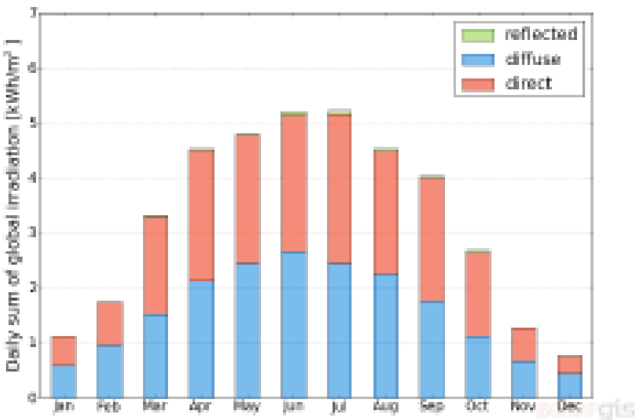
Gh_m Monthly sum of global irradiation [kWh/m^2]
Gh_d Daily sum of global irradiation [kWh/m^2]
Dh_d Daily sum of diffuse irradiation [kWh/m^2]
T_{24} Daily (diurnal) air temperature [°C]

Interannual variability of annual global horizontal irradiation at P(90): **5.3%**

6. Global in-plane irradiation

Fixed surface, azimuth 180° (S), incl. 33°

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	35	1.13	0.58	0.00	5.4
Feb	49	1.75	0.96	0.00	2.0
Mar	103	3.32	1.52	0.03	0.0
Apr	136	4.53	2.13	0.03	0.0
May	149	4.80	2.45	0.03	0.0
Jun	156	5.21	2.67	0.07	0.0
Jul	162	5.22	2.45	0.06	0.0
Aug	140	4.52	2.26	0.03	0.0
Sep	121	4.03	1.77	0.03	0.0
Oct	83	2.68	1.13	0.03	0.0
Nov	38	1.27	0.67	0.00	5.0
Dec	24	0.77	0.45	0.00	4.0
YEAR	**1196**	**3.28**	**1.59**	**0.03**	**1.4**



Long-term monthly averages:

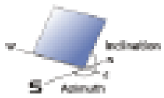
Gi_m Monthly sum of global irradiation [kWh/m^2]
Gi_d Daily sum of global irradiation [kWh/m^2]
Di_d Daily sum of diffuse irradiation [kWh/m^2]
Ri_d Daily sum of reflected irradiation [kWh/m^2]

Sh_{loss} Losses of global irradiation by terrain shading [%]

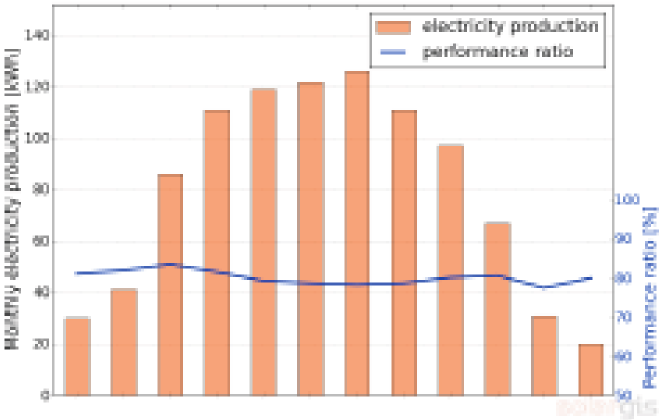
Average yearly sum of global irradiation for different types of surface:

	kWh/m^2	relative to optimally inclined
Horizontal	1053	88.0%
Optimally inclined (33°)	1197	100.0%
2-axis tracking	1499	125.2%
Your option (see Section 6 subtitle)	**1196**	**99.9%**

7. PV electricity production in the start-up



Month	Es_m	Es_d	Et_m	E_{share}	PR
Jan	30	0.97	30	3.1	81.1
Feb	41	1.46	41	4.3	82.0
Mar	86	2.77	86	8.9	83.5
Apr	111	3.70	111	11.6	81.6
May	119	3.84	119	12.4	79.3
Jun	122	4.07	122	12.7	78.7
Jul	126	4.06	126	13.1	78.3
Aug	111	3.58	111	11.6	78.7
Sep	97	3.23	97	10.1	80.2
Oct	67	2.16	67	7.0	80.7
Nov	31	1.03	31	3.2	77.5
Dec	20	0.65	20	2.1	80.0
YEAR	**961**	**2.63**	**961**	**100.0**	**80.0**



Long-term monthly averages:

Es_m Monthly sum of specific electricity prod. [kWh/kWp]
Es_d Daily sum of specific electricity prod. [kWh/kWp]
Et_m Monthly sum of total electricity prod. [kWh]
E_{share} Percentual share of monthly electricity prod. [%]
PR Performance ratio [%]

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1202	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1196	-6	-0.5	99.5	99.5
3. Global irradiation reduced by reflectivity	1157	-39	-3.3	96.7	96.3
4. Conversion to DC in the modules	1071	-86	-7.4	92.6	89.1
5. Other DC losses	1012	-59	-5.5	94.5	84.2
6. Inverters (DC/AC conversion)	987	-25	-2.5	97.5	82.1
7. Transformer and AC cabling losses	972	-15	-1.5	98.5	80.9
8. Reduced availability	962	-10	-1.0	99.0	80.1
Total system performance	**962**	**-240**	**-19.9**	**-**	**80.1**

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at http://solargis.info/doc/pvplanner/.

Appendix 3: Energy output calculation of 1-axis tracking system located in Komárno

1. Site info

Site name:	**Komárno**
	Komárno, Nitriansky kraj, Slovenská republika
Coordinates:	**47° 45' 47.84" N, 18° 07' 41.76" E**
Elevation a.s.l.:	114 m
Slope inclination:	1°
Slope azimuth:	10° (N)

Annual global in-plane irradiation: **1835 kWh/m²**
Annual air temperature at 2 m: **11.0 °C**

2. PV system info

Installed power:	**1.0 kWp**
Type of modules:	crystalline silicon (c-Si)
Mounting system:	**1-axis tracking, inclined axis**
Inclination:	39°
Inverter Euro eff.:	97.5%
DC / AC losses:	5.5% / 1.5%
Availability:	99.0%

Annual average electricity production: **1487 kWh**
Average performance ratio: **81.2%**

Location on the map: http://solargis.info/imaps/#lat=47.763289&lon=18.128266

3. Geographic position

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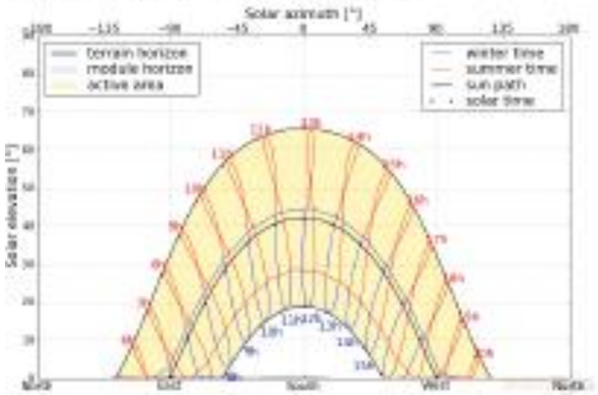
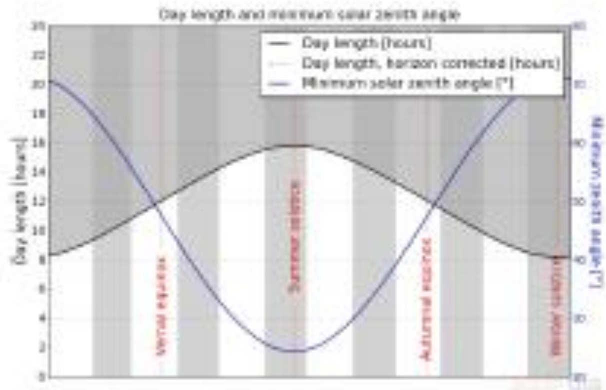
4. Terrain horizon and day length



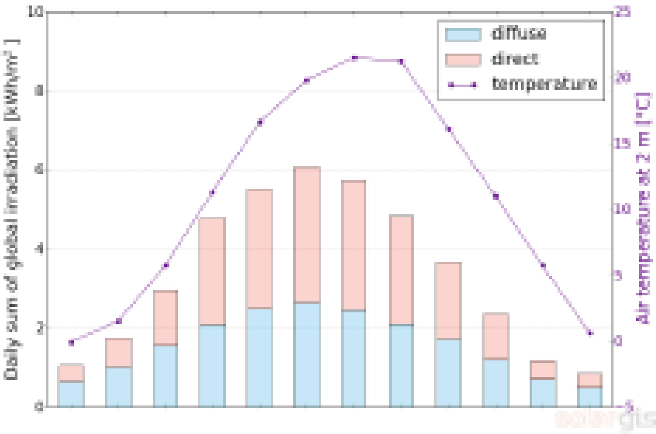


Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Red and blue labels show Local Clock Time in summer and winter, respectively.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	33	1.06	0.65	-0.1
Feb	49	1.75	1.00	1.5
Mar	92	2.97	1.55	5.7
Apr	143	4.77	2.07	11.3
May	171	5.52	2.48	16.6
Jun	182	6.07	2.63	19.8
Jul	178	5.74	2.45	21.5
Aug	150	4.84	2.10	21.2
Sep	110	3.67	1.70	16.1
Oct	73	2.35	1.19	11.0
Nov	35	1.17	0.70	5.7
Dec	26	0.84	0.48	0.6
YEAR	**1242**	**3.40**	**1.59**	**11.0**



Long-term monthly averages:

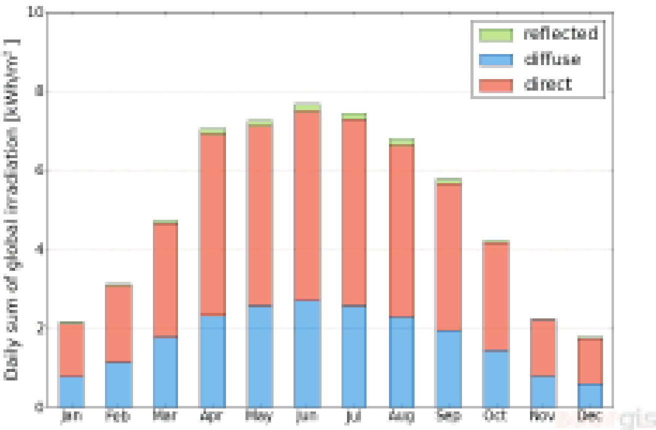
Gh_m Monthly sum of global irradiation [kWh/m^2]
Gh_d Daily sum of global irradiation [kWh/m^2]
Dh_d Daily sum of diffuse irradiation [kWh/m^2]
T_{24} Daily (diurnal) air temperature [°C]

Interannual variability of annual global horizontal irradiation at P(90): 6.2%

6. Global in-plane irradiation

1 axis tracking surface, incl. 39°

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	67	2.15	0.77	0.03	0.0
Feb	87	3.11	1.14	0.04	0.0
Mar	147	4.73	1.77	0.06	0.0
Apr	212	7.06	2.33	0.13	0.0
May	225	7.26	2.58	0.13	0.0
Jun	230	7.67	2.70	0.17	0.0
Jul	231	7.45	2.58	0.16	0.0
Aug	210	6.77	2.29	0.13	0.0
Sep	173	5.77	1.97	0.10	0.0
Oct	131	4.22	1.45	0.06	0.0
Nov	67	2.23	0.80	0.03	0.0
Dec	55	1.77	0.61	0.03	0.0
YEAR	**1835**	**5.02**	**1.75**	**0.09**	**0.0**



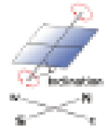
Long-term monthly averages:

Gi_m Monthly sum of global irradiation [kWh/m^2]
Gi_d Daily sum of global irradiation [kWh/m^2]
Di_d Daily sum of diffuse irradiation [kWh/m^2]
Ri_d Daily sum of reflected irradiation [kWh/m^2]

Sh_{loss} Losses of global irradiation by terrain shading [%]

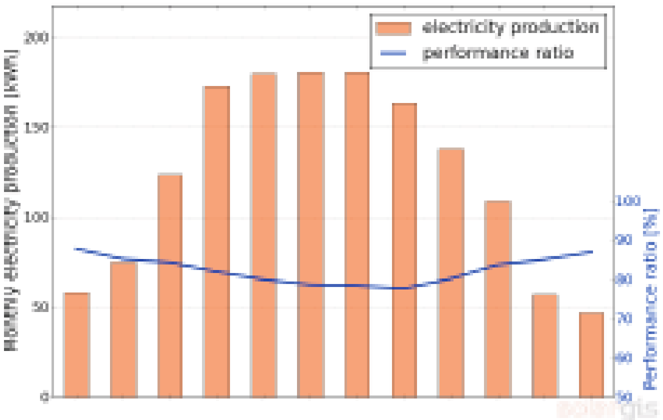
Average yearly sum of global irradiation for different types of surface:

	kWh/m^2	relative to optimally inclined
Horizontal	1242	92.5%
Optimally inclined (10°)	1343	100.0%
2-axis tracking	1879	139.9%
Your option (see Section 6 subtitle)	**1832**	**136.4%**



7. PV electricity production in the start-up

Month	Es_m	Es_d	Et_m	E_{share}	PR
Jan	58	1.87	58	3.9	87.9
Feb	75	2.68	75	5.0	85.2
Mar	124	4.00	124	8.3	84.4
Apr	173	5.77	173	11.6	82.0
May	180	5.81	180	12.1	80.0
Jun	181	6.03	181	12.2	78.7
Jul	181	5.84	181	12.2	78.4
Aug	164	5.29	164	11.0	77.7
Sep	138	4.60	138	9.3	80.2
Oct	109	3.52	109	7.3	83.8
Nov	57	1.90	57	3.8	85.1
Dec	47	1.52	47	3.2	87.0
YEAR	**1487**	**4.07**	**1487**	**100.0**	**81.2**



Long-term monthly averages:

Es_m Monthly sum of specific electricity prod. [kWh/kWp]
Es_d Daily sum of specific electricity prod. [kWh/kWp]
Et_m Monthly sum of total electricity prod. [kWh]
E_{share} Percentual share of monthly electricity prod. [%]
PR Performance ratio [%]

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1832	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1832	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	1801	-31	-1.7	98.3	98.3
4. Conversion to DC in the modules	1653	-148	-8.2	91.8	90.2
5. Other DC losses	1562	-91	-5.5	94.5	85.3
6. Inverters (DC/AC conversion)	1523	-39	-2.5	97.5	83.1
7. Transformer and AC cabling losses	1500	-23	-1.5	98.5	81.9
8. Reduced availability	1485	-15	-1.0	99.0	81.1
Total system performance	**1485**	**-347**	**-18.9**	**-**	**81.1**

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at http://solargis.info/doc/pvplanner/.

Appendix 4: Energy output calculation of fixed system located in Komárno

1. Site info

Site name:	**Komárno**
	Komárno, Nitriansky kraj, Slovenská republika
Coordinates:	**47° 45' 47.84" N, 18° 07' 41.76" E**
Elevation a.s.l.:	**114 m**
Slope inclination:	**1°**
Slope azimuth:	**10° (N)**

Annual global in-plane irradiation: **1454 kWh/m²**
Annual air temperature at 2 m: **11.0 °C**

2. PV system info

Installed power:	**1.0 kWp**
Type of modules:	**crystalline silicon (c-Si)**
Mounting system:	**fixed mounting, free standing**
Azimuth/inclination:	**180° (S) / 36°**
Inverter Euro eff.:	**97.5%**
DC / AC losses:	**5.5% / 1.5%**
Availability:	**99.0%**

Annual average electricity production: **1165 kWh**
Average performance ratio: **80.0%**

Location on the map: http://solargis.info/imaps/#lat=47.763289&lon=18.128266

3. Geographic position

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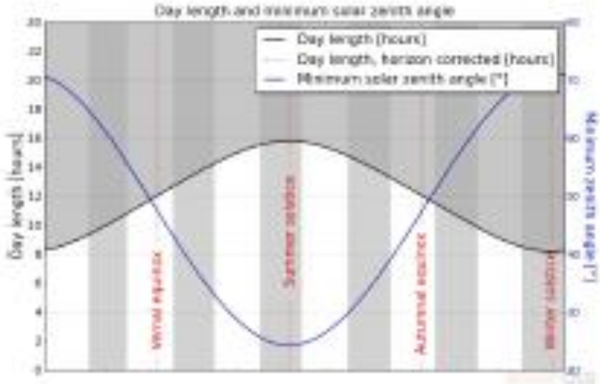
4. Terrain horizon and day length

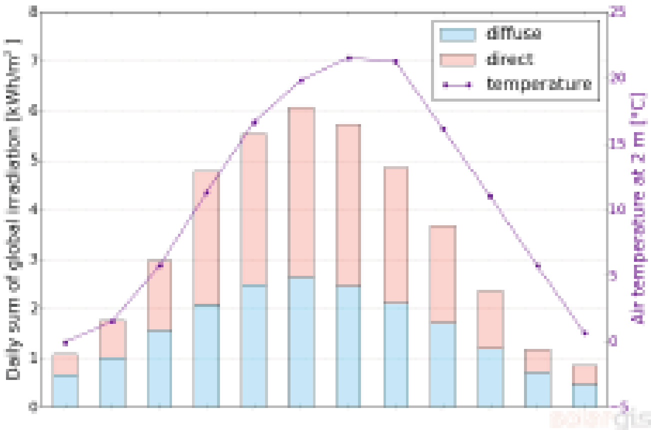


Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Red and blue labels show Local Clock Time in summer and winter, respectively.

Right: Change of the day length and solar zenith angle during a year. The local day length (time when the Sun is above the horizon) is shorter compared to the astronomical day length, if obstructed by higher terrain horizon.

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	33	1.06	0.65	-0.1
Feb	49	1.75	1.00	1.5
Mar	92	2.97	1.55	5.7
Apr	143	4.77	2.07	11.3
May	171	5.52	2.48	16.6
Jun	182	6.07	2.63	19.8
Jul	178	5.74	2.45	21.5
Aug	150	4.84	2.10	21.2
Sep	110	3.67	1.70	16.1
Oct	73	2.35	1.19	11.0
Nov	35	1.17	0.70	5.7
Dec	26	0.84	0.48	0.6
YEAR	**1242**	**3.40**	**1.59**	**11.0**



Long-term monthly averages:

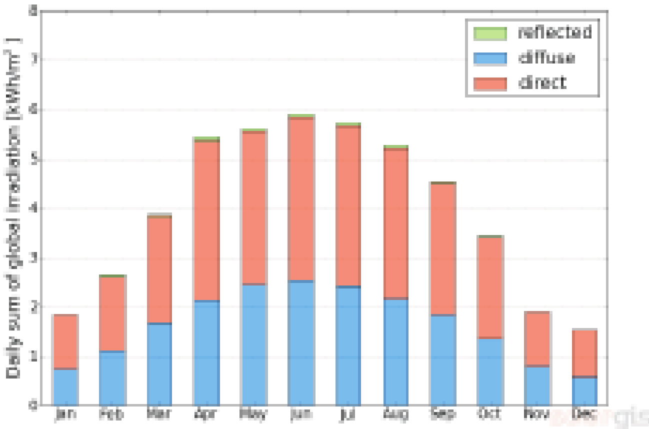
Gh_m Monthly sum of global irradiation [kWh/m^2]
Gh_d Daily sum of global irradiation [kWh/m^2]
Dh_d Daily sum of diffuse irradiation [kWh/m^2]
T_{24} Daily (diurnal) air temperature [°C]

Interannual variability of annual global horizontal irradiation at P(90): **6.2%**

6. Global in-plane irradiation

Fixed surface, azimuth 180° (S), incl. 36°

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	57	1.84	0.74	0.00	0.0
Feb	74	2.65	1.11	0.04	0.0
Mar	120	3.87	1.68	0.03	0.0
Apr	163	5.43	2.13	0.07	0.0
May	174	5.61	2.45	0.06	0.0
Jun	177	5.90	2.53	0.07	0.0
Jul	178	5.74	2.42	0.06	0.0
Aug	164	5.28	2.16	0.06	0.0
Sep	136	4.53	1.83	0.03	0.0
Oct	107	3.44	1.35	0.03	0.0
Nov	57	1.90	0.80	0.00	0.0
Dec	47	1.52	0.58	0.00	0.0
YEAR	**1454**	**3.98**	**1.65**	**0.04**	**0.0**



Long-term monthly averages:

Gi_m Monthly sum of global irradiation [kWh/m^2]
Gi_d Daily sum of global irradiation [kWh/m^2]
Di_d Daily sum of diffuse irradiation [kWh/m^2]
Ri_d Daily sum of reflected irradiation [kWh/m^2]

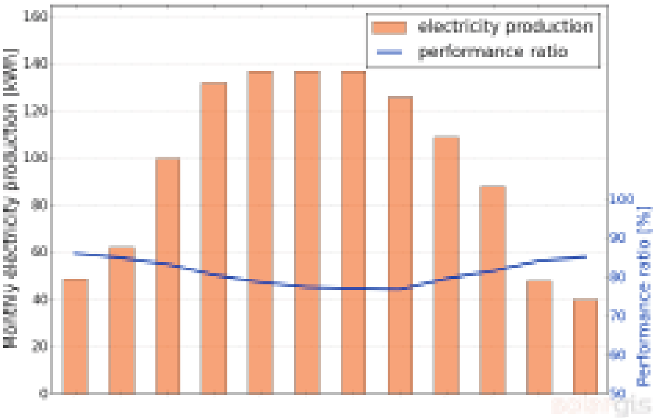
Sh_{loss} Losses of global irradiation by terrain shading [%]

Average yearly sum of global irradiation for different types of surface:

	kWh/m^2	relative to optimally inclined
Horizontal	1242	85.3%
Optimally inclined (36°)	1456	100.0%
2-axis tracking	1879	129.1%
Your option (see Section 6 subtitle)	**1456**	**100.0%**

7. PV electricity production in the start-up

Month	Es_m	Es_d	Et_m	E_{share}	PR
Jan	49	1.58	49	4.2	86.0
Feb	62	2.21	62	5.3	84.9
Mar	100	3.23	100	8.6	83.3
Apr	132	4.40	132	11.3	80.5
May	137	4.42	137	11.8	78.7
Jun	137	4.57	137	11.8	77.4
Jul	137	4.42	137	11.8	77.0
Aug	126	4.06	126	10.8	76.8
Sep	109	3.63	109	9.4	79.6
Oct	88	2.84	88	7.6	81.5
Nov	48	1.60	48	4.1	84.2
Dec	40	1.29	40	3.4	85.1
YEAR	**1165**	**3.19**	**1165**	**100.0**	**80.0**



Long-term monthly averages:

- Es_m Monthly sum of specific electricity prod. [kWh/kWp]
- Es_d Daily sum of specific electricity prod. [kWh/kWp]
- Et_m Monthly sum of total electricity prod. [kWh]
- E_{share} Percentual share of monthly electricity prod. [%]
- PR Performance ratio [%]

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1456	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1456	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	1414	-42	-2.9	97.1	97.1
4. Conversion to DC in the modules	1296	-118	-8.3	91.7	89.0
5. Other DC losses	1225	-71	-5.5	94.5	84.1
6. Inverters (DC/AC conversion)	1194	-31	-2.5	97.5	82.0
7. Transformer and AC cabling losses	1176	-18	-1.5	98.5	80.8
8. Reduced availability	1164	-12	-1.0	99.0	80.0
Total system performance	**1164**	**-292**	**-20.0**	**-**	**80.0**

Energy conversion steps and losses:

1. Initial production at Standard Test Conditions (STC) is assumed,
2. Reduction of global in-plane irradiation due to obstruction of terrain horizon and PV modules,
3. Proportion of global irradiation that is reflected by surface of PV modules (typically glass),
4. Losses in PV modules due to conversion of solar radiation to DC electricity; deviation of module efficiency from STC,
5. DC losses: this step assumes integrated effect of mismatch between PV modules, heat losses in interconnections and cables, losses due to dirt, snow, icing and soiling, and self-shading of PV modules,
6. This step considers euro efficiency to approximate average losses in the inverter,
7. Losses in AC section and transformer (where applicable) depend on the system architecture,
8. Availability parameter assumes losses due to downtime caused by maintenance or failures.

Losses at steps 2 to 4 are numerically modeled by pvPlanner. Losses at steps 5 to 8 are to be assessed by a user. The simulation models have inherent uncertainties that are not discussed in this report. Read more about simulation methods and related uncertainties to evaluate possible risks at http://solargis.info/doc/pvplanner/.

Appendix 5: Project cash flow - PV power plant Buzitka (tracking system)

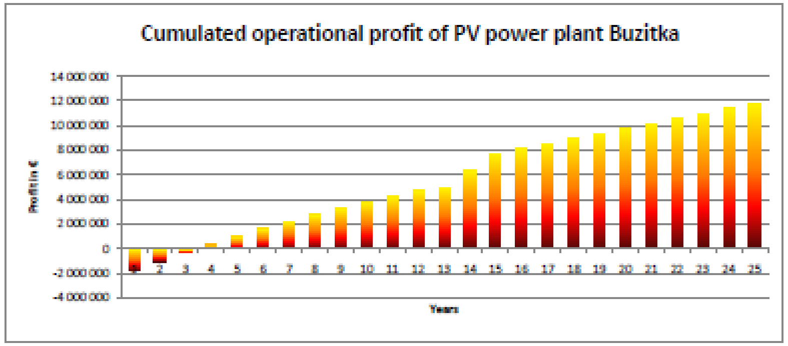
	0	1	2	3	4	5	6	7	8	9
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018	2 019
Operational income		2 199 280	2 177 258	2 155 405	2 133 936	2 112 591	2 091 465	2 070 550	2 049 845	2 029 346
TOTAL OPERATION COSTS (€)		239 967	246 470	253 166	260 067	267 173	274 493	282 032	289 797	297 796
EBITDA		1 959 283	1 930 788	1 902 317	1 873 863	1 845 417	1 816 972	1 788 519	1 760 048	1 731 552
Depreciation		1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626
EBIT		913 656	885 162	856 691	828 237	799 792	771 347	742 893	714 422	685 926
Interest expenses		592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079	280 926
Gross profit		321 415	324 487	329 446	336 394	345 439	356 697	370 288	386 344	405 000
Tax		67 497	68 142	69 184	70 643	72 542	74 906	77 761	81 132	85 050
Net profit		253 918	256 345	260 262	265 751	272 897	281 790	292 528	305 211	319 950
Principal repayment		535 036	566 605	600 035	635 437	672 927	712 630	754 675	799 201	846 354
EBITDA – Tax		1 891 786	1 862 645	1 833 133	1 803 220	1 772 875	1 742 066	1 710 758	1 678 916	1 646 502
Cash flow BEFORE repayment of installments	-2 509 502	1 299 544	1 301 970	1 305 888	1 311 377	1 318 523	1 327 416	1 338 153	1 350 837	1 365 576
Cash flow AFTER repayment of installments	-2 509 502	764 508	735 365	705 853	675 940	645 595	614 786	583 478	551 636	519 222
Cumulated Cash Flow	-2 509 502	-1 744 996	-1 009 630	-303 777	372 163	1 017 758	1 632 544	2 216 023	2 767 659	3 286 880
IRR	26,87%									
NPV	€ 3 779 249									
SPP Equity	3,43									

	10	11	12	13	14	15	16	17	18
	2 020	2 021	2 022	2 023	2 024	2 025	2 026	2 027	2 028
Operational income	2 009 053	2 022 514	2 036 064	2 049 706	2 063 439	2 077 264	876 328	882 200	888 110
TOTAL OPERATION COSTS (€)	306 033	301 321	310 061	319 062	328 334	337 884	347 721	357 852	368 288
EBITDA	1 703 020	1 721 193	1 726 004	1 730 644	1 735 105	1 739 380	528 607	524 347	519 822
Depreciation	1 045 626	1 045 626	1 045 626	0	0	0	0	0	0
EBIT	657 395	675 567	680 378	1 730 644	1 735 105	1 739 380	528 607	524 347	519 822
Interest expenses	230 991	178 110	122 109	62 804	0	0	0	0	0
Gross profit	426 403	497 457	558 269	1 667 840	1 735 105	1 739 380	528 607	524 347	519 822
Tax	89 545	104 466	117 236	350 246	364 372	365 270	111 008	110 113	109 163
Net profit	336 859	392 991	441 032	1 317 593	1 370 733	1 374 110	417 600	414 234	410 660
Principal repayment	896 289	949 170	1 005 171	1 064 476	0	0	0	0	0
EBITDA – Tax	1 613 476	1 616 727	1 608 767	1 380 397	1 370 733	1 374 110	417 600	414 234	410 660
Cash flow BEFORE repayment of installments	1 382 484	1 438 617	1 486 658	1 317 593	1 370 733	1 374 110	417 600	414 234	410 660
Cash flow AFTER repayment of installments	486 196	489 447	481 487	253 117	1 370 733	1 374 110	417 600	414 234	410 660
Cumulated Cash Flow	3 773 076	4 262 523	4 744 010	4 997 127	6 367 860	7 741 970	8 159 570	8 573 804	8 984 464

	19	20	21	22	23	24	25	TOTAL	Average
	2 029	2 030	2 031	2 032	2 033	2 034	2 035		
Operational income	894 061	900 051	906 081	912 152	918 263	924 416	930 609	38 110 780	1 270 359
TOTAL OPERATION COSTS (€)	379 037	390 108	401 511	413 256	425 354	437 815	450 649	8 045 279	321 811
EBITDA	515 024	509 943	504 570	498 896	492 909	486 601	479 960	30 065 502	1 202 620
Depreciation	0	0	0	0	0	0		11 501 883	460 075
EBIT	515 024	509 943	504 570	498 896	492 909	486 601	479 960	18 563 619	742 545
Interest expenses	0	0	0	0	0	0	0	4 024 391	160 976
Gross profit	515 024	509 943	504 570	498 896	492 909	486 601	479 960	14 539 228	581 569
Tax	108 155	107 088	105 960	104 768	103 511	102 186	100 792	3 053 238	122 130
Net profit	406 869	402 855	398 611	394 128	389 398	384 415	379 169	11 485 990	459 440
Principal repayment	0	0	0					10 038 007	401 520
EBITDA – Tax	406 869	402 855	398 611	394 128	389 398	384 415	379 169	28 904 050	1 156 162
Cash flow BEFORE repayment of installments	406 869	402 855	398 611	394 128	389 398	384 415	379 169	24 287 416	971 497
Cash flow AFTER repayment of installments	406 869	402 855	398 611	394 128	389 398	384 415	379 169	14 249 410	569 976
Cumulated Cash Flow	9 391 333	9 794 188	10 192 798	10 586 926	10 976 324	11 360 739	11 739 908		

FINANCING		
Senior bank financing	10 038 007	80%
Equity financing (incl. development cost)	2 509 502	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301183	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	10 038 007	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105	3 018 817	2 069 647	1 064 476							
Total Payment (interest + principal)	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280							
Interest	592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079	280 926	230 991	178 110	122 109	62 804							
Loan Repaid	535 036	566 605	600 035	635 437	672 927	712 630	754 675	799 201	846 354	896 289	949 170	1 005 171	1 064 476							
Capital Outstanding c/f	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105	3 018 817	2 069 647	1 064 476	0							
Interest Cover	3,19	3,32	3,48	3,67	3,90	4,20	4,59	5,12	5,86	6,99	9,08	13,17	21,98							
DSCR	1,68	1,65	1,63	1,60	1,57	1,55	1,52	1,49	1,46	1,43	1,43	1,43	1,22							



Appendix 6: Project cash flow - PV power plant Buzitka (fixed system)

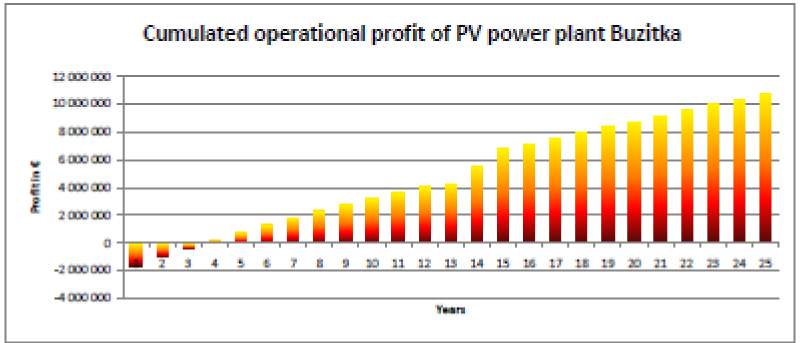
	0	1	2	3	4	5	6	7	8	9	10	11	12
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018	2 019	2 020	2 021	2 022
Operational Income		1 925 618	1 906 362	1 887 299	1 868 426	1 849 741	1 831 244	1 812 932	1 794 802	1 776 854	1 759 086	1 770 872	1 782 736
TOTAL OPERATION COSTS (€)		180 364	180 229	185 240	190 401	195 718	201 193	206 833	212 642	218 625	224 788	217 939	224 478
EBITDA		1 745 254	1 726 133	1 702 059	1 678 024	1 654 024	1 630 051	1 606 099	1 582 160	1 558 229	1 534 297	1 552 932	1 558 258
Depreciation		955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254
EBIT		790 001	770 880	746 805	722 771	698 770	674 797	650 845	626 907	602 975	579 044	597 679	603 005
Interest expenses		541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724	256 646	211 027	162 716	111 555
Gross profit		248 945	258 663	265 129	273 437	283 687	295 985	310 444	327 183	346 329	368 017	434 962	491 450
Tax		52 278	54 319	55 677	57 422	59 574	62 157	65 193	68 708	72 729	77 284	91 342	103 204
Net profit		196 667	204 344	209 452	216 015	224 113	233 828	245 251	258 475	273 600	290 733	343 620	388 245
Principal repayment		488 795	517 634	548 174	580 517	614 767	651 038	689 450	730 127	773 205	818 824	867 134	918 295
EBITDA – Tax		1 692 976	1 671 814	1 646 382	1 620 603	1 594 450	1 567 894	1 540 905	1 513 452	1 485 500	1 457 014	1 461 590	1 455 054
Cash flow BEFORE repayment of installments	-2 292 609	1 151 920	1 159 587	1 164 705	1 171 269	1 179 366	1 189 082	1 200 504	1 213 728	1 228 854	1 245 987	1 298 874	1 343 499
Cash flow AFTER repayment of installments	-2 292 609	663 125	641 953	616 531	590 752	564 599	538 043	511 055	483 601	455 649	427 163	431 739	425 204
Cumulated Cash Flow	-2 292 609	-1 629 483	-987 520	-370 989	219 763	784 362	1 322 405	1 833 460	2 317 061	2 772 710	3 199 873	3 631 613	4 056 816
IRR	25,65%												
NPV	€ 3 326 540												
SPP Equity	3,83												

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
	2 023	2 024	2 025	2 026	2 027	2 028	2 029	2 030	2 031	2 032	2 033	2 034	2 035	
Operational Income	1 794 681	1 806 705	1 818 810	787 295	772 436	777 611	782 821	788 066	793 346	798 662	804 013	809 400	814 823	33 389 622
TOTAL OPERATION COSTS (€)	231 212	238 148	245 293	252 652	260 231	268 038	276 079	284 361	292 892	301 679	310 729	320 051	329 653	5 889 107
EBITDA	1 563 469	1 568 557	1 573 517	514 644	512 205	509 573	506 742	503 705	500 454	496 982	493 283	489 348	485 170	27 499 915
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0		10 507 790
EBIT	1 563 469	1 568 557	1 573 517	514 644	512 205	509 573	506 742	503 705	500 454	496 982	493 283	489 348	485 170	16 992 126
Interest expenses	57 376	0	0	0	0	0	0	0	0	0	0	0	0	3 676 568
Gross profit	1 506 093	1 568 557	1 573 517	514 644	512 205	509 573	506 742	503 705	500 454	496 982	493 283	489 348	485 170	13 315 557
Tax	316 279	329 397	330 439	108 075	107 563	107 010	106 416	105 778	105 095	104 366	103 589	102 763	101 886	2 796 267
Net profit	1 189 813	1 239 160	1 243 079	406 568	404 642	402 563	400 326	397 927	395 359	392 616	389 694	386 585	383 284	10 519 290
Principal repayment	972 475	0	0	0	0	0	0	0	0					9 170 434
EBITDA – Tax	1 247 189	1 239 160	1 243 079	406 568	404 642	402 563	400 326	397 927	395 359	392 616	389 694	386 585	383 284	26 398 624
Cash flow BEFORE repayment of installments	1 189 813	1 239 160	1 243 079	406 568	404 642	402 563	400 326	397 927	395 359	392 616	389 694	386 585	383 284	22 179 000
Cash flow AFTER repayment of installments	217 338	1 239 160	1 243 079	406 568	404 642	402 563	400 326	397 927	395 359	392 616	389 694	386 585	383 284	13 008 566
Cumulated Cash Flow	4 274 155	5 513 315	6 756 393	7 162 962	7 567 604	7 970 167	8 370 493	8 768 420	9 163 778	9 556 394	9 946 088	10 332 673	10 715 957	

FINANCING

Senior bank financing	9 170 434	80%
Equity financing (incl. development cost)	2 292 609	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301163	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	9 170 434	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728	2 757 904	1 890 770	972 475							
Total Payment (interest + principal)	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851							
Interest	541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724	256 646	211 027	162 716	111 555	57 376							
Loan Repaid	488 795	517 634	548 174	580 517	614 767	651 038	689 450	730 127	773 205	818 824	867 134	918 295	972 475							
Capital Outstanding c/f	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728	2 757 904	1 890 770	972 475	0							
Interest Cover	3,13	3,26	3,42	3,61	3,84	4,14	4,53	5,05	5,79	6,90	8,98	13,04	21,74							
DSCR	1,64	1,62	1,60	1,57	1,55	1,53	1,50	1,47	1,44	1,41	1,42	1,41	1,21							



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Appendix 7: Project cash flow – Excel formulas

	0	1	2	3	4	5	6	7
	2010	2011	2012	2013	2014	2015	2016	2017
Income								
Incremental prediction of the feed-in tariff's growth		=Assumptions!D15	=D8	=E8	=F8	=G8	=H8	=I8
Feed-in tariff (€/kWh)		=Assumptions!E9	=D9*(1+E8)	=E9*(1+F8)	=F9*(1+G8)	=G9*(1+H8)	=H9*(1+I8)	=I9*(1+J8)
Estimated production decrease		=Assumptions!D14	=D10	=E10	=F10	=G10	=H10	=I10
Estimated annual production (kWh)		=Assumptions!E7	=Assumptions!E7*(1+E10)	=E11*(1+F10)	=F11*(1+G10)	=G11*(1+H10)	=H11*(1+I10)	=I11*(1+J10)
Operational income		=D11*D9	=E11*E9	=F11*F9	=G11*G9	=H11*H9	=I11*I9	=J11*J9
OPERATION COSTS								
Prediction of annual rate of inflation's growth (%)		=Assumptions!D21	=D15	=E15	=F15	=G15	=H15	=I15
Land lease		=Assumptions!E21	=D16*(1+E15)	=E16*(1+F15)	=F16*(1+G15)	=G16*(1+H15)	=H16*(1+I15)	=I16*(1+J15)
Insurance		=Assumptions!E22	=D17*(1+E15)	=E17*(1+F15)	=F17*(1+G15)	=G17*(1+H15)	=H17*(1+I15)	=I17*(1+J15)
Security costs		=Assumptions!E23	=D18*(1+E15)	=E18*(1+F15)	=F18*(1+G15)	=G18*(1+H15)	=H18*(1+I15)	=I18*(1+J15)
Maintenance		=Assumptions!E24	=D19*(1+E15)	=E19*(1+F15)	=F19*(1+G15)	=G19*(1+H15)	=H19*(1+I15)	=I19*(1+J15)
Administrative costs		=Assumptions!E25	=D20*(1+E15)	=E20*(1+F15)	=F20*(1+G15)	=G20*(1+H15)	=H20*(1+I15)	=I20*(1+J15)
Own energy consumptions		=Assumptions!E26	=Assumptions!F26	=Assumptions!G26	=Assumptions!H26	=Assumptions!I26	=Assumptions!J26	=Assumptions!K26
Annual payment to State agricultural Fund		=Assumptions!E27	=D22	=E22	=F22	=G22	=H22	=I22
Annual payment to municipality		=Assumptions!E28	=D23	=E23	=F23	=G23	=H23	=I23
TOTAL OPERATION COSTS (€)		=Assumptions!E29	=SUM(E16:E23)	=SUM(F16:F23)	=SUM(G16:G23)	=SUM(H16:H23)	=SUM(I16:I23)	=SUM(J16:J23)
EBITDA		=D12-D24	=E12-E24	=F12-F24	=G12-G24	=H12-H24	=I12-I24	=J12-J24
Depreciation		=Assumptions!E32	=D28	=E28	=F28	=G28	=Assumptions!E32	=I28
EBIT		=D26-D28	=E26-E28	=F26-F28	=G26-G28	=H26-H28	=I26-I28	=J26-J28
Interest expenses		=C59	=D59	=E59	=F59	=G59	=H59	=I59
Gross profit		=D30-D32	=E30-E32	=F30-F32	=G30-G32	=H30-H32	=I30-I32	=J30-J32
Tax		=IF(D34<0;0;D34*0,21)	=IF(E34<0;0;E34*0,21)	=IF(F34<0;0;F34*0,21)	=IF(G34<0;0;G34*0,21)	=IF(H34<0;0;H34*0,21)	=IF(I34<0;0;I34*0,21)	=IF(J34<0;0;J34*0,21)
Net profit		=D34-D35	=E34-E35	=F34-F35	=G34-G35	=H34-H35	=I34-I35	=J34-J35
Principal repayment		=C60	=D60	=E60	=F60	=G60	=H60	=I60
EBITDA – Tax		=D26-D35	=E26-E35	=F26-F35	=G26-G35	=H26-H35	=I26-I35	=J26-J35
Cash flow BEFORE repayment of installments	=-C50	=D26-D32-D35	=E26-E32-E35	=F26-F32-F35	=G26-G32-G35	=H26-H32-H35	=I26-I32-I35	=J26-J32-J35
Cash flow AFTER repayment of installments	=-C50	=D26-D32-D35-D38	=E26-E32-E35-E38	=F26-F32-F35-F38	=G26-G32-G35-G38	=H26-H32-H35-H38	=I26-I32-I35-I38	=J26-J32-J35-J38
Cumulated Cash Flow	=-C50	=C43+D42	=D43+E42	=E43+F42	=F43+G42	=G43+H42	=H43+I42	=I43+J42
IRR	=IRR(C42:AB42;)							
NPV	=NPV(C54;C42;D42:AB42)							
SPP Equity	=F5+(ABS(F43)/G42)							

	8	9	10	11	12	13	14	15
	2018	2019	2020	2021	2022	2023	2024	2025
Income								
Incremental prediction of the feed-in tariff's growth	=J8	=K8	=L8	=M8	=N8	=O8	=P8	=Q8
Feed-in tariff (€/kWh)	=J9*(1+K8)	=K9*(1+L8)	=L9*(1+M8)	=M9*(1+N8)	=N9*(1+O8)	=O9*(1+P8)	=P9*(1+Q8)	=Q9*(1+R8)
Estimated production decrease	=J10	=K10	=L10	=0,0067	=N10	=O10	=P10	=Q10
Estimated annual production (kWh)	=J11*(1+K10)	=K11*(1+L10)	=L11*(1+M10)	=M11*(1+N10)	=N11*(1+O10)	=O11*(1+P10)	=P11*(1+Q10)	=Q11*(1+R10)
Operational income	=K11*K9	=L11*L9	=M11*M9	=N11*N9	=O11*O9	=P11*P9	=Q11*Q9	=R11*R9
OPERATION COSTS								
Prediction of annual rate of inflation's growth (%)	=J15	=K15	=L15	=M15	=N15	=O15	=P15	=Q15
Land lease	=J16*(1+K15)	=K16*(1+L15)	=L16*(1+M15)	=M16*(1+N15)	=N16*(1+O15)	=O16*(1+P15)	=P16*(1+Q15)	=Q16*(1+R15)
Insurance	=J17*(1+K15)	=K17*(1+L15)	=L17*(1+M15)	=M17*(1+N15)	=N17*(1+O15)	=O17*(1+P15)	=P17*(1+Q15)	=Q17*(1+R15)
Security costs	=J18*(1+K15)	=K18*(1+L15)	=L18*(1+M15)	=M18*(1+N15)	=N18*(1+O15)	=O18*(1+P15)	=P18*(1+Q15)	=Q18*(1+R15)
Maintenance	=J19*(1+K15)	=K19*(1+L15)	=L19*(1+M15)	=M19*(1+N15)	=N19*(1+O15)	=O19*(1+P15)	=P19*(1+Q15)	=Q19*(1+R15)
Administrative costs	=J20*(1+K15)	=K20*(1+L15)	=L20*(1+M15)	=M20*(1+N15)	=N20*(1+O15)	=O20*(1+P15)	=P20*(1+Q15)	=Q20*(1+R15)
Own energy consumptions	=Assumptions!L26	=Assumptions!M26	=Assumptions!N26	=Assumptions!O26	=Assumptions!P26	=Assumptions!Q26	=Assumptions!R26	=Assumptions!S26
Annual payment to State agricultural Fund	=J22	=K22	=L22	=M22	=N22	=O22	=P22	=Q22
Annual payment to municipality	=J23	=K23	=L23					
TOTAL OPERATION COSTS (€)	=SUM(K16:K23)	=SUM(L16:L23)	=SUM(M16:M23)	=SUM(N16:N23)	=SUM(O16:O23)	=SUM(P16:P23)	=SUM(Q16:Q23)	=SUM(R16:R23)
EBITDA	=K12-K24	=L12-L24	=M12-M24	=N12-N24	=O12-O24	=P12-P24	=Q12-Q24	=R12-R24
Depreciation	=J28	=K28	=L28	=M28	=N28	0	0	0
EBIT	=K26-K28	=L26-L28	=M26-M28	=N26-N28	=O26-O28	=P26-P28	=Q26-Q28	=R26-R28
Interest expenses	=J59	=K59	=L59	=M59	=N59	=O59	=P59	=Q59
Gross profit	=K30-K32	=L30-L32	=M30-M32	=N30-N32	=O30-O32	=P30-P32	=Q30-Q32	=R30-R32
Tax	=IF(K34<0;0;K34*0,21)	=IF(L34<0;0;L34*0,21)	=IF(M34<0;0;M34*0,21)	=IF(N34<0;0;N34*0,21)	=IF(O34<0;0;O34*0,21)	=IF(P34<0;0;P34*0,21)	=IF(Q34<0;0;Q34*0,21)	=IF(R34<0;0;R34*0,21)
Net profit	=K34-K35	=L34-L35	=M34-M35	=N34-N35	=O34-O35	=P34-P35	=Q34-Q35	=R34-R35
Principal repayment	=J60	=K60	=L60	=M60	=N60	=O60	=P60	=Q60
EBITDA – Tax	=K26-K35	=L26-L35	=M26-M35	=N26-N35	=O26-O35	=P26-P35	=Q26-Q35	=R26-R35
Cash flow BEFORE repayment of installments	=K26-K32-K35	=L26-L32-L35	=M26-M32-M35	=N26-N32-N35	=O26-O32-O35	=P26-P32-P35	=Q26-Q32-Q35	=R26-R32-R35
Cash flow AFTER repayment of installments	=K26-K32-K35-K38	=L26-L32-L35-L38	=M26-M32-M35-M38	=N26-N32-N35-N38	=O26-O32-O35-O38	=P26-P32-P35-P38	=Q26-Q32-Q35-Q38	=R26-R32-R35-R38
Cumulated Cash Flow	=J43+K42	=K43+L42	=L43+M42	=M43+N42	=N43+O42	=O43+P42	=P43+Q42	=Q43+R42

FINANCING

Senior bank financing	=(SUM(Capex!D8:E17)*D49)	=(1-Assumptions!H13)
Equity financing (incl. development cost)	=(SUM(Capex!D8:E17)*(1-D4	=1-D49
Interest rate	=Assumptions!H15	
Loan period	=Assumptions!H14	
Bank koef.	=((C51*(1+C51)^C52)/((1+C5	
Discount rate	0,08	

	1	2	3	4	5	6	7	8	9	10	11	12	13
Capital Outstanding b/f	=C49	=C61	=D61	=E61	=F61	=G61	=H61	=I61	=J61	=K61	=L61	=M61	=N61
Total Payment (interest + principal)	=C53*C57	=C58	=D58	=E58	=F58	=G58	=H58	=I58	=J58	=K58	=L58	=M58	=N58
Interest	=C57*C51	=D57*C51	=E57*C51	=F57*C51	=G57*C51	=H57*C51	=I57*C51	=J57*C51	=K57*C51	=L57*C51	=M57*C51	=N57*C51	=O57*C51
Loan Repaid	=C58-C59	=D58-D59	=E58-E59	=F58-F59	=G58-G59	=H58-H59	=I58-I59	=J58-J59	=K58-K59	=L58-L59	=M58-M59	=N58-N59	=O58-O59
Capital Outstanding c/f	=C57-C60	=D57-D60	=E57-E60	=F57-F60	=G57-G60	=H57-H60	=I57-I60	=J57-J60	=K57-K60	=L57-L60	=M57-M60	=N57-N60	=O57-O60
Interest Cover	=(D26-D35)/D32	=(E26-E35)/E32	=(F26-F35)/F32	=(G26-G35)/G32	=(H26-H35)/H32	=(I26-I35)/I32	=(J26-J35)/J32	=(K26-K35)/K32	=(L26-L35)/L32	=(M26-M35)/M32	=(N26-N35)/N32	=(O26-O35)/O32	=(P26-P35)/P32
DSCR	=(D26-D35)/C58	=(E26-E35)/D58	=(F26-F35)/E58	=(G26-G35)/F58	=(H26-H35)/G58	=(I26-I35)/H58	=(J26-J35)/I58	=(K26-K35)/J58	=(L26-L35)/K58	=(M26-M35)/L58	=(N26-N35)/M58	=(O26-O35)/N58	=(P26-P35)/O58

16	17	18	19	20	21	22	23	24	25	TOTAL	Average
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035		
=R8	=S8	=T8	=U8	=V8	=W8	=X8	=Y8	=Z8	=AA8		
=Assumptions!E10	=S9*(1+T8)	=T9*(1+U8)	=U9*(1+V8)	=V9*(1+W8)	=W9*(1+X8)	=X9*(1+Y8)	=Y9*(1+Z8)	=Z9*(1+AA8)	=AA9*(1+AB8)		
=R10	=S10	=T10	=U10	=V10	=W10	=X10	=Y10	=Z10	=AA10		
=R11*(1+S10)	=S11*(1+T10)	=T11*(1+U10)	=U11*(1+V10)	=V11*(1+W10)	=W11*(1+X10)	=X11*(1+Y10)	=Y11*(1+Z10)	=Z11*(1+AA10)	=AA11*(1+AB10)	=AB11*(1+AC10)	=AC11*(1+AD10)
=S11*S9	=T11*T9	=U11*U9	=V11*V9	=W11*W9	=X11*X9	=Y11*Y9	=Z11*Z9	=AA11*AA9	=AB11*AB9	=SUM(E12:AB12)	=AC12/30
=R15	=S15	=T15	=U15	=V15	=W15	=X15	=Y15	=Z15	=AA15		
=R16*(1+S15)	=S16*(1+T15)	=T16*(1+U15)	=U16*(1+V15)	=V16*(1+W15)	=W16*(1+X15)	=X16*(1+Y15)	=Y16*(1+Z15)	=Z16*(1+AA15)	=AA16*(1+AB15)		
=R17*(1+S15)	=S17*(1+T15)	=T17*(1+U15)	=U17*(1+V15)	=V17*(1+W15)	=W17*(1+X15)	=X17*(1+Y15)	=Y17*(1+Z15)	=Z17*(1+AA15)	=AA17*(1+AB15)	=SUM(E17:AB17)	=AC17/25
=R18*(1+S15)	=S18*(1+T15)	=T18*(1+U15)	=U18*(1+V15)	=V18*(1+W15)	=W18*(1+X15)	=X18*(1+Y15)	=Y18*(1+Z15)	=Z18*(1+AA15)	=AA18*(1+AB15)	=SUM(E18:AB18)	=AC18/25
=R19*(1+S15)	=S19*(1+T15)	=T19*(1+U15)	=U19*(1+V15)	=V19*(1+W15)	=W19*(1+X15)	=X19*(1+Y15)	=Y19*(1+Z15)	=Z19*(1+AA15)	=AA19*(1+AB15)	=SUM(E19:AB19)	=AC19/25
=R20*(1+S15)	=S20*(1+T15)	=T20*(1+U15)	=U20*(1+V15)	=V20*(1+W15)	=W20*(1+X15)	=X20*(1+Y15)	=Y20*(1+Z15)	=Z20*(1+AA15)	=AA20*(1+AB15)	=SUM(E20:AB20)	=AC20/25
=Assumptions!T26	=Assumptions!U26	=Assumptions!V26	=Assumptions!W26	=Assumptions!X26	=Assumptions!Y26	=Assumptions!Z26	=Assumptions!AA26	=Assumptions!AB26	=Assumptions!AC26	=SUM(E21:AB21)	=AC21/25
=R22	=S22	=T22	=U22	=V22	=W22	=X22	=Y22	=Z22	=AA22	=SUM(E22:AB22)	=AC22/25
										=SUM(E23:AB23)	=AC23/25
=SUM(S16:S23)	=SUM(T16:T23)	=SUM(U16:U23)	=SUM(V16:V23)	=SUM(W16:W23)	=SUM(X16:X23)	=SUM(Y16:Y23)	=SUM(Z16:Z23)	=SUM(AA16:AA23)	=SUM(AB16:AB23)	=SUM(E24:AB24)	=AC24/25
										=SUM(E25:AB25)	=AC25/25
=S12-S24	=T12-T24	=U12-U24	=V12-V24	=W12-W24	=X12-X24	=Y12-Y24	=Z12-Z24	=AA12-AA24	=AB12-AB24	=SUM(E26:AB26)	=AC26/25
										=SUM(E27:AB27)	=AC27/25
0	0	0	0	0	0	0	0	0		=SUM(E28:AB28)	=AC28/25
										=SUM(E29:AB29)	=AC29/25
=S26-S28	=T26-T28	=U26-U28	=V26-V28	=W26-W28	=X26-X28	=Y26-Y28	=Z26-Z28	=AA26-AA28	=AB26-AB28	=SUM(E30:AB30)	=AC30/25
										=SUM(E31:AB31)	=AC31/25
=R59	=S59	=T59	=U59	=V59	=W59	=Y59	=Z59	=AA59	=Z74	=SUM(E32:AB32)	=AC32/25
											=AC33/25
=S30-S32	=T30-T32	=U30-U32	=V30-V32	=W30-W32	=X30-X32	=Y30-Y32	=Z30-Z32	=AA30-AA32	=AB30-AB32	=AC30-AC32	=AC34/25
=IF(S34<0;0;S34*0,21)	=IF(T34<0;0;T34*0,21)	=IF(U34<0;0;U34*0,21)	=IF(V34<0;0;V34*0,21)	=IF(W34<0;0;W34*0,21)	=IF(X34<0;0;X34*0,21)	=IF(Y34<0;0;Y34*0,21)	=IF(Z34<0;0;Z34*0,21)	=IF(AA34<0;0;AA34*0,21)	=IF(AB34<0;0;AB34*0,21)	=IF(AC34<0;0;AC34*0,21)	=AC35/25
=S34-S35	=T34-T35	=U34-U35	=V34-V35	=W34-W35	=X34-X35	=Y34-Y35	=Z34-Z35	=AA34-AA35	=AB34-AB35	=AC34-AC35	=AC36/25
=R60	=S60	=T60	=U60	=V60	=W60					=SUM(D38:AB38)	=AC38/25
										=SUM(D39:AB39)	
=S26-S35	=T26-T35	=U26-U35	=V26-V35	=W26-W35	=X26-X35	=Y26-Y35	=Z26-Z35	=AA26-AA35	=AB26-AB35	=SUM(D40:AB40)	=AC40/25
=S26-S32-S35	=T26-T32-T35	=U26-U32-U35	=V26-V32-V35	=W26-W32-W35	=X26-X32-X35	=Y26-Y32-Y35	=Z26-Z32-Z35	=AA26-AA32-AA35	=AB26-AB32-AB35	=SUM(D41:AB41)	=AC41/25
=S26-S32-S35-S38	=T26-T32-T35-T38	=U26-U32-U35-U38	=V26-V32-V35-V38	=W26-W32-W35-W38	=X26-X32-X35-X38	=Y26-Y32-Y35-Y38	=Z26-Z32-Z35-Z38	=AA26-AA32-AA35-AA38	=AB26-AB32-AB35-AB38	=SUM(D42:AB42)	=AC42/25
=R43+S42	=S43+T42	=T43+U42	=U43+V42	=V43+W42	=W43+X42	=X43+Y42	=Y43+Z42	=Z43+AA42	=AA43+AB42		

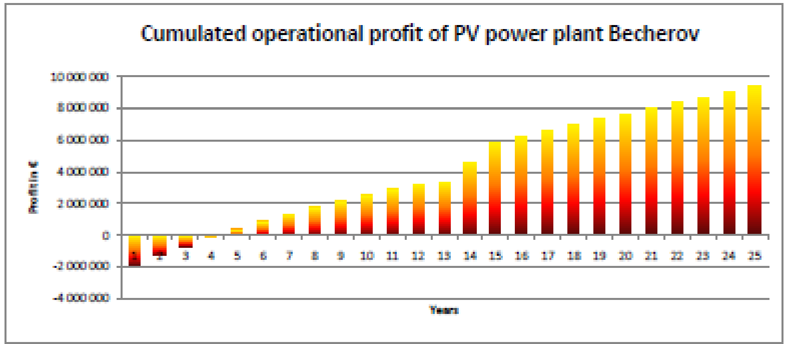
Appendix 8: Project cash flow - PV power plant Becherov (tracking system)

	0	1	2	3	4	5	6	7	8	9	10	11	12
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018	2 019	2 020	2 021	2 022
Operational income		2 032 692	2 012 365	1 992 241	1 972 318	1 952 595	1 933 070	1 913 739	1 894 601	1 875 655	1 856 898	1 869 340	1 881 865
TOTAL OPERATION COSTS (€)		239 967	246 470	253 168	260 067	267 173	274 493	282 032	289 797	297 795	306 033	301 321	310 061
EBITDA		1 792 725	1 765 895	1 739 073	1 712 251	1 685 422	1 658 577	1 631 707	1 604 805	1 577 861	1 550 866	1 568 019	1 571 804
Depreciation		1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626
EBIT		747 099	720 269	693 447	666 626	639 796	612 951	586 082	559 179	532 235	505 241	522 394	526 179
Interest expenses		592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079	280 926	230 891	178 110	122 109
Gross profit		154 857	159 594	166 202	174 782	185 444	198 301	213 477	231 100	251 309	274 349	344 283	404 069
Tax		32 520	33 515	34 902	36 704	38 943	41 643	44 830	48 531	52 775	57 592	72 300	84 855
Net profit		122 337	126 079	131 299	138 078	146 501	156 658	168 647	182 569	198 534	216 657	271 984	319 215
Principal repayment		535 038	566 605	600 035	635 437	672 927	712 630	754 675	799 201	846 354	896 289	949 170	1 005 171
EBITDA – Tax		1 760 205	1 732 380	1 704 171	1 675 547	1 646 479	1 616 934	1 586 877	1 556 274	1 525 086	1 493 274	1 495 720	1 486 950
Cash flow BEFORE repayment of installments	-2 509 502	1 167 963	1 171 705	1 176 925	1 183 704	1 192 126	1 202 284	1 214 272	1 228 195	1 244 160	1 262 383	1 317 610	1 364 840
Cash flow AFTER repayment of installments	-2 509 502	632 925	605 100	576 891	548 267	519 199	489 654	459 597	428 994	397 806	365 994	368 440	359 670
Cumulated Cash Flow	-2 509 502	-1 876 577	-1 271 477	-694 586	-146 319	372 880	862 534	1 322 131	1 751 125	2 148 931	2 514 925	2 883 364	3 243 034
IRR	21,36%												
NPV	€ 2 677 418												
SPP Equity	4,20												

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL	Average
	2 023	2 024	2 025	2 026	2 027	2 028	2 029	2 030	2 031	2 032	2 033	2 034	2 035		
Operational income	1 894 473	1 907 166	1 919 944	809 960	815 387	820 850	826 350	831 886	837 460	843 071	848 719	854 406	860 130	35 224 492	1 174 150
TOTAL OPERATION COSTS (€)	319 062	328 334	337 884	347 721	357 852	368 288	379 037	390 108	401 511	413 256	425 354	437 815	450 649	8 045 278	321 811
EBITDA	1 575 411	1 578 832	1 582 060	462 239	457 535	452 562	447 313	441 779	435 949	429 815	423 366	416 591	409 481	27 179 214	1 087 169
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0		11 501 883	460 075
EBIT	1 575 411	1 578 832	1 582 060	462 239	457 535	452 562	447 313	441 779	435 949	429 815	423 366	416 591	409 481	15 677 331	627 093
Interest expenses	62 804	0	0	0	0	0	0	0	0	0	0	0	0	4 024 391	160 976
Gross profit	1 512 607	1 578 832	1 582 060	462 239	457 535	452 562	447 313	441 779	435 949	429 815	423 366	416 591	409 481	11 652 940	466 118
Tax	317 647	331 555	332 233	97 070	96 082	95 038	93 936	92 773	91 549	90 261	88 907	87 484	85 991	2 447 117	97 885
Net profit	1 194 959	1 247 277	1 249 827	365 169	361 452	357 524	353 377	349 005	344 400	339 554	334 459	329 107	323 490	9 205 823	368 233
Principal repayment	1 064 476	0	0	0	0	0	0	0	0					10 038 007	401 520
EBITDA – Tax	1 257 763	1 247 277	1 249 827	365 169	361 452	357 524	353 377	349 005	344 400	339 554	334 459	329 107	323 490	26 492 301	1 059 692
Cash flow BEFORE repayment of installments	1 194 959	1 247 277	1 249 827	365 169	361 452	357 524	353 377	349 005	344 400	339 554	334 459	329 107	323 490	21 875 686	875 027
Cash flow AFTER repayment of installments	130 483	1 247 277	1 249 827	365 169	361 452	357 524	353 377	349 005	344 400	339 554	334 459	329 107	323 490	11 837 661	473 506
Cumulated Cash Flow	3 373 518	4 620 795	5 870 622	6 235 791	6 597 244	6 954 768	7 308 145	7 657 150	8 001 550	8 341 103	8 675 562	9 004 669	9 328 159		

FINANCING		
Senior bank financing	10 038 007	80%
Equity financing (incl. development cost)	2 509 502	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301183	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	10 038 007	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105	3 018 817	2 069 647	1 064 476							
Total Payment (interest + principal)	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280							
Interest	592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079	280 926	230 891	178 110	122 109	62 804							
Loan Repaid	535 038	566 605	600 035	635 437	672 927	712 630	754 675	799 201	846 354	896 289	949 170	1 005 171	1 064 476							
Capital Outstanding c/f	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105	3 018 817	2 069 647	1 064 476	0							
Interest Cover	2,97	3,09	3,23	3,41	3,62	3,90	4,26	4,74	5,43	6,46	8,40	12,16	20,03							
DSCR	1,56	1,54	1,51	1,49	1,46	1,43	1,41	1,38	1,35	1,32	1,33	1,32	1,12							



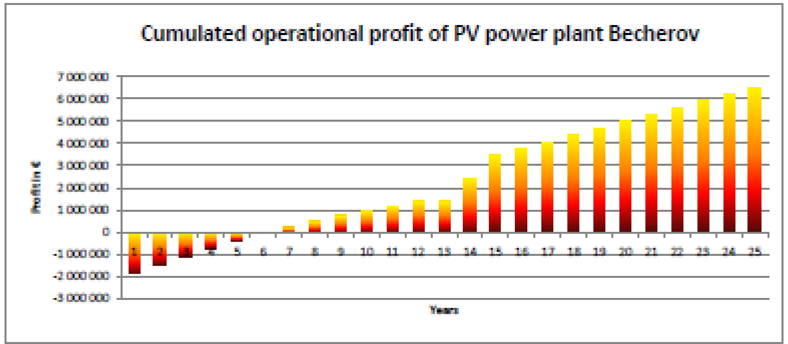
Appendix 9: Project cash flow - PV power plant Becherov (fixed system)

	0	1	2	3	4	5	6	7	8	9	10	11	12
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018	2 019	2 020	2 021	2 022
Operational income		1 633 292	1 616 959	1 600 789	1 584 781	1 568 933	1 553 244	1 537 712	1 522 334	1 507 111	1 492 040	1 502 037	1 512 106
TOTAL OPERATION COSTS (€)		180 364	180 229	185 240	190 401	195 716	201 180	206 833	212 642	218 625	224 780	217 909	224 478
EBITDA		1 452 927	1 436 730	1 415 549	1 394 380	1 373 216	1 352 061	1 330 879	1 309 692	1 288 486	1 267 252	1 284 097	1 287 623
Depreciation		955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254
EBIT		497 674	481 476	460 295	439 126	417 962	396 797	375 625	354 439	333 232	311 998	328 844	332 369
Interest expenses		541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724	256 648	211 027	162 716	111 555
Gross profit		-43 382	-30 741	-21 381	-10 208	2 879	17 985	35 224	54 715	76 586	100 971	166 127	220 814
Tax		0	0	0	0	605	3 777	7 397	11 490	16 083	21 204	34 887	46 371
Net profit		-43 382	-30 741	-21 381	-10 208	2 274	14 208	27 827	43 225	60 503	79 767	131 241	174 443
Principal repayment		488 795	517 634	548 174	580 517	614 767	651 036	689 450	730 127	773 205	818 824	867 134	918 295
EBITDA – Tax		1 452 927	1 436 730	1 415 549	1 394 380	1 372 611	1 348 274	1 323 482	1 298 202	1 272 403	1 246 048	1 249 211	1 241 252
Cash flow BEFORE repayment of installments	-2 292 609	911 872	924 513	933 873	945 046	957 528	969 462	983 080	998 479	1 015 757	1 035 021	1 086 494	1 129 696
Cash flow AFTER repayment of installments	-2 292 609	423 077	406 879	385 698	364 529	342 761	318 423	293 631	268 352	242 552	216 197	219 360	211 401
Cumulated Cash Flow	-2 292 609	-1 869 532	-1 462 653	-1 076 955	-712 425	-369 665	-51 241	242 390	510 741	753 293	969 490	1 188 850	1 400 251
IRR	15,14%												
NPV	€ 1 376 020												
SPP Equity	6,96												

	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL	Average
	2 023	2 024	2 025	2 026	2 027	2 028	2 029	2 030	2 031	2 032	2 033	2 034	2 035		
Operational income	1 522 231	1 532 430	1 542 698	650 812	655 173	659 563	663 982	668 430	672 909	677 417	681 956	686 525	691 125	28 303 292	943 443
TOTAL OPERATION COSTS (€)	231 212	238 148	245 293	252 652	260 231	268 038	276 079	284 361	292 892	301 679	310 729	320 051	329 653	5 869 107	234 764
EBITDA	1 291 019	1 294 282	1 297 405	398 161	394 942	391 525	387 903	384 069	380 016	375 738	371 227	366 474	361 472	22 434 185	897 367
Depreciation	0	0	0	0	0	0	0	0	0	0	0	0		10 507 790	420 312
EBIT	1 291 019	1 294 282	1 297 405	398 161	394 942	391 525	387 903	384 069	380 016	375 738	371 227	366 474	361 472	11 926 396	477 056
Interest expenses	57 376	0	0	0	0	0	0	0	0	0	0	0	0	3 678 566	147 083
Gross profit	1 233 643	1 294 282	1 297 405	398 161	394 942	391 525	387 903	384 069	380 016	375 738	371 227	366 474	361 472	8 249 826	329 993
Tax	259 065	271 799	272 455	83 614	82 938	82 220	81 460	80 654	79 803	78 905	77 958	76 959	75 909	1 732 464	69 299
Net profit	974 578	1 022 483	1 024 950	314 547	312 004	309 304	306 443	303 414	300 213	296 833	293 269	289 514	285 563	6 517 364	260 695
Principal repayment	972 475	0	0	0	0	0	0	0	0					9 170 434	366 817
EBITDA – Tax	1 031 954	1 022 483	1 024 950	314 547	312 004	309 304	306 443	303 414	300 213	296 833	293 269	289 514	285 563	22 141 590	885 662
Cash flow BEFORE repayment of installments	974 578	1 022 483	1 024 950	314 547	312 004	309 304	306 443	303 414	300 213	296 833	293 269	289 514	285 563	17 923 936	716 957
Cash flow AFTER repayment of installments	2 104	1 022 483	1 024 950	314 547	312 004	309 304	306 443	303 414	300 213	296 833	293 269	289 514	285 563	8 753 502	350 140
Cumulated Cash Flow	1 402 355	2 424 838	3 449 788	3 764 335	4 076 339	4 385 643	4 692 086	4 995 501	5 295 714	5 592 547	5 885 816	6 175 330	6 460 893		

FINANCING		
Senior bank financing	9 170 434	80%
Equity financing (incl. development cost)	2 292 609	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301183	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	9 170 434	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728	2 757 904	1 890 770	972 475							
Total Payment (interest + principal)	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851							
Interest	541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724	256 648	211 027	162 716	111 555	57 376							
Loan Repaid	488 795	517 634	548 174	580 517	614 767	651 036	689 450	730 127	773 205	818 824	867 134	918 295	972 475							
Capital Outstanding c/f	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728	2 757 904	1 890 770	972 475	0							
Interest Cover	2,69	2,80	2,94	3,10	3,31	3,56	3,89	4,33	4,96	5,90	7,68	11,13	17,99							
DSCR	1,41	1,40	1,37	1,35	1,33	1,31	1,29	1,26	1,24	1,21	1,21	1,21	1,00							



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Appendix 10: Project cash flow - PV power plant Komárno (tracking system)

	0	1	2	3	4	5	6	7	8
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018
Operational income		2 527 260	2 501 995	2 476 975	2 452 206	2 427 684	2 403 407	2 379 373	2 355 579
TOTAL OPERATION COSTS (€)		239 967	246 470	253 168	260 067	267 173	274 493	282 032	289 797
EBITDA		2 287 301	2 255 525	2 223 807	2 192 138	2 160 510	2 128 914	2 097 341	2 065 782
Depreciation		1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626	1 045 626
EBIT		1 241 676	1 209 900	1 178 182	1 146 513	1 114 885	1 083 288	1 051 715	1 020 157
Interest expenses		592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079
Gross profit		649 433	649 225	650 936	654 669	660 532	668 638	679 111	692 078
Tax		136 381	136 337	136 697	137 481	138 712	140 414	142 613	145 336
Net profit		513 052	512 887	514 240	517 189	521 820	528 224	536 497	546 741
Principal repayment		535 038	566 605	600 035	635 437	672 927	712 630	754 675	799 201
EBITDA – Tax		2 150 920	2 119 188	2 087 111	2 054 658	2 021 799	1 988 500	1 954 728	1 920 446
Cash flow BEFORE repayment of installments	-2 509 502	1 558 678	1 558 513	1 559 865	1 562 814	1 567 446	1 573 850	1 582 123	1 592 367
Cash flow AFTER repayment of installments	-2 509 502	1 023 640	991 908	959 831	927 378	894 519	861 220	827 448	793 166
Cumulated Cash Flow	-2 509 502	-1 485 861	-493 953	465 878	1 393 255	2 287 774	3 148 994	3 976 442	4 769 608
IRR	37,67%								
NPV	€ 5 949 181								
SPP Equity	2,81								

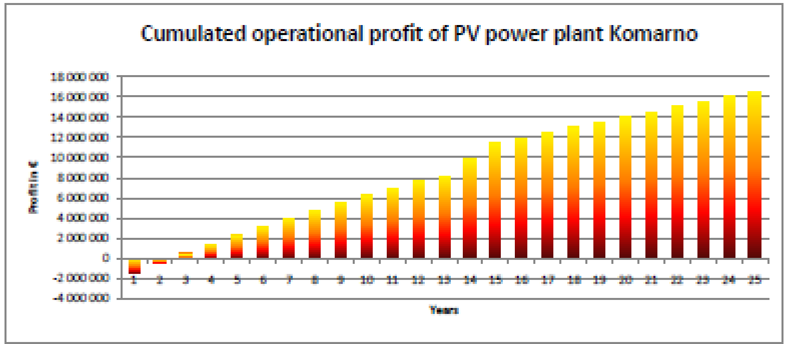
	9	10	11	12	13	14	15	16	17
	2 019	2 020	2 021	2 022	2 023	2 024	2 025	2 026	2 027
Operational income	2 332 023	2 308 703	2 324 171	2 339 743	2 358 419	2 371 281	2 387 088	1 007 032	1 013 780
TOTAL OPERATION COSTS (€)	297 795	306 033	301 321	310 061	319 062	328 334	337 884	347 721	357 852
EBITDA	2 034 229	2 002 670	2 022 850	2 029 683	2 036 357	2 042 867	2 049 204	659 312	655 927
Depreciation	1 045 626	1 045 626	1 045 626	1 045 626	0	0	0	0	0
EBIT	988 603	957 045	977 225	984 057	2 036 357	2 042 867	2 049 204	659 312	655 927
Interest expenses	280 926	230 991	178 110	122 109	62 804	0	0	0	0
Gross profit	707 677	726 053	799 114	861 948	1 973 553	2 042 867	2 049 204	659 312	655 927
Tax	148 612	152 471	167 814	181 009	414 446	429 002	430 333	138 455	137 745
Net profit	559 065	573 582	631 300	680 939	1 559 107	1 613 865	1 618 871	520 858	518 182
Principal repayment	846 354	896 289	949 170	1 005 171	1 064 478	0	0	0	0
EBITDA – Tax	1 885 616	1 850 199	1 855 036	1 848 674	1 621 911	1 613 865	1 618 871	520 858	518 182
Cash flow BEFORE repayment of installments	1 604 690	1 619 208	1 676 926	1 726 564	1 559 107	1 613 865	1 618 871	520 858	518 182
Cash flow AFTER repayment of installments	758 336	722 919	727 756	721 394	494 631	1 613 865	1 618 871	520 858	518 182
Cumulated Cash Flow	5 527 944	6 250 863	6 978 620	7 700 013	8 194 644	9 808 509	11 427 380	11 948 238	12 466 418

	18	19	20	21	22	23	24	25	TOTAL	Average
	2 028	2 029	2 030	2 031	2 032	2 033	2 034	2 035		
Operational income	1 020 572	1 027 418	1 034 293	1 041 223	1 048 189	1 055 222	1 062 292	1 069 410	43 795 880	1 459 833
TOTAL OPERATION COSTS (€)	368 288	379 037	390 108	401 511	413 256	425 354	437 815	450 649	8 045 279	321 811
EBITDA	652 284	648 373	644 186	639 712	634 943	629 868	624 478	618 761	35 749 722	1 429 989
Depreciation	0	0	0	0	0	0	0		11 501 683	460 075
EBIT	652 284	648 373	644 186	639 712	634 943	629 868	624 478	618 761	24 247 639	969 914
Interest expenses	0	0	0	0	0	0	0	0	-4 024 391	160 976
Gross profit	652 284	648 373	644 186	639 712	634 943	629 868	624 478	618 761	20 223 448	808 938
Tax	136 980	136 158	135 279	134 340	133 338	132 272	131 140	129 940	-4 246 924	169 877
Net profit	515 304	512 215	508 907	505 373	501 605	497 596	493 337	488 821	15 976 524	639 061
Principal repayment	0	0	0	0					10 038 007	401 520
EBITDA – Tax	515 304	512 215	508 907	505 373	501 605	497 596	493 337	488 821	30 053 718	1 348 149
Cash flow BEFORE repayment of installments	515 304	512 215	508 907	505 373	501 605	497 596	493 337	488 821	29 037 064	1 161 483
Cash flow AFTER repayment of installments	515 304	512 215	508 907	505 373	501 605	497 596	493 337	488 821	18 999 078	759 963
Cumulated Cash Flow	12 981 722	13 493 937	14 002 844	14 508 217	15 009 822	15 507 418	16 000 755	16 489 576		

FINANCING		
Senior bank financing	10 038 007	80%
Equity financing (incl. development cost)	2 509 502	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301183	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10
Capital Outstanding b/f	10 038 007	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105
Total Payment (interest + principal)	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280	1 127 280
Interest	592 242	560 675	527 245	491 843	454 353	414 650	372 605	328 079	280 926	230 991
Loan Repaid	535 038	566 605	600 035	635 437	672 927	712 630	754 675	799 201	846 354	896 289
Capital Outstanding c/f	9 502 969	8 936 364	8 336 330	7 700 893	7 027 966	6 315 336	5 560 660	4 761 459	3 915 105	3 018 817
Interest Cover	3,83	3,78	3,96	4,18	4,45	4,80	5,25	5,85	6,71	8,01
DSCR	1,91	1,88	1,85	1,82	1,79	1,76	1,73	1,70	1,67	1,64

	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	3 018 817	2 069 647	1 064 476							
Total Payment (interest + principal)	1 127 280	1 127 280	1 127 280							
Interest	178 110	122 109	62 804							
Loan Repaid	949 170	1 005 171	1 064 476							
Capital Outstanding c/f	2 069 647	1 064 476	0							
Interest Cover	10,42	15,14	25,82							
DSCR	1,65	1,64	1,44							



Appendix 11: Project cash flow - PV power plant Komárno (fixed system)

	0	1	2	3	4	5	6	7	8
	2 010	2 011	2 012	2 013	2 014	2 015	2 016	2 017	2 018
Operational income		1 980 005	1 960 205	1 940 603	1 921 197	1 901 995	1 882 965	1 864 135	1 845 494
TOTAL OPERATION COSTS (€)		180 364	180 229	185 240	190 401	195 718	201 193	206 833	212 642
EBITDA		1 799 641	1 779 976	1 755 363	1 730 795	1 706 287	1 681 772	1 657 302	1 632 852
Depreciation		955 254	955 254	955 254	955 254	955 254	955 254	955 254	955 254
EBIT		844 387	824 722	800 109	775 542	751 014	726 518	702 049	677 598
Interest expenses		541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724
Gross profit		303 332	312 505	318 433	326 208	335 930	347 706	361 648	377 875
Tax		63 700	65 626	66 871	68 504	70 545	73 018	75 946	79 354
Net profit		239 632	246 879	251 562	257 704	265 385	274 688	285 702	298 521
Principal repayment		488 795	517 634	548 174	580 517	614 767	651 036	689 450	730 127
EBITDA – Tax		1 735 941	1 714 350	1 688 492	1 662 292	1 635 722	1 608 754	1 581 356	1 553 498
Cash flow BEFORE repayment of installments	-2 292 609	1 194 886	1 202 133	1 206 615	1 212 958	1 220 838	1 229 641	1 240 955	1 253 775
Cash flow AFTER repayment of installments	-2 292 609	706 091	684 499	658 441	632 441	605 871	578 903	551 506	523 647
Cumulated Cash Flow	-2 292 609	-1 586 518	-902 019	-243 378	389 063	994 934	1 573 837	2 125 343	2 648 990
IRR	27,60%								
NPV	€ 3 608 321								
SPP Equity	3,38								

	9	10	11	12	13	14	15	16	17
	2 019	2 020	2 021	2 022	2 023	2 024	2 025	2 026	2 027
Operational income	1 827 039	1 808 769	1 820 887	1 833 087	1 845 369	1 857 733	1 870 180	788 966	794 252
TOTAL OPERATION COSTS (€)	218 625	224 788	217 939	224 478	231 212	238 148	245 293	252 652	260 231
EBITDA	1 608 413	1 583 980	1 602 948	1 608 610	1 614 157	1 619 585	1 624 887	536 315	534 021
Depreciation	955 254	955 254	955 254	955 254	0	0	0	0	0
EBIT	653 160	628 727	647 694	653 356	1 614 157	1 619 585	1 624 887	536 315	534 021
Interest expenses	256 646	211 027	162 716	111 555	57 376	0	0	0	0
Gross profit	396 514	417 700	484 978	541 801	1 556 781	1 619 585	1 624 887	536 315	534 021
Tax	83 266	87 717	101 845	113 778	326 924	340 113	341 226	112 626	112 144
Net profit	313 246	329 983	383 133	428 023	1 229 857	1 279 472	1 283 661	423 689	421 877
Principal repayment	773 205	818 824	867 134	918 295	972 475	0	0	0	0
EBITDA – Tax	1 525 146	1 496 263	1 501 103	1 494 832	1 287 233	1 279 472	1 283 661	423 689	421 877
Cash flow BEFORE repayment of installments	1 268 500	1 285 236	1 338 386	1 383 278	1 229 857	1 279 472	1 283 661	423 689	421 877
Cash flow AFTER repayment of installments	495 295	466 413	471 252	464 981	257 382	1 279 472	1 283 661	423 689	421 877
Cumulated Cash Flow	3 144 285	3 610 698	4 081 950	4 546 931	4 804 313	6 083 785	7 367 446	7 791 134	8 213 011

	18	19	20	21	22	23	24	25	TOTAL	Average
	2 028	2 029	2 030	2 031	2 032	2 033	2 034	2 035		
Operational income	799 574	804 931	810 324	815 753	821 219	826 721	832 260	837 836	34 311 483	1 143 716
TOTAL OPERATION COSTS (€)	268 038	276 079	284 361	292 892	301 679	310 729	320 051	329 653	5 869 107	234 764
EBITDA	531 536	528 852	525 962	522 861	519 540	515 991	512 209	508 183	28 442 376	1 137 695
Depreciation	0	0	0	0	0	0	0		10 507 790	420 312
EBIT	531 536	528 852	525 962	522 861	519 540	515 991	512 209	508 183	17 934 587	717 383
Interest expenses	0	0	0	0	0	0	0	0	3 676 568	147 063
Gross profit	531 536	528 852	525 962	522 861	519 540	515 991	512 209	508 183	14 258 019	570 321
Tax	111 623	111 059	110 452	109 801	109 103	108 358	107 564	106 718	2 994 184	119 767
Net profit	419 913	417 793	415 510	413 060	410 436	407 633	404 645	401 465	11 263 835	450 553
Principal repayment	0	0	0	0					9 170 434	366 817
EBITDA – Tax	419 913	417 793	415 510	413 060	410 436	407 633	404 645	401 465	27 184 134	1 087 365
Cash flow BEFORE repayment of installments	419 913	417 793	415 510	413 060	410 436	407 633	404 645	401 465	22 966 510	918 660
Cash flow AFTER repayment of installments	419 913	417 793	415 510	413 060	410 436	407 633	404 645	401 465	13 796 075	551 843
Cumulated Cash Flow	8 632 925	9 050 717	9 466 226	9 879 286	10 289 724	10 697 357	11 102 002	11 503 467		

FINANCING		
Senior bank financing	9 170 434	80%
Equity financing (incl. development cost)	2 292 609	20%
Interest rate	5,90%	
Loan period	13	
Bank koef.	0,112301183	
Discount rate	8,00%	

	1	2	3	4	5	6	7	8	9	10
Capital Outstanding b/f	9 170 434	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728
Total Payment (interest + principal)	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851	1 029 851
Interest	541 056	512 217	481 676	449 334	415 084	378 812	340 401	299 724	256 646	211 027
Loan Repaid	488 795	517 634	548 174	580 517	614 767	651 036	689 450	730 127	773 205	818 824
Capital Outstanding c/f	8 681 639	8 164 006	7 615 831	7 035 315	6 420 548	5 769 509	5 080 060	4 349 932	3 576 728	2 757 904
Interest Cover	3,21	3,35	3,51	3,70	3,94	4,25	4,65	5,18	5,94	7,09
DSCR	1,69	1,66	1,64	1,61	1,59	1,56	1,54	1,51	1,48	1,45

	11	12	13	14	15	16	17	18	19	20
Capital Outstanding b/f	2 757 904	1 890 770	972 475							
Total Payment (interest + principal)	1 029 851	1 029 851	1 029 851							
Interest	162 716	111 555	57 376							
Loan Repaid	867 134	918 295	972 475							
Capital Outstanding c/f	1 890 770	972 475	0							
Interest Cover	9,23	13,40	22,44							
DSCR	1,46	1,45	1,25