

Follow the Sun!
**How investments in solar power plants
in Sicily can generate high returns of
investments and help to prevent global
warming**

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Abstract:

Germany could have reached obligations set by the Kyoto protocol earlier if German solar investments had been relocated to Sicily. Under the protocol, additional benefits of emission savings and energy production should rise to 72%. However in 2008, German solar power plants only accounted for 20% of the financial benefits through support mechanisms such as EEG for renewable energies, while the share of green energy produced was no more than 4.8%. Although from an economic point of view the system seems absurd; it is adopted by many other countries. This paper will firstly underline the importance of renewable energies being financially supported and why policy makers can justify subsidies for selected technologies through social costs affected by carbon exhaust. The second point is that place does in fact matter and physics sets the limit: the chosen approach for expected final yield shrinks the additional benefits of the theoretical relocated south solar investments to +37%. In closing, the conclusions provide political recommendations for the design of further subsidies of solar energies in Europe.

Keywords: emission savings, renewable energy sources, feed in tariffs, photovoltaics, green investments

JEL classifications: Q42, Q48, Q54, L51, H23

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1. Introduction

Developed countries in particular must swiftly reduce their CO² emissions in large dimensions. For member states of the European Union it is not simply a question of meeting the 20% reduction in line with the Kyoto protocol or the 30% reduction in line with the Copenhagen agreements, but the negative impact on growth of not acting now. The UK-governmental Stern review (2006) states that the costs of natural extremes and the negative long term impact on growth will be much higher for countries that do not act now. Carbon dioxide and other climate gases are causing global warming, the so-called greenhouse effect. "Warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG [greenhouse gas] concentrations were to be stabilised." (IPPC, 2007, 48)

An important milestone in European action for climate protection has been passed by the European Council: the "20 20 by 2020" decree for an obligatory reduction of 20% of CO² emissions and a 20% increase in the share of renewable energies used in total energy production by the year 2020. Thus the question is not if, but how the aims of "20 20 by 2020" should be reached (EU Commission, 2008).

Due to the neutrality of the location of the emissions, the problem in question is how to best reduce CO² exhaust. Photovoltaics are one piece of the puzzle: highly effective solar cells use the almost unlimited potential of solar radiance to produce clean energy without any CO² emissions, but this approach is cost intensive. To date it has not been possible to produce a kilowatt hour of solar electricity at the same price as conventional energies. The challenge is to minimise the costs and to maximise the earnings. Further implementation of European-wide CO² certificate markets would allow better regulation and thus make it easier to intensify the application of certain technologies in the areas in which they are most effective. The varied geographical conditions of different countries demand different needs in terms of energy production and these must be taken into account.

Each member state must reach the European goal and Germany in particular must commit to restructuring the energy mix with the intention of increasing the share of renewable energies through subsidies; this approach must aim to not only produce energy, but also reduce CO² emissions (Klobasa, Ragwitz 2005).

This paper estimates the amount of solar power that could theoretically be produced if German private investments resulting from governmental action between 2000 and 2007 were diverted to Italy. It considers the capacity of photovoltaics that could be

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installed today and thus what the theoretical harvest of electricity and surplus of CO² savings and the additional return on investment could have been.

In Chapter 2 the theoretical framework of social costs due to environmental damage of carbon exhaust is firstly discussed, with a focus on price solutions as emission taxes. Further, the subsidy system for solar power plants in Germany and Italy, as a kind of environmental Pigou tax - caused by a national clearance system will be explained. These mechanisms are important in order to understand how policy makers can justify the high costs associated with promoting solar energy as a privileged technology. The particular intentions of German support regimes for renewable energies to gain research and development support through market demand, trigger changes in social behaviour (Bartle, Vass, 2007) and optimisation of subsidies (Staiß, Schmidt, Musiol, 2007) will also be discussed.

Secondly, the question of what would occur if Germany invested in extra territorial solar plants will be considered. In one of the biggest and southern-most European islands, Sicily, solar irradiation should promise a surplus in solar harvest of up to 85% in comparison to that harvested in Germany. Why not take advantage of higher irradiation and a higher expected electricity production of solar cells? In 2008 the installed capacity in the whole Italy was only 2% of that in Germany. Are there any natural or technological obstacles hindering the realisation of Italy's solar energy potential? To calculate the physical limited solar harvest, modifications of the conventional method for the expected annual yield in Italy will be completed in Chapter 3.

Thirdly, the conclusions in Chapter 4 summarise the cost and benefit surpluses of German solar investments in Sicily and make political recommendations for the design of further solar energies subsidies.

2. Linking the social costs of carbon exhaust to regimes supporting renewable energies

This paper is linked to the environmental economic question of the internalisation and minimisation of both the social costs of CO² emissions and the higher production costs of generating electricity from renewable energies: what is the best practice to reduce CO² exhaust by growing renewable energy investments? Policy makers seek to design support systems that internalise the costs within national markets. The social costs of CO² emissions are described in a broad range of topics, following the first ideas of Pigou (1912 and 1932) when humans first indicated warming as an

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externality not correctly priced in the market. Pigou proposed a tax equal to the ecological damages caused by (carbon) exhausts. Market participants cannot avoid the tax and mitigation will occur where it is most efficient. The concern of the direct exhaust as the cause of pollution and damages to the environment is then discussed within the scope of social costs of emissions (Crocker, 1966), negative impacts on growth perspectives (Bovenberg, Smulders 1995) and external costs of electricity production and CO₂ in modern economies (Krewitt, Schlomann, 2006). It is important to question even the best political actions and the impact of CO₂ certificates on the channelling and reduction of emissions as a choice of prices (taxes) for exhaust or quantities (=certificates) (Weitzman, 1974), where environmental taxes should be the price of the damages (Segerson, 1988).

There are different ways in which renewable energies can be supported. One example being Feed In Tariffs for Renewable Energies (REFITs), which are often adopted in combination with a clearance system. The general design of a REFIT system guarantees investors a fixed price for every kilowatt hour produced and access to the national grid: local grid providers must then absorb the energy. A national clearance system allocates the cost of the system to all consumers of electricity: any REFIT is in itself an instrument that internalises the higher costs of renewable energies. This approach thus led to private decentralised investments in renewable energies but as described by Segerson (1988), due to the surcharge for all consumers it is similar to an energy tax in terms of the uncertainty of environmental damages. Through incentives paid by all consumers as a kind of a Pigou-tax, investors choose the most profitable technique and their benefit in sum is equal to the tax. The damages will be internalised in the optimal proportion to the absolute waste.

Feed in Tariffs are adopted in a broad range of countries; within the European Union 15 of the 27 member states and Switzerland are included. All REFIT have the support of technology without direct subsidies to producers of technical equipment and systems in common. Large solar farms can also profit from REFIT, but often small-sized private power plants are the beneficiaries of a higher tariff. According to analysis of the EU (Jäger, Waldau, 2008), REFITs are highly effective in terms of market stimulation if the return of investment is reached in a period between 10 and 12 years and if the private investors have direct access to local grid connectivity. The author states that the conditions are fitted by the German REFIT and that it appears to be clear that in 2007, 80% of the European photovoltaic capacity was installed in

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Germany.

Produced solar energy is climate-neutral; the production of 1 KWh does not create any greenhouse gas exhaust once the plant is in operation. The German Federal Government announced an extension of up to 59% of renewable energies in order to reach the aim of having 20% of emission savings as officially announced by Nitsch (2008) on behalf of the BMU. The photovoltaics contribution to environmental protection targets is more important than the production of energy. Without renewable energies, the total CO₂ emissions of Germany would be 15% higher, but as stated by Böhme, Dürschmidt (2008), the share of gross electricity production in 2007 was only approximately 6.7%.

It is difficult to price the social costs of carbon exhaust as the exhaust of emissions can be located, but the aftermath or impact can be global. The time perspective makes this task even more difficult. As described by Pigou (1932), the damages through GHG cannot be immediately measured, but the long-term impacts affected by the uncertainties of long periods and the preferences of today's consumption make it also difficult to measure in the longer term. The problem thus arises of how the so called Pigou-tax (Pigou, 1912) for environmental waste can internalise the social costs of carbon damages. The optimum is reached when the tax, social costs of carbon exhausts and marginal abatement costs are equal. Because of decreasing costs of abating exhaust, the tax has to increase in the "growth rate of pollution augmenting" (Bovenberg, Smulders, 1995).

One can calculate the social costs per 1t CO₂ as the aftermath of climate change. The problem is however to examine exactly what "costs" are. Man-made heating pushes nature to extremes and changes the diversity and natural conditions for living. It is thus a question of socially accepted costs, bearing in mind that there are also some positive effects of climate change such as lower mortality through cold winters in Europe. Finally, nobody denies the negative impacts emissions but must decide on the (current) price of carbon emissions. If as suggested by Krewitt and Schlomann (2006)¹, the costs are 70 EUR per ton of CO₂ exhaust, the explained substitution of conventional electricity leads to an avoided social costs of 5.5 Cents per KWh of produced solar electricity. In another dimension, the price for conventional energy from coal must increase by eight Cents/ KWh.

¹ 70 EUR are the middle bound of estimated aftermath through CO₂ exhaust on climate change, where the lower bound is approximately 15 EUR and the upper bound is 280 EUR.

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If the costs of CO₂ are known then the next question asks, what the information is worth; if REFITs per KWh are equal to the social costs of carbon exhaust caused by the production of the energy unit, the optimum is reached in accordance with the ideas of Pigou.

The problem of determining CO₂ savings by kilowatt per hour is the uncertainty with which energy is used for production, but also with which conventional plants are going to be substituted. For the production process of pure silicon, raw material for a high share of solar cells creates high energy outputs that degrade the balance of solar energy.² New procedures decrease energy consumption for the production but at the same time the degree of efficiency is increasing. Krewitt and Schlomann (2006) consider a significant decrease in CO₂ emissions and that the calculated CO₂ exhaust per solar kilowatt-hour will halve from 99g (2000) to 54g (2030e). Through the above explanation it appears clear that it is not acceptable to determine saved CO₂ equivalents with expectations for future power production. There are too many uncertainties with regard to the innovation of newly installed (conventional) power plants and incomprehensible assumptions in the scenarios. It is difficult to reliably calculate the absolute value of greenhouse gas savings by photovoltaics. Nevertheless it seems to make sense to take emissions caused by the production and erection of power plants into account and divide these emissions by the expected solar harvest for an assumed life span of 20 years, which is also the paying-period for many national REFITs.³

The German REFIT serves here as the example for deeper analysis of the state-of-art promotion of renewable energies. Early German dominance in the installed capacity of solar power plants appears to be linked to the role of an early innovator as other countries did not have a similar promotion system as early as Germany. The all-in-one-degree EEG⁴ (Erneuerbare Energien Gesetz) for renewable energies covers amounts of feed in tariffs, duration of subsidies payments, free access to and priority in national grids of application and discrimination of certain technologies. Only

² Spenke, 1956: The so called Siemens production technique is the industrial standard, introduced by Spenke in the Siemens laboratories: trichlorsilane and hydrogen molecules are triggered in a heat reactor, the result is polycrystalline silicon. Trichlorsilane is itself a higher order intermediate good, for its production of silica sand and coke fuse to produce raw silicon at 2000 °C, the next processing is conditioning with hydrogen chloride.

³ The expected lifetime however should be much higher. The German REFIT is already recompensed for an average of 20 1/2 years, in the year of erection plus 20 years; see EEG, 2008, §18, Par. 2. Through this extension the calculated CO₂ emissions per kilowatt-hour are reducing by an additional 2.5%. Renken and Häberlin, (1999) report on early test plants in Switzerland that have been in operation for 30 years without showing a significant degradation of annual solar harvest.

⁴ While the feed in in the grid is covered by §16 EEG, the legal foundation for the general grid access is the former decree StromNZV; for biogases and renewable fuel classifications see also BiomassV.

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plants in the national area of the federal state can apply for subsidies as positively discriminated by §§23-33 are e.g. Photovoltaics and other less efficient technologies.⁵

It is important to consider that subsidies paid to green energy producers are non-government⁶ payments. The paid REFIT subsidies are incorporated into the earnings of the power plant owners, the producers of eligible energy are receiving guaranteed compensations from the local grid carrier, while the additional costs over market price are a surplus on the bills paid by all consumers.⁷ A nation-wide clearance charges the proportionate costs internally to every kilowatt per hour sold, whether produced renewably or conventionally. The entire financing of both renewable energy plant erection⁸ and feed in tariffs comes from the private sector and consumers. Subsidies mean a reallocation within the market that is a steering effect of the EEG. The electricity price increase is thus a kind of environmental tax and should aim to avoid energy consumption.

The EEG is not only a support of a status quo technology, but also pushes employment and R&D in this sector. The knowledge allows companies to enter global markets as innovators. The German photovoltaic industry in 2007 for example consisted of 43,000 employees, a turnover of about 5.7 Billion EUR (BSW, 2008) and an international market share of around 30% (Dürschmidt, Van Mark 2006); all of which in turn led to an increase in R&D and acceleration of the learning curve. It must be stated that during this time the prices did not decrease in proportion to the innovative progressions undertaken at the same time (Forst et al, 2006).⁹

*Through the Conto Energia II*¹⁰, Italy can be named as an adopter of the EEG where numerous national and regional laws were replaced with the intention of supporting renewable energies. Some local laws in addition to those at the national level are still

⁵ The highest tariff counts for the privileged solar energy technology, see also BDEW, 2008: The electricity produced by solar power plants has a share of about 4.6% of all renewable energies, while the share of REFIT compensation (according to EEG §§ 6-11) is round about 20%.

⁶ See the judgement of the Court of Justice of the European Communities, C-379/98, 2001, I-2099, PreussenElektra: because the obligation to feed renewable energies is not granted directly by the state and "does not constitute State aid within the meaning of Article 92(1) of the Treaty."

⁷ Exceptions are made for industries with a high quantified consumption of electricity.

⁸ The federal owned KfW bank announced different promotions for private investments in renewable energies, as e.g. interest-reduced credits for grid connected solar power plants with an output of up to 50 kWp e.g. the so called "100.000-roof-programm" (2000-2003). Since 2004 the programme continues with similar promotions. The KfW is organised as a private sector bank.

⁹ Caused by high market demand firms sold with increasing margins. In addition, shortages of silicon production led to increasing panel prices between 2004 and 2006, converter prices were shrinking.

¹⁰ DM 19/02/2007, following a former law, the "Conto Energia I", DM 28/07/05 and 06/02/06, that was not even valid for one year because of capacity limitation, see Pasquini, Vacca (2006): the author noticed that the primary limitation of supported capacity of 100 MW was completely demanded in the first month after declaration of the national law.

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legal with respect to the national decree¹¹, but policy makers learned from the failing of the former decree. Local political regimes can no longer avoid solar power plants, but still provide minor influence.¹²

When considering the details there are further differences to the German law, for example the charge for newly installed plants is adjusted annually in accordance with DM 19/02/2007, Art. 6-9 and the legislators focussed at a very early stage on the hierarchical feed in tariff with positive discrimination for certain technology, such as totally or partially integrated roof solar power plants. This led to a significantly higher demand in Italy for less profitable technologies, where there is no (relevant) market in Germany. In Italy, after the amendment to the Conto Energia II, 26% of the newly installed capacity in 2008 was architecturally integrated, mostly roof integrated, as discussed by Montanino (2008).

The grid carrier has the obligation to feed-in electricity produced for power plants below 1 MWp. As discussed above, other regulations like the former decree of green certificates apply, which forces the grid carrier to absorb a mandatory quota of renewably produced electricity but also means a limit in terms of absorption obligations. Thus the Italian REFIT is more flexible. The green energy certificate quota applies also to extra territorial. If the German EEG were adjusted in the same way, the calculation done in the next chapter would no longer be imaginary. The fundamental elements have been laid to open Italy as the German granary for the solar harvest, but some legal issues remain and the structure must be modified:

1. The Conto Energia II specifies high commission for produced electricity, but is limited through DM 19/02/2007, §13, Par.1, to a maximum capacity of about 1200 MWp, which is only a little more than the sum of newly installed plants in just one year in Germany. Thus Italy does not take advantage of its full sun potential.¹³
2. The state-of-art design of the many national REFITs actually led to a higher share of small private investments. The Italian market shares already changed dramatically in the first year after the declaration of the Conto Energia II; the average size of newly installed plants shrank while their sum grew as measured by GSE in 2009. For

¹¹ e.g. for simplification, the simple building notice is at local administration instead of an official building permit. Even the protection of historical architecture expired in certain cases and if the erected power plant is for example roof integrated, regional decrees are allowed for regional architectural compliance or limitation to certain areas.

¹² The limitation of a supported capacity of 100 MW was completely demanded in the first month after declaration of the national law, according Pasquini, Vacca (2006). Thus in 2009 the national authority GSE noticed and this led to an increase in new investments instead of boosting it up.

¹³ Spain, with similar radiation conditions did not implement such a limitation before 2009 and can count newly installed capacities of almost 2000 MWp in the year 2007, as measured by state authority CNE 2008.

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maximum efficiency, solar parks appear to be the better solution and thus must be proved in the following.

3. Limitations placed on the solar harvest by the physical conditions

If the general calculation of the expected yield, the solar harvest, would be the same as the global radiation E_{eg} in watt per square metre multiplied by the peak capacity in kilowatt KWp of the solar power plan as the final yield Y_F in kilowatt, the calculation would be completed here:

$$(1) \quad Y_F = E_{eg} \cdot KWp$$

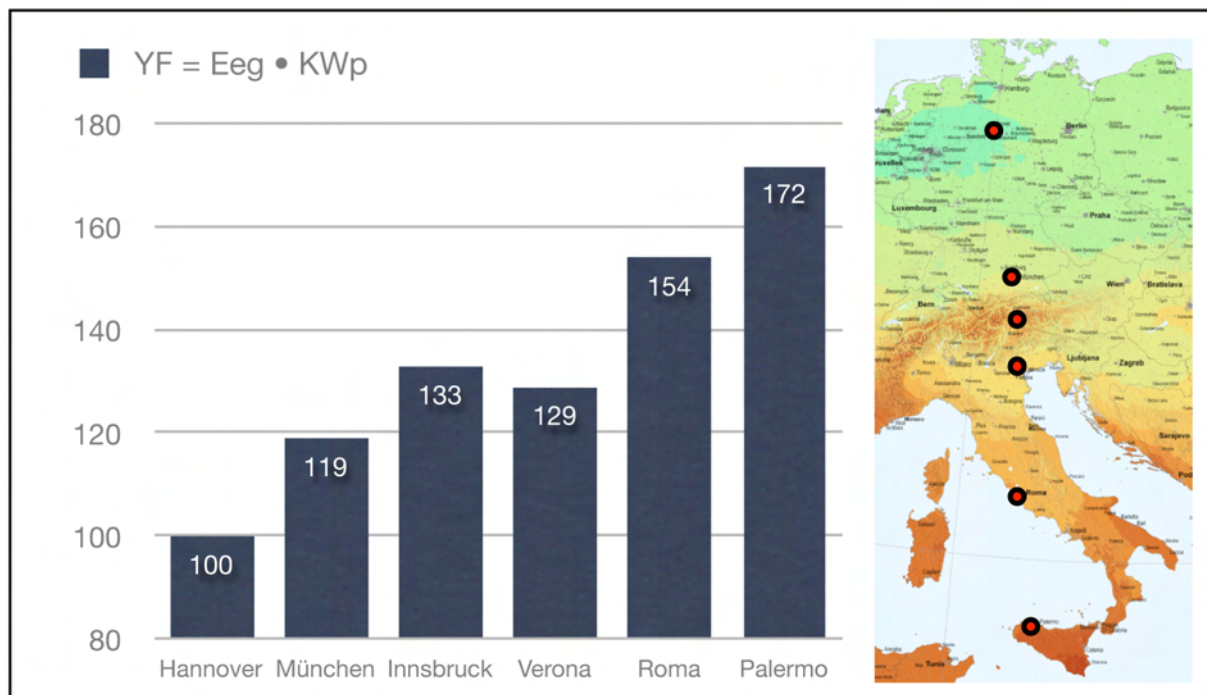


Figure 1: Index for expected final yield, traditional approach, Hannover = 100

Source: own calculation according PV-GIS

The result indicates that the increase in efficiency of the solar harvest should be about 72% when installed in Palermo, relative to a plant in Hannover. For such a simple calculation we must of course obtain standard test conditions (STC)¹⁴. In addition, there are some parameters with unclear effects. What impact on the solar harvest does for example, topography, air pollution or general losses have?

The chosen approach modifies the conventional calculation method due to geological and meteorological conditions but is also used in technology. In the following, the factors, preconditions and parameters will be discussed and evaluated for the

¹⁴ Generally we cannot have these special conditions outside any laboratory: STC force an inner cell temperature of exactly 25° C, a radiance of 1000 W/m² and an air mass about 1.5. The STC serve to compare different module types and producers. For different geographical locations one has to take into account the specific environmental conditions which can differ in fundamental dimensions.

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analysis to ensure that the expectation or discard are marginal: the physics are the limitation for the economics and thus limit the return of investment. Thus, most common state of the art technology will be expected. The reader can gain more in depth information in the technical appendix for their own modifications within on-going technological development or individually applied yield calculations for specific locations.

Temperature losses: The performance of silicon based solar panels is dependent on inner heating. The warmer the cells, the weaker the absorption potential in accordance with the surrounding temperature and the power of solar radiation. For comparisons, the cell temperature coefficient is measured to the STC. Through this generalisation any aberration above 25°C leads to a negative and any below to a positive performance effect. The question that thus arises is whether solar panels are as effective in the warmer south as in the colder north. Temperature losses appear to be the factor that most influence the differences in macro comparisons of regional yields.

The temperature in the cell is linked to the environmental conditions, but can also be regulated in a certain spread by cell design. To approximate the annual temperature loss for a specific location, the measured surrounding temperature T_s has to be corrected, a surplus of $\Delta^\circ\text{C}=7$ would be sufficient for further calculations due to the often missing data on day length temperatures.¹⁵

The kind of installation is also important, especially the cooling on the back side of the panels: the correction factor due to installation should be T_i , with $\Delta^\circ\text{C}=10$ for on-roof plants and $\Delta^\circ\text{C}=20$ ¹⁶ for roof integrated plants-

The radiance intensity in watt per square metre is the most important factor when calculating regional differences for expected yields and is also responsible for heating the panels. The cell temperature follows the radiation curves over the day and year and thus lead to a heat surplus of $\Delta^\circ\text{C}=\text{W}/\text{m}^2 \cdot 0.03$ ¹⁷

¹⁵ One has to pay attention to the seasonal path of the sun and diverse lengths of days. Solar electricity will be produced over the day, foremost in spring, summer and early autumn. Discrepancies in the day lengths caused by north-south positioning will not be taken into account, but micro climates, influenced by e.g. vegetation or buildings can dramatically differ as shown by Renken, Häberlin (1999).

¹⁶ STC are most equal to installations in the plain or with triangle brackets on flat roofs, while on-roof panels have a higher inner temperature.

¹⁷ There is no generalised correlation for the cell heating. The laboratory experiments and field studies by the named authors, but also BETT 2008 refer heating per $\Delta\text{W}/\text{m}^2=100$ between. $\Delta^\circ\text{C}=4$ up to $\Delta^\circ\text{C}=5,3$. Not all types of cells are effected in equal measure.

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The producers of solar panels are intensifying research for the better design of temperature management in the cell¹⁸ which results in a smaller temperature correction factor. Locations exposed to warmth and sun will benefit in particular, the advantage for Sicily continues to increase.

The calculation is thus modified as follows:

$$(2) \quad Y_F = E_{eg} \cdot KWp \cdot K_T \quad ; \quad \text{where } K_T = 1 - 0.005 (7 + T_S + T_I + E_{eg} \cdot 0.03)$$

Converter losses: Solar power plants need a converter. Silicon made solar cells operate as semiconductors and absorb photons, which are light quanta. These particles are the smallest energetic loaded elements of light. Through the absorption of photons in the solar cell it is possible to harness the solar energy. The flow of the photons is the direct current of electricity and will be converted into an alternate current at the converter. The converter charged electricity can be fed into the national grid.

The converter causes losses in operation because of permanent power fluctuations. Other reasons for converter losses are heat, inadequate capacity or frequent voltage fluctuation. In the following an analysis will account for a loss of 3%, which is the lower bound for the average loss of state of the art converters.¹⁹

The calculation is thus modified as follows:

$$(3) \quad Y_F = E_{eg} \cdot KWp \cdot K_T \cdot K_C \quad ; \quad \text{where } K_C = 1 - 0.03$$

General losses: There are other factors that have either a positive or negative influence on the solar harvest such as aerosols and topography. Please refer to the technical appendix for further details. To summarise all of the effects, in the following a general correction factor of 4% will be introduced to the calculation. Thus conditions that are highly determined by local conditions but equally distributed for all power plants in general are included.

The calculation is thus modified as follows:

$$(4) \quad Y_F = E_{eg} \cdot KWp \cdot K_T \cdot K_C \cdot K_L \quad ; \quad \text{where } K_L = 1 - 0.04$$

Radiation angle: Solar cells can produce electricity through photon absorption only if the light energy penetrates. The light itself is a component of two kinds of radiance:

¹⁸ Heating will decrease through extension of surface, better air flow or new materials.

¹⁹ An exception, that modern converters often beat, the absolute factor influence will increase. See Market survey and regularly tests by e.g. Photon, 12/2008, 66-72.

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direct normal radiation²⁰, light which comes directly from the sun and diffuse radiation, which is broadly dispersed through reflections and mirroring. Both types of radiance when used in conjunction are the so called global solar radiation and the measuring unit for calculation of the expected yield. In the near future, photovoltaics must be compared with concentrated solar heat, a technique which uses direct normal radiation.²¹ This technique has an impact on the direct comparison of the global solar radiation into the two decoded components named above. In the following the twice declaration of radiance types is renounced because the intention of this paper is to analyse the efficiency of photovoltaics in different areas and not conduct an evaluation of techniques.

To summarise this effect, the structure of power plants is too varied to adopt an additional correction factor and investors will seek to erect cells at the best angle. Minor losses due to an incorrect installation angle appear to be marginal and will be included in the general correction factor explained previously.

Module efficiency: The module efficiency is important where space is a limiting factor. The following analysis will be calculated using average module efficiency.²² Plants that were newly erected in 2008 were constructed with the same shares of mono and poly crystalline cells. This technology mix expects an efficiency of about 15%, however due to a rising share of the less efficient thin film modules²³ efficiency decreased to about 12.75%.²⁴ For the plain installation it signifies the need for approximately 8 square metres to install a nominal capacity of 1 KWp. The calculation can be modified for the expected yield per square metre, what is important for individual investment calculations where the ground has a price that must be taken into account.

$$(5) \quad Y_F = Y_F/m^2 = E_{eg} \cdot K_G \cdot K_T \cdot K_C \cdot K_L \quad ; \quad \text{where } K_G = 1 - 0.875$$

²⁰ For maximum use of the direct normal radiation, solar panels have to be installed in a 90° angle to the sun light radiance. The angle of installation grows smaller the further south the position is, on the equator the angle is 0 ° to ground.

²¹ In Southern Europe the direct irradiation is on a very high level which allows the operation of concentrated solar heat plants. Solar radiance is bundled to a very high concentration to heat a carrier like oil. The accumulated heat can be converted into electricity. The advantage is a certain possibility to save heat for later use in the carrier. Energy production costs are low.

²² The module efficiency is not the same as the cell efficiency that counts higher rates but is not relevant in practice. For realised power plants it is very important to know the need of the plain needed because installation does not imply the installation of only cells but modules.

²³ Forst et. al (2006) mentioned a 93% market share for mono- and poly crystalline panels.

²⁴ This is a market typical condition for solar power plants. The basis are markets that offer poly crystalline cells, e.g. BP 3170, Umweltfreundliche Haustechnik GmbH, Göttingen, Germany 2008.

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Prices: Given the question, what is the expected return of investment, one has to estimate the price. Due to the use of the 2008 data base, the total costs are fixed for the year. For the erection of a solar power plant with the capacity of 1 KWp, approximately 400 EUR of capital was required for an on-roof installation and 4200 EUR was required for the installation of plain roof or ground plants.²⁵

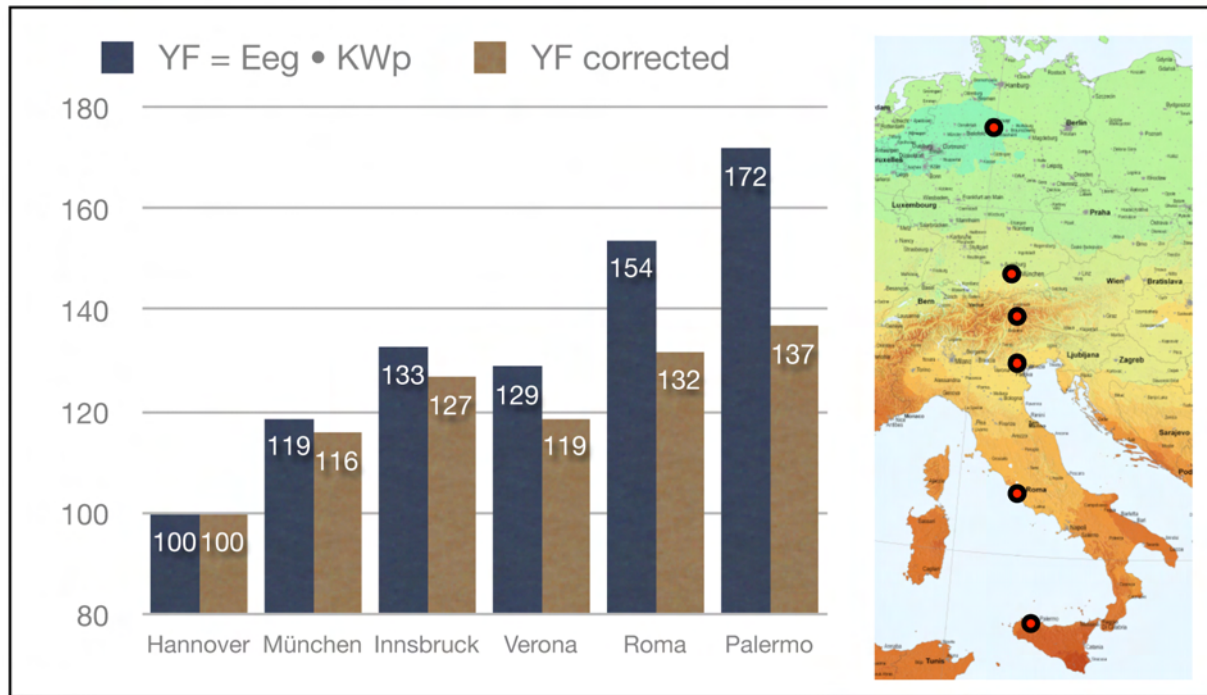


Figure 2: Index of expected final yield, modified approach; Hannover = 100.

Source: own calculation according PV-GIS

The calculation formula for the final yield has been modified as follows:

$$(4) \quad Y_F = E_{eg} \cdot KWp \cdot k_C \cdot k_T \cdot k_L$$

or
$$(5) \quad Y_F/m^2 = E_{eg} \cdot K_G \cdot K_T \cdot K_C \cdot K_L$$

where the price is fixed, $P = P_{KWp} = P_{2008}$

4. Final calculation and conclusions

The application of the Conto Energia II in comparison to the EEG raises the following question: What additional benefits accumulated from solar investments in Italy equal the amount invested in Germany between 2000 and 2007 in CO₂ savings, energy surplus and return on investment?

²⁵ The global financial crisis led to a price dampening effect, it is unknown if this impact is only for the short term or for the long term also. Further, before analysts noticed an annual price decrease between 6-8%, see e.g. WEST LB Research (2009). The market is changed to a buyers' market, according Zindler, McCrone (2008).

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The factors and their influence on solar harvest have been introduced and discussed above. In the following these factors will be drawn together and statistical data from Germany will be used to merge the different years into one table and show the sum of solar energy investments that occurred after the declaration of the EEG. The figures will be a little higher than the expectations completed in this paper. This can be interpreted as a sign of conservatism, but true assumption of criterions. Exactly the same investment sum will be converted for Italy. The calculation follows the determination of Staiß, Schmidt and Musiol (2007) that 1 KWh of solar energy accounts for a saving of about 787 kg CO₂ equivalent.²⁶ The CO₂ savings are accounted for in accordance with a cross section analysis (Klobasa, Ragwitz, 2007) that assumes solar electricity substitutes to 50% natural gas and to 50% mineral coal plants.²⁷ Solar power is not a very secure resource as it is produced following the cycle of the sun, but on the contrary, a key advantage is that this cycle more or less reflects power consumption; peak periods during the day time and summer (air conditioning in offices) are often covered by the high performance of solar power plants at the same time. Due to a lack of accumulators, electricity is not storable and has to be consumed in the moment of production; as a result solar energy cannot yet substitute conventional plants, but can substitute gas and coal.

Firstly, for the purpose of the analysis, only areas with an average annual radiance of about 1750 KWh will be advised for on-roof plant installation that can be found particularly in Sicily, but also with minor deductions on the mainland of Italy (Apulia, Calabria) and in the south of Sardinia. No technology processes that occurred after 2008 will be taken into account, the status quo will be fixed for cost prices and the degree of efficiency.

Secondly and importantly a deeper analysis on the arrays, systems that adjust panel orientation over the day and annually track the sun will be included. Such arrays have a strong positive influence over the final yield. Nevertheless such systems are neither cheap nor dedicated or financially feasible. However, the advantage is obvious. The solar panel is always orientated to the sun and the direct normal radiation can thus be optimally used ensuring the potential to reach the maximum

²⁶ CO₂ equivalents are a theoretical measuring unit, which not only take into account direct CO₂ emissions, but also other emissions that are excreted into the atmosphere and are boosting the greenhouse effect: CH₄, Methane, and N₂O, nitrous oxide. They are converted for better comparison according to scientific standards to a show their effect as they were CO₂. This method is globally accepted and adjusted, to have equality of national emissions analysis.

²⁷ The CO₂ savings are not calculated explicitly, some observed studies also contain initial operation losses of substituted plants.

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yield is always present. The benefits are especially present when the direct normal radiation is high.

Thirdly, a calculation will be completed for the areas exposed to the sun, where additionally the Italian power supplier ENEL could invest in solar farms instead of erecting new nuclear power plants which according to the economic plan, are budgeted at 24 Billion Euro. Is solar energy an alternative? What would be the production cost for one kilowatt-hour? Would the grid parity be reached?

1) Table 1 shows all German investments for the erection of new solar power plants since the first declaration of the EEG in 2000. Values are estimated from an analysis conducted for the German Federal Ministry of Environment. For a better valuation of investments made, amounts are adjusted by the annual inflation rate and thus show the real presence equivalent for 2008. The total production of German solar energy

Table 1: Global annual irradiation per square metre (kWh/m²):

	<u>newly installed capacity MWp</u>	<u>total electricity production (GWh)</u>	<u>Real turnover from construc- tion of solar power plants</u>
2000	42	22	343 Mio. €
2001	78	74	507 Mio. €
2002	80	146	575 Mio. €
2003	150	271	709 Mio. €
2004	610	515	2430 Mio. €
2005	863	1240	3183 Mio. €
2006	830	2178	3888 Mio. €
2007	1100	3458	4782 Mio. €
Total	3753		16417 Mio. €

Source: own calculation according to data of BMU, 2001-2008 and ECB, 2009

for the capacity of 3753 MWp between Rhine and Oder was approximately 3458 GWh, with CO₂ savings of around 2,400,000t in comparison to conventionally produced energy according to the approach shown above.

General technical conditions are the same for each location and thus can be eliminated for the calculation with relative, but not real comparisons: losses by the converter, soldering joints, cables etc. and the degree of efficiency.²⁸

²⁸ Newly developed solar panels are more efficient, but production costs are higher and thus realisable capacity can be smaller with newer technologies where investment is steady. Technological progresses will influence the yield per installed capacity of 1 KWp or reduce the required ground area. The learning curve favours later investments and would influence the profitability positively, but is not taken into account in the calculation due to many uncertainties

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The only correction factor that is always very important is the temperature which as explained before, minimises the degree of efficiency. Positions have been taken typically for the chosen regions.²⁹ Roof integrated power plants will not be included because they do not account for a high market share.³⁰

If Germany EEG supports are converted to Sicily, the expected production cost per kilowatt-hour is about 19 ct. The additional solar harvest provides an amount of 860 GWh and a surplus in CO² emission savings of 665,000 tons and thus for the investors, the additional return is approximately 370 million Euro per year. Because the lower costs are significant grounds for solar farms, the harvest could be enlarged if it were the intention of the (local) policy maker. The investment sum thus leads to a higher installable capacity.

2) The use of the tracking systems could cut the electricity production price per KWh down to 16.5 Cent. Due to the higher system prices through tracking systems, the installable capacity increases by 20%. The additional harvest suffices in lean scales to generate a positive effect, but if the lifetime can be extended, tracking systems will become a very economical alternative.

3) Controversial discussions in politics and enormous investments in the power supply company ENEL are present. If the planned investment of about 24 Billion Euro for new nuclear power plants could be invested in solar parks with tracking systems, over a 20-year life span, one kilowatt-hour could be produced for a price of about 12.2 Cents.³¹

As described by Nitsch (2008), the German EEG was designed to stimulate the market and force cost reductions through market growth. The conclusion of this paper underlines the success of the REFIT for the new installation of and R&D in solar power plants. But further, it is proved that investments in other European regions would be more lucrative and efficient. Italy can account for a higher solar harvest in the regions of Sicily, Sardinia and on the mainland (Calabria / Campania) when using the same installed capacity. Without REFIT, grid parity can be reached in

²⁹ *Single positions can differ, but not only positively: as negative aberrations higher temperatures or less radiance can be called, e.g.*

³⁰ For individual investment calculations however, the higher heating of on- roof installations with a surplus of 10 degrees in comparison to on ground installations has to be taken into account. That seems to make sense if the recommendation pro or contra support of on- roof plants or solar parks is an intended.

³¹ The investments of ENEL in nuclear power plants do not produce any electricity and thus the production costs have to be taken into account and are announced by 4.3 Cent / KWh.

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the South of Europe. A scenario with a system of decentralised solar power plants as established in Germany through the EEG would lead to an increase in efficiency of about 25%. If the investment sum of 2008 would be divided into the expected solar power harvest of one kilowatt-hour, it could be produced for 19.02 Cents, whilst the average market price in 2006 was approximately 21.08 Cents, as accounted by Goerten, Clement, (2006).

Through better heat management, losses can be reduced in the near future and thus benefiting in particular, locations with high surrounding temperatures and intensive radiance. Time is running for Italy and the advantages will continue to grow.

It is difficult to complete a monetary validation of the EEG programme. Surveys conducted by Frondel et al (2007 and 2008) account for a subvention of 108,000 to 205,000 EUR for each employee in the German solar sector. The analysis considers the REFIT transfer payments paid for the past and those estimated for the future. The amount is then divided by the number of employees. The author calculates a life cycle balance, but remains with a fiscal result without taking into account external social costs of CO₂ emissions and thus the survey differs from the approach of this paper.

It is important to not only act as the innovator for techniques, but also for policies. Wiekert (2008) expects a stagnant German market and thus the domestic companies are forced to enter foreign markets. The EEG itself is a successfully exported and accepted model for many countries across Europe and the world. The German EEG is generally adopted with only small adjustments made to meet local needs.

While the European Union (1996) declared within Directive 96/92/EC that European wide energy markets would be open as the goal for 2007, discrimination through national supporting systems for renewable energies remained legal to avoid a concentration of investors at the most profitable REFITs. Thus, following the conclusions of the calculations completed here, the efficient implementation of solar power plants for example, was renounced.

If German investments had been accrued over the years and invested in solar parks with tracking systems in the Sicilian area in 2008, a European wide single market with clearing mechanism, Germany could have accounted for an additional reduction of about 1.2 million tons of CO₂ per year. This correlates to two thirds of the 2005 emissions from the production branch "ground transportation and transport in pipelines" or further is even 0.1 million tons more than from "shipping"³². It also

³² Destatis 2008, Document 85111-0001

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implies a potential avoidance of social costs accrued through CO₂ emissions of approximately 84 million Euros. Measured by the total energy-induced CO₂ emissions of Germany in 2006 at about 819 million tons³³ per year, the additional contribution of total greenhouse gas savings would be approximately 0.15%. In relation to the obligations as stipulated by the UN Kyoto Protocol³⁴, this would account for a saving of around 0,5% of total CO₂ equivalent saving obligations, whilst the additional amount of power supply of 1519 GWh accounts for only 0.25% of gross annual electricity production.³⁵ The United Nations protocol provides for the arrangements that allow such projects as proposed in the calculation. Kyoto Protocol Annex-B states, as Germany and Italy can stipulate "Joint Implementation" and count additional CO₂ savings extra territorial as done inter territorial to fulfil the contractual terms.

The objectives of the politicians through the "20 20 by 2020" treaty would be more rapidly reached if Europe would act as a single player. Those member states in the South should now in particular accept photovoltaics as one component of their future energy mix and climate protection aims. A path-goal-strategy must implement a REFIT parallel to the German model for market stimulation and inter Union concentration on technologies at the place of highest efficiency is recommended. This approach would reduce CO₂ emissions faster and thus the European Union could apply more pressure on other states worldwide to intensify their contribution and efforts in preventing global warming.

³³ Energy caused CO₂ equivalents, as analysed by Böhme, Dürschmidt, (2008)

³⁴ The obligations in CO₂ savings according the Kyoto-Protocol for Germany account for 257 Million tons of carbon equivalent exhaust by 2012 in relation to the basic of 1990.

³⁵ 2006, datasource: BMU

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Technical Appendix to Chapter 3

Technological terms and conditions used for the approach outlined above.

Temperature losses: An aberration from STC of $\Delta^{\circ}\text{C}=1$ leads to a temperature loss of 0.5% for silicon based cells, as broadly shown in a series of papers (Armani et al, 2007 (verifying Bucher, 1997), Häberlin, 2007, Rüdiger et al, 2007). The authors demonstrate the influence of the natural surrounding temperature. The reasons for a lesser performance appears to be a worsening absorption potential of silicon, and another coloration of the light, a variation in wave lengths, which cannot be absorbed from the cell, with a boosting of the effect the higher the temperature is.³⁶

Converter losses: Even if the sun is shining brightly, the radiation alternates permanently. The converter tries to "catch" the maximum power point (MPP) valid in a certain moment. It is an approximation³⁷ and is forced to be done uninterrupted. It seems to be clear that it cannot be more than a try of optimisation. At low radiation converters are less efficient because of physical limitations. The higher the radiance, the lower the losses of the converter are. If the nominal capacity of the solar power plant is less than 30% of the converter capacity, the degree of efficiency also decreases significantly.

General losses:

- Ground and topography: Different soils have different absorption characteristics. Barren, rocky soils for example reflect more radiance due to a lower absorption potential of photons, in opposition to e.g. green lawns. Pollution through pollen of near plants or the specific micro-climate (wind, rainfall, heat) also affect the system performance.
- Geographic location: Urban areas are heated more than rural areas. Locations near to the sea will benefit from light reflections of the water surface; sandy ground reflects radiation, while forests absorb photons. In the mountains it is more likely to have snow, with subsequent failure of performance of the covered modules, as in the lowland areas.
- Aerosols: Aerosols are the smallest particles of air pollution. They have a direct impact on the location of their origin,³⁸ but are not necessarily affected adversely by urban areas. Metropolitan areas basically have a high level of air pollution caused by exhaust emissions from traffic and industrial pollution, but here reflected global radiation can even increase. Thus the reduction of direct radiation caused by misty skies can at least be compensated. In contrast, rural areas are more polluted by pollen. Near to the seaside salt particles impact the pureness of the sky.

³⁶ See Jaus et al (2008), Rüdiger et al (2007), and Kapusta, Karner, Heidenreich (2002): An additive correction factor should be designed exponentially. But on the other hand, under less intensive radiance condition, solar panels do not operate in the maximum power point MPP, and the resistance of material is becoming more important in per cent figures. In conclusion one should agree to the simplification completed above.

³⁷ See Häberlin, 2007, 280-289: Converters are modularly designed: solar panels are connected string by string. Every converter has a specific performance which is limited. For bigger power plants converters can be combined to reach a common higher maximum performance. If the performance is lower than the power plant capacity, any operation under full load will lead to a loss in electricity production due to the capacity to convert the whole current conduction in the connected strings being too small.

³⁸ Häberlin, Graf (1998): The non-representative survey calculates a 10% loss of generator due to pollution by settled particles on the panel surface.

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In accumulation, aerosols can reach higher air layers of the atmosphere. They influence the formation of clouds in quantity and quality. Lohmann (2006) describes this as follows: The less the land mass, the less the sky cover.³⁹

- Altitudes: Higher locations are more favourable than valleys, they benefit particularly in months with minor radiance. The exposed positions lead to an advantageous angle between the panel and the sun, and the manner of sun radiation is shorter (the so called "air mass"). Is the sun is low, the incoming radiance to fix-mounted panels on mountains is better than in the plains. In addition, covered skies and temperatures are lower over the annual period. These pros can be named for solar power plants in the mountains, but seem to be less relevant for most investors.
- General losses: An almost optimal installation cannot prevent losses through e.g. breaks of soldering joints or cables, leakage currents or the occurrence of minor defects and a little degradation over time, but Renken, Häberlin (2003) mentioned no significant effect in the long term survey.

Radiation angle: Useful for the final yield is the all penetrating radiance: especially when skies are covered by clouds, reflected radiance by mist or aerosol pollution can reach high values and compensate installations not done in the optimum angle. For latitudes of < 45 ° North the proportion of diffuse radiation can become even more important than the direct normal one, as shown by Quaschnig, Geyer (2001).

The installation angle appears to be very tolerant: +/- 20° aberration to the optimised angle which led to a radiance loss of around 5%: Even if different locations in Europe are compared by optimum angle and 0° (=plain) installation of solar panels, the difference is not very high. In addition, an azimuth aberration of up to 60° in West-East-direction from optimum South-positioning has only a marginal influence.⁴⁰

The optimisation of the installation angle is a necessity in reaching at least periodically the best fitted angle to radiance input for maximum solar harvest. Private investors must (and do⁴¹) ensure a fit to the optimum installation angle, for the macro analysis it is negligible.

Table 2: Global annual irradiation per square metre (kWh/m²):

	<u>optimum installation angle</u>	<u>0 ° angle</u>	<u>loss</u>
Goteborg	1070 kWh (39°)	918 kWh	14.20%
Nürnberg	1210 kWh (36°)	1060 kWh	12.40%
Napoli	1690 kWh (33°)	1500 kWh	11.25%

own calculation, data source: PV-GIS, 2008, <http://re.jrc.ec.europa.eu>

³⁹ Aerosols lead to smaller cloud parts and increase the life cycle of clouds; land mass becomes warmer in shorter periods and alleviates the allocation of clouds.

⁴⁰ See Dürschmidt et al, 2006b: according to DLR, depending on the angle of the roof, the loss of direct irradiation in this radius is not above 10%.

⁴¹ Empirical analysis concluded that private investors pay attention to expected solar harvest of their plants. Also if monitored some plants are installed to a north position, meta-analysis with global sums of produced energy are pleasantly high, e.g. ISE, 2005: A broadly designed survey of about 500 solar power plants in the region of Freiburg, Germany, gave as a result an average annual yield of 839 kWh/kwp, also if installation was not always done in optimised angle; but also Fachhochschule Osnabrück, 2005: A satellite survey of Osnabrück, a typical German city in the range under 500.000 inhabitants, attested 12 square metre of optimised angled roof area for photovoltaics per capita.

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Module efficiency: Solar cells cannot absorb the radiance in a 1:1 relation. Due to the limitations in the design, modern cells make use of only a part of light wavelength⁴², the different types are shown in the graphic below. Mostly based on mono or poly crystalline silicon,⁴³ the absorption potential is limited to the absolute potential of the raw material. Mono crystalline cells consist of purer silicon than the poly crystalline ones, that are based no doubt on their name, on several (=poly) crystals. Poly crystalline cells are a little bit less expensive but the efficiency is also slightly reduced. The modularly assembled cells are the product from wafers, cut slices from heavy silicon cubes. The abstract is much simpler than the reality, but enough for the time being to understand the fundamentals of how cells are working.

Prices: Where do the system costs come from? The greatest costs come from the solar panels. Their prices are dependent on raw materials, mainly silicon, which is the fundamental component of cells: Häberlin (2007) mentioned that mass production of panels intends to set a learning curve which could lead to cost reductions of about 20% if the production was doubled.

Approximately 8-12% of costs are for the installation and the initial operational procedures. These costs will increase proportionately with the inflation rate. If the degree of efficiency rises, required space will be reduced and the costs will reduce in parallel.

Cable, clamp systems, brackets and other installation materials account for 5% of costs, prices are relatively steady in relative prices. Marginal differentiation caused by the installation type (on-roof, on-plain) are negligible. One type of installation requires a few more small parts and the other more human power. In sum it should be more or less equal.

The converter is the last cost component in the calculation. The converter price increased substantially over the past years, but remains at 8-12% of the total power plant costs. For the whole investment, no more significant reduction is expected, but little reductions are imaginable. It is often not declared that converters are not expected to have a life span of more than 15 years. To take this into account, the following analysis will count converter prices twice, which leads to a huge percentage increase in the costs of the converters.

For the final yield calculation, there is an alternative in the market: two axis tracking systems, which adjust panels over the day and year in position to the sun track. They have additional costs per 1 KWp of about 1000 EUR. One must consider whether the tracking systems are a rewarding investment, because with the same investment sum installable capacity could be increased by 20%.

⁴² The cell producers are interested in broadening the useable spectrum. Physical limitations are more or less the exhaust. Future solar cells will be multilayer. Every layer will absorb a specific part of the light wavelength and the total used spectrum will be amplified. The efficiency will increase too. In the STT exploitation rates of about 25% in the year 2040 will become the industrial standard, see Hirschberg et al (2005). Cells under laboratory conditions today already reached higher rates of efficiency with a world record of 41% by Fraunhofer ISE (2009).

⁴³ For thoroughness, it must be added that other raw materials are also able to absorb photons. In the near future they will be used for cells. They are still not ready for the market or too expensive or less efficient to reach a crucial market share. Only the so called "thin film" cells have a significant market share: the need for raw materials shrinks for a new technique of vaporisation of the cell to different layers. The production method leads to decreasing prices. The advantage is the flexibility. Like a foil uneven surfaces can also be harnessed for the production of solar energy. Cells on sale in the market today need twice as much as the plain of mono or poly crystalline cells. Laboratory cells don't have compensated disadvantages of efficiency, see e.g. IPHT, 2009: With a new method scientists of the IPHT want to increase the efficiency from 10% to 15%.

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Abbreviations

BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
°C	Degree Celsius
CO ₂	Carbon Dioxide
DM	Decreto Ministeriale (it.), Ministerial Decree
GHG	Green House Gases
K _C	Converter Correction Factor
K _G	Generator Correction Factor; module efficiency
K _L	Correction Factor for General Losses
K _T	Temperature Correction Factor
KWh	Kilowatt hour
KWp	Kilowatt/peak; capacity
E _{eg}	Global Radiation
EEG	Decree of German REFITs and support for renewable energies ("Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften")
MPP	Maximum Power Point
P	Prices
PV	Photovoltaic
REFIT	Renewable Energy Feed In Tariff
STC	Standard Test Conditions
T _I	Temperature surplus due to installation
T _S	Surrounding Temperature
W	Watt
Y _F	Final Yield in kilowatt

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