Center for European, Governance and Economic Development Research

cege

Discussion Papers

Number 105 – June 2010

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ISSN: 1439-2305

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How investments in solar power plants in Sicily can generate high returns of investments and help to prevent global warming

December 2009

Abstract:
Germany could have reached Kyoto protocol obligations earlier if German solar investments would be relocated to Sicily. Additional benefits of emission savings and energy production should rise up to 72%. Nevertheless German solar power plants 2008 counted for 20 % of the financial benefits through support mechanisms EEG for renewable energies while the share at produced green energy was not more than 4,8%. The system seems absurd from an economical view, but is adopted in many other countries. Firstly, the paper will analyse general economic theories to underline the importance of financial supports for renewable energies and why policy maker can justify the subsidies for selected technologies through social costs effected by carbon exhaust. Secondly, place does matter and physics are the limit: the following chosen approach for expected final yield shrinks the additional benefits of the theoretical relocated south solar investments to +37%. Thirdly, the conclusions give political recommendations for the design of further subsidies of solar energies in Europe.

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1. Introduction

Especially developed countries have to reduce CO_2-emission fast and in high dimensions. Fo the member states of the European Union it is not the question if 20% due to the Kyoto protocol or 30% due to Copenhagen agreements: the UK-governmental Stern (2006) review mentions, that the costs of natural extremes and the negative long term impacts on growth will be much more higher than those involved in acting now. Carbon dioxide and other climate gases are causing global warming, the so-called green house 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 gases] concentrations were to be stabilised." (IPPC, 2007, 48).

One 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 CO_2-emissions and an increase of 20% in the share of renewable energies in total energy production until 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 place of emissions the question is how to best reduce CO_2-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 CO_2-emissions, but it is cost intensive: Until now it has not been possible to produce a kilowatt hour of solar electricity at the same price of conventional energies. The challenge is to minimise the costs and to maximise the earnings: Further implementation of Europe-wide CO_2-certificates markets would allow better regulation, thus making it easier to intensify the application of certain technologies in the areas in which they are most effective: due to geographical conditions different countries have different needs of energy production.

Every member state has to reach the European goal, and especially Germany shows big efforts in restructuring its energy mix with the intention of increasing the share of renewable energies through subsidies, that aim not only to produce energy, but also to reduce CO_2-emissions (Klobasa, Ragwitz 2005).

This paper estimates the amount of solar power that could be theoretical produced if the German private investments caused by governmental actions in the years 2000-2007 were diverted to Italy: what capacity of photovoltaics could be installed today and what would the theoretical harvest of electricity and the surplus of CO_2-savings, and the additional return on investment be?

Firstly, in chapter 2, the theoretical framework of social costs due to environmental damage of carbon exhaust is discussed with a focus on price solutions as emission taxes. It will be explained the subsidy system for solar power plants in Germany and Italy, as kind of an environmental Pigou tax - caused by a national clearance system. The mechanisms are important to understand how policy makers can justify high costs of promoting solar energy as a privileged technology. The particular intentions of German support regimes for renewable energies aiming to R&D supports through market demand, changes in social behaviour (Bartle, Vass, 2007) and optimisation of subsidies (Staiß, Schmidt, Musiol, 2007) will be added.

Secondly, what if Germany invests in extra territorial solar plants? 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 relation to Germany. Why do not take advantage of higher irradiation and a higher expected electricity production of solar cells? The installed capacity 2008 in the whole Italy is just 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 done in chapter 3.

Thirdly, the conclusion in chapter 4 summarises the costs and benefits surplus of German solar investments in Sicily, and makes political recommendations for the design of further subsidies of solar energies.

2. The linkage from social costs of carbon exhaust to support regimes for renewable energies

The paper is linked to the environmental economic question about the internalisation and minimisation of both the social costs of CO_2-emissions and higher production costs of generating electricity from renewable energies: what is the best practice to reduce CO_2-exhaust through growing renewable energy investments? Policy maker try to design support systems that internalise the costs into the national markets. The social costs of CO_2-emissions are described in a broad range of topics, following the first ideas of Pigou (1912 and 1932) as human indicated warming as an externality not correctly priced in the market. Thus, he proposed a tax equal to the ecological damages caused by (carbon) exhausts. Market participants cannot avoid the tax and mitigation will be done 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 CO_2 in modern economies (Krewitt, Schlomann, 2006). It is important to question the best political actions and the impacts of CO_2-certificates on the channelling and the reduction of emissions as a choice of prices (taxes) for exhaust or quantities (certificates) (Weitzman, 1974), where environmental taxes should be the price for damages (Segerson, 1998).

There are different possibilities to support renewable energies. One are Feed In Tariffs for Renewable Energies (REFITs), 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 an access to the national grid: local grid providers have to take up the energy. A national clearance system allocates the cost of the system to all consumers of electricity: any REFIT is itself an instrument that internalises the higher costs of renewable energies. Thus led to private decentralised investments in renewable energies but because of surcharge for all costumers it is also similar to an energy tax under uncertainty of environmental damages, as described by Segerson (1988). Through incentives, paid by all costumers as a kind of a Pigou-tax, investors choose the most profitable technique and their benefit in sum is equal the tax. The damages will be internalised, in the optimum proportional to the absolute wastage.

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

Produced solar energy is climate-neutral, the production of 1 KWh doesn't cause any greenhouse gas exhaust, if the plant is ones in operation. The German Federal Government intend an extension of renewable energies up to 50% to reach the aim of emissions savings of 20%, as official announced by Nitsch (2008) on behalf of BMU. The photovoltaics contribution to environmental protection targets is more important than the production of energy. Without renewable energies, the total CO_2 emissions of Germany would be 15% higher, but the share of gross electricity production 2007 was only about 6,7%, as Böhme, Dürschmidt (2008) mentioned.

It is difficult to price the social costs of carbon exhaust. Thus the exhaust of emissions can be located, but the aftermath are global. Even more difficult the time perspective. Damages through GHG cannot be measured immediately, but affect on the long run, affected by uncertainties on long period effects and the preferences of today consumption, as described by Pigou (1932). Implying that, the problem arise, how the so called Pigou-tax (Pigou, 1912) for environmental wastage 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 CO_2, aftermath on climate change. The problem is to examine what exactly are "costs". Man made heating cause nature extremes and changes in diversity and natural conditions for live. It is thus a question of socially accepted costs, and there are some positive effects of climate change such as less mortality through cold winters in Europe, too. Finally, nobody will deny negative impacts and has to decide for the (nowadays) price of carbon emissions: if the costs are 70 EUR per exhausted ton CO_2, as Krewitt, Schlomann (2006)[1], suggest: the explained substitution of conventional electricity leads to avoided social costs of 5.5 Cent per KWh of produced solar electricity. In other dimension: the price for conventional energy from coal has to increase by 8 Cent/ KWh.

If the costs of CO_2 are known, the next question is, 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 according the ideas of Pigou.

The problem of determination of CO_2 savings per kilowatt-hour is the uncertainty, which energy is used for production, but also which conventional plants are going to

[1] 70 EUR are the middle bound of estimated aftermath through CO_2-exhaust on climate change, while the lower bound is about 15 EUR, the upper bound 280 EUR.

be substituted. For the production process of pure silicon, the raw material for a high share of solar cells, make high energy efforts, that degrade the balance of solar energy.[2] New procedures decrease energy consumption for the production, at the same time the degree of efficiency is increasing: Krewitt, Schlomann (2006), consider a significant decrease of CO_2 emission and the calculated CO_2-exhaust per solar kilowatt-hour will halve from 99g (2000) to 54g (2030e). Through the explanation in above, it seems clear that it is not acceptable to determine saved CO_2-equivalents with expectations for the future power production. To many uncertainties about innovation in new installed (conventional) power plants, and incomprehensible assumptions in the scenarios. It is difficult to figure reliably the absolute value of greenhouse gas savings by photovoltaics. Nevertheless it seems to make sense to take into account emissions caused by the production and erection of power plants and divide emissions through expected solar harvest for an assumptions of a 20 years life span. what is also the paying-period of a lot of national REFITs.[3]

The German REFIT serves as the example for the deeper analysis of the state-of-art promotion of renewable energies. The early German dominance in the installed capacity of solar power plants seems to be linked to the role of an early innovator, other countries did not have a similar promotion system as early as Germany. The all-in-one-degree EEG[4] (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 plants in the national area of the federal state can apply for subsidies, positive discriminated by §§23-33 are e.g. Photovoltaics and other less efficient technologies.[5]

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[2] Spenke, 1956: The so called Siemens production technique is 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 silica sand and coke get in fusion to raw silicon at 2000 °C, the next processing is conditioning with hydrogen chloride.

[3] The lifetime should be expected, however, much higher. Already the German REFIT is 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 CO_2-emissions per kilowatt-hour are reducing by additional 2,5%. Renken, Häberlin, (1999), report about early test plants in Switzerland, in operation for 30 years, without showing a significant degration 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.

[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%.

It is important to notice that subsidies paid to green energy producers are non governmental[6] payments: The paid REFIT subsidies are part of the earning of the power plant owners, the producer of eligible energy are getting the guaranteed compensations from the local grid carrier, while the additional costs over market price are a surplus on the bills paid by all costumers.[7] A national-wide clearance charge the proportionate costs internally to every kilowatt hour sold - renewably or conventionally produced. The entire financing of both renewable energy plant erection[8] and feed in tariffs comes from the private sector and costumers. Subsidies mean reallocation into the market as a steering effect of the EEG. The electricity price increase is 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 counts 43,000 employees in 2007, a turn over of about 5.7 Billion EUR (BSW, 2008), and an international market share round about 30% (Dürrschmidt, Van Mark , 2006), and thus led to an increase in R&D and acceleration of the learning curve; meantime the prices did not decrease in proportion to innovation progresses done 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. Numerous national and regional laws with the intention of supporting for renewable energies were replaced. Some local laws in addition to national law are still legal in respect to the national decree.[11] but policy makers learned from the failing of the for-

[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 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 to high market demand firms sold with increasing margins. In addition shortages of silicon production lead a increasing panel prices from 2004 -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 not even was 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 completed demanded in the first month after declaration of the national law.

[11] e.g. for the simplification is the simple building notice 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.

mer decree. Local political regimes cannot avoid solar power plants anymore, just affect with minor influence.[12]

In detail, there are some more differences to the German law, as e.g. the charge for new installed plants is adjusted year by year, according DM 19/02/2007, Art. 6-9, and the legislators cared on a very early stage about a hierarchised feed in tariff with positive discrimination also within a certain technology, for example for totally or partially roof integrated solar power plants. This led to a significantly higher demand in Italy for less profitable technologies, while there for is no (relevant) market for in Germany. In Italy, after the amendment to the Conto Energia II, 26% of the new installed capacity in 2008 was architecturally integrated, mostly roof integrated, following Montanino (2008).

The grid carrier has the obligation to feed in produced electricity for power plants below 1 MWp. Above, other regulations like the former decree of green certificates apply, which forces the grid carrier to absorb a mandatory quota of renewable produced electricity but also means a limit to absorption obligations. Thus the Italian REFIT is on the other hand more flexible. The green energy certificate quota applies also extra territorial. If the German EEG were adjusted in the same way, the calculation done in the next chapter would not be any longer only imaginary. The fundaments are grounded to open Italy as the German granary for the solar harvest, but some legal problems remain and has to be modified:

1. The Conto Energia II specify 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 doesn't take advantage of its full sun potential.[13]

2. Actually, the state-of-art design of the many national REFITs, led to a higher share of small private investments. The Italian market shares changed dramatically already in the first year after declaration of the Conto Energia II: the average size of newly installed plants shrinks while their sum is growing, as measured by GSE, 2009. For maximum efficiency, solar parks seem to be the better solution and has to be proved in the follow.

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

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

3. Physical conditions as the limitation of the solar harvest

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 meter multiplied by the peak capacity in kilowatt KWp of the solar power plan as the final yield Y_F in kilowatt, the calculation would end here:

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

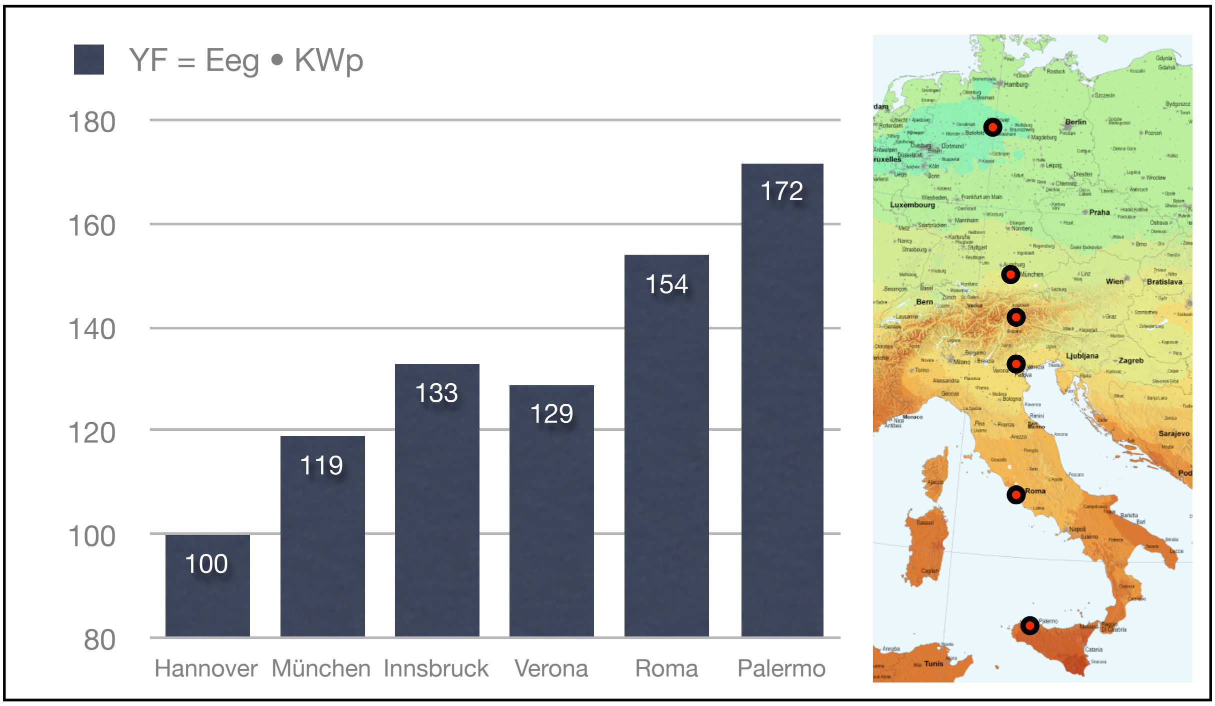

Figure 1: Index for expected final yield, traditional approach, Hannover = 100

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 obtain standard test conditions (STC)[14], of course. In addition, there are some parameters with unclear effects. What is the impact on solar harvest of, for example, topography, air pollution, or general losses?

The chosen approach modifies the conventional calculation method due to geological and meteorological conditions but also used technology. In the following, factors, preconditions and parameters will be discussed and evaluated for the analysis to ensure the expectation or discard as marginal: the physics are the limitation for

[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/m^2 and an air mass about 1.5. The STC serve to compare different module types and producers. For different geographical locations one have to take into account the specific environmental conditions which can differ in fundamental dimensions.

the economics and thus limit the returns of investments. Thus, most common state of art technology will be expected. Reader can have a deeper view with references in the technical appendix for own modifications within ongoing technological development or individual applied yield calculation for specific location.

Temperature losses: The performance of silicon based solar panels depends on inner heating. The warmer the cells, the weaker the absorption potential - in affection to 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, below to a positive performance effect. Thus, the question arise if solar panels are as effective in the warmer south as in the colder north. Temperature losses seems to be the factor that influence most differences in macro comparisons of regional yields.

The temperature in the cell is linked to environmental conditions, but can also be regulated in a certain spread by cell design. To have an approximation about the annual temperature loss for a specific location, the measured surrounding temperature T_S has to be corrected, a surplus of $\Delta°C=7$ should be good for further calculations. due to the often missing of day length temperatures.[15]

The kind of installation is important, too. Especially the cooling on the back side of the panels: the correction factor due to installation should be T_I, with $\Delta°C=10$ for on roof plants, for roof integrated $\Delta°C=20$[16].

The radiance intensity in watt per squaremeter, most important factor for regional differences of expected yields, is heating the panels, too. The cell temperature follows the radiation curves over the day and year. Thus lead to a surplus on heating by $\Delta°C=W/m^2 \cdot 0.03$[17]

The producer of solar panels intensify research for better design of temperature management in the cell[18]: it results in a smaller temperature correction factor. Par-

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[15] One has to pay attention to the seasonal path of the sun and diverse lengths of days. Solar electricity will be produced on 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, 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 $\Delta W/m^2=100$ between. $\Delta°C=4$ up to $\Delta°C=5,3$. Not all types of cells are effected in equal measure.

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

ticularly warm and sun exposed locations will benefit, the advantage for Sicily continues to increase.
The calculation has to be modified:

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

Converter losses: Solar power plant needs a converter. Silicon made solar cells operate like semiconductors and absorb photons, the light quantums. These particles are the smallest energetic loaded elements of the light. Through the absorption of photons in the solar cell it is possible to harness the solar energy. The flow of photons is a direct current electricity and will be converted into alternate current at the converter. The converter charged electricity can be fed in 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, analysis will account a loss of 3%, the lower bound for average loss for state of art converters.[19]
The calculation has to be modified:

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

General losses: There are some other factors, which influence the solar harvest positive or negative like aerosols, topography and others, see the technical appendix for a deeper view. To summarise all effects, in the following a general correction factor of 4% will be introduced for the calculation. It includes conditions, highly determined by local conditions but are all over equally distributed for all power plants.
The calculation has to be modified:

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

Radiation angle: Solar cells can produce electricity through photon absorption only if light energy penetrates. The light itself is a component of two kinds of radiance: direct normal radiation[20], light which is coming directly from the sun, and diffuse radiation, which is broadly dispersed by reflections and mirroring. Both in conjunction is the so called global solar radiation and the measuring unit for calculation about ex-

[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.

[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 is getting smaller as more south the position is, on the equator the angle is 0 ° to ground.

pected yield. In the near future, photovoltaics have to be compared with concentrated solar heat, a technique which is using the direct normal radiation.[21] That impacts the direct comparison of the global solar radiation into the two decoded components named before. In the following the renounce of the twice declaration of radiance types is done because the intention of this paper: the analysis of efficiency of photovoltaics in different areas, not evaluation of techniques.
To summarise the effect, power plants are too different to adopt an additional correction factor: investors will try to erect cells in the best angle. minor losses due to wrong installation angle seems to be marginal and will be included in the general correction factor explained before.

Module efficiency: The module efficiency is important, if space is the matter. The following analysis will calculate with an average module efficiency.[22] New erected plants 2008 were constructed to same shares with mono and poly crystalline cells. This technology mix expects an efficiency of about 15%, due to a rising share of the less efficient thin film modules[23] efficiency decrease to about 12.75%.[24] For the plain it signifies the need of round about 8 square meters to install a nominal capacity of 1 KWp. The calculation can be modified for the expected yield per square meter, what is important for individual investment calculation, where ground has a price and has to be taken into account.

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

Prices: Given the question, what is the expected return of investment, one has to estimate prices. Because of the used 2008 data base, the total costs are fixed in the same year: for the erection of a solar power plant capacity of 1 KWp, the needed capital was about 4400 EUR for on roof installation, 4200 EUR for installation on plain roofs or ground.[25]

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[21] In Southern Europe the direct irradiation is on a very high level, allows the operation of concentrated solar heat plants. Solar radiance is getting bundled to 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 modul efficiency is not the same as the cell efficiency that count higher rates but is not relevant in the 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 market offers with poly crystalline cells, e.g. BP 3170, Umweltfreundliche Haustechnik GmbH, Göttingen, Germany 2008.

[25] The global financial crises led to a price dampen effect.It is unknown if only for short or both for long run. Also before analysts noticed an annual price decrease between 6-8%, see e.g. WEST LB Research (2009). The market is changed to a buyer market, according Zindler, McCrone (2008).

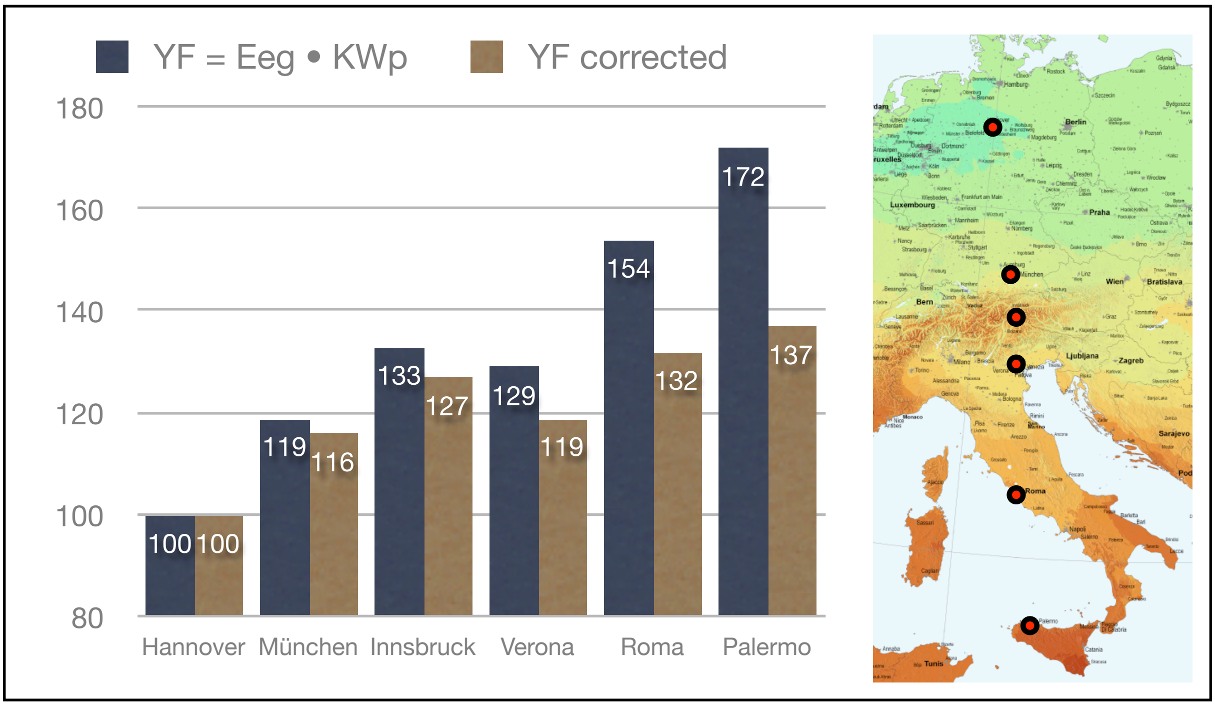

Figure 2: Index of expected final yield, modified approach; Hannover = 100.

source: own calculation according PV-GIS

The calculation formula for final yield has been modified as shown to:

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

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

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

4. Final Calculation and conclusions

The application of the Conto Energia II comparable to the EEG arise the question: What additional benefits accumulate from solar investments in Italy equal the amount invested in Germany from 2000 to 2007 in CO_2-savings, energy surplus and return of investments?

In the previous, the factors and their influence on solar harvest were introduced. In the following, all come together: statistical data from Germany will be taken to merge the different years in one table and show the sum of solar energy investments after declaration of the EEG. The figures will be a little higher as the expectations done in this paper. That can be interpreted as a sign of conservative, but true assumption of criterions. Exactly the same investment sum will be converted to Italy. The calculation follow the determination of Staiss (2007), that 1 KWh solar energy account for a saving of about 787 kg CO_2-equivalent.[26] The CO_2 savings are accounting according a cross section analysis (Klobasa, Ragwitz, 2007) that assumes that solar electricity substitutes to 50% natural gas and to 50% mineral coal plants.[27] Solar power is not a very secure resource, produced following the sun cycle, on the contrary an advantage is a more or less similarity to power consumption: peaks on day time and during summer (air conditioning in offices) are often covered by high performance of solar power plants at the same time. Because a miss of accumulators, electricity is not storable and has to be consumed in the moment of production. For that, solar energy cannot substitute conventional plants yet, but gas and coal.

Firstly, for the analysis, only areas with an average annual radiance around 1750 KWh will be advised for on roof plants installation and can be found especially in Sicily, but also with minor deductions on the mainland of Italy (Apulia, Calabria) and in the south of Sardinia. No technology process will be taken into account after 2008, the status quo will be fixed for cost prices and degrees of efficiency.

Secondly, important, and worth a deeper view: arrays - systems to adjust panel orientation over the daily and annual sun track. They have a strongly positive influence to final yield. Nevertheless, the systems are not very cheap and nor dedicated nor financially feasible. However, the advantage is obvious. The solar panel is always best orientated to the sun and the direct normal radiation can be optimally used, always potential to reach the maximum yield. The usefulness is especially given were the direct normal radiation is high.

Thirdly, a calculation will be done of sun exposed areas, where the Italian wide power supplier ENEL could invest in solar farms instead erect new nuclear power plants: according an economical plan 24 Billion Euro are the budget. Is solar energy an alternative? Which would be the production cost for one kilowatt-hour? Would the grid parity be reached?

1) Table 1 shows all German investments for erection of new solar power plants since the first declaration of the EEG in 2000. Values are estimated from analysis in

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[26] CO_2-equivalents a theoretical measuring unit, which not only take into account direct CO_2-emissions, but also other emissions that are excreted into the atmosphere and are boosting the greenhouse effect: CH_4, Methane, and N_20, nitrous oxide. They are converted for better comparison according to scientific standards to a show their effect as they were CO_2. This method is globally accepted and adjusted, to have equality of national emissions analysis.

[27] The CO_2 savings are not calculated explicit, some observed studies also contain initial operation losses of substituted plants.

mandate for the German Federal Ministry for Environment. For better valuation of done investments, amounts are adjusted by annual inflation rate and show the real presence equivalent 2008. The total production of German solar energy capacity of 3753 MWp between Rhine and Oder was about 3458 GWh, with CO_2-savings of about 2,400,000t in comparison to conventional produced energy according the approach shown before.

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

	new installated capacity MWp	total electricity production (GWh)	Real turnoiver from construction of solar power pants
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

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

The only correction factor always highly important, is the temperature which minimises the degree of efficiency, as explained before. Positions have been taken typically for the chosen regions.[29] Roof integrated power plants will not be included, because they don't count for a high market share.[30]

If German EEG supports are converted to Sicily, the expected production cost per kilowatt-hour is of about 19 ct. The additional solar harvest gives an amount of 860 GWh and a surplus in CO_2-emission savings of 665,000 tons, for the investors, the additional return is about 370 million Euro - every year. Because of not insignificant

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

[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 degree 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 intent.

lower costs for on ground solar farms, the harvest could be enlarged if it is the intention of (local) policy maker: the investment sum lead to a higher installable capacity.

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

3) Controversial discussions in the politics: enormous investments of the power supply company ENEL. If the planned investment of about 24 Billion Euro for new nuclear power plants would be done in solar parks with tracking systems, over a 20-years life span, one kilowatt-hour could be produced for a price of about 12.2 Cent.[31]

The German EEG were designed to intent market simulation and force to cost reductions through market growth, described well by Nitsch, (2008). The conclusion of this paper underlines the success of the REFIT for new installation of and R&D in solar power plants. But more, it is proved, that investments in other European regions would be more lucrative and efficient: Italy can count for higher solar harvest in the regions of Sicily, Sardinia and on the mainland (Calabria / Campania) with the same installed capacity. Without REFIT grid parity can be reached in the South of Europe. A scenario with a system of decentralised solar power plants how it is established in Germany through the EEG would lead to an increase in efficiency of about 25%. If the investment sum with a basic of 2008 would be divided of expected solar power harvest one kilowatt-hour could be produced for 19.02 Cent - while the average market price 2006 was about 21.08 ct, as counted by Goerten, Clement, (2006).
Through a better heat management, losses will be reduced in the near future. Thereby benefiting locations with high surrounding temperatures and intensive radiance, especially. Time is running for Italy and advantages will continue to grow.
It is difficult to do a monetary validation of the EEG promotion. Surveys of Frondel et al (2007 and 2008) are counting a subvention of 108,000 to 205,000 EUR for every employee in the German solar sector: the analysis considers the REFIT trans-

[31] The investments of ENEL in nuclear power plants do not produce any electricity, for that the production costs has to be taken into account and are announced by 4,3 Cent / KWh.

fer payments done for the past and estimated for the future. The amount will be divided by the number of employees. The author calculate a life cycle balance, but remain with a fiscal result without take into account external social costs of CO_2-emissions, and so differ from the approach of this paper.

It is important to act as the innovator not only for technique, but also for policies. Wiekert (2008), expects a stagnant German market, thus the domestic companies have to enter foreign markets. The EEG itself is well exported and an accepted model for many other countries across Europe and the world. Generally the German EEG is adopted with only small adjustments for local needs.

While the European Union (1996), declared within Directive 96/92/EC, European wide open energy markets as the goal for 2007, discrimination through national supporting systems for renewable energies remain legal to avoid concentration of investors to most profitable REFITs. Thus, following the conclusions of the calculation done here, renounce efficient implementation of e.g. solar power plants:

If the German investments would have been accrued over the years and been invested in solar parks with tracking systems in the Sicilian area 2008, a European wide single market with clearing mechanism, Germany could count an additional reduction of about 1.2 million tons CO_2 - every year. That correlates to two thirds of 2005 emissions from the production branch "ground transportation and transport in pipelines" or is even 0.1 million tons more than from "shipping"[32]. It also implies a potential avoiding of social costs through CO_2-emissions of about 84 million Euro. Measured by the total energy-induced CO_2-emissions of Germany 2006 about 819 million tons[33] per year, the additional contribution of total greenhouse gas savings would be about 0.15%. In relation to the obligations due to the UN Kyoto Protocol[34], it counts for an saving about 0,5% of total CO_2-equivalent saving obligations - while the additional amount of power supply of 1519 GWh counts for only 0.25% for gross annual electricity production.[35] The United Nations protocol take arrangements that allow such a project like proposed in the calculation: Kyoto Protocol Annex-B states, like Germany and Italy, can stipulate "Joint Implementation" and count additional CO_2-savings extra territorial as done inter territorial to fulfil the contractual terms.

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[32] destatis 2008, Document 85111-0001

[33] Energy caused CO_2-equivalents, as analysed by Böhme, Dürrschmidt, (2008)

[34] The obgliations in CO_2-savings according the Kyoto-Protocol for Germany counts for 257 Million tons of carbon equivalent exhaust until 2012 in relation to the basic of 1990.

[35] 2006, datasource: BMU

The objects of politics through the "20 20 by 2020" treatment would be faster reachable, if Europe would act as a single player. Particularly member states in the South should now accept photovoltaics as one component of future energy mix and climate and climate protection aims. A path-goal-strategy has to implement a REFIT in parallelism to German model for market stimulation, and inter Union concentration on technologies at the place of highest efficiency is recommend. It would imply faster reach of CO_2-emission reduction and thus the European Union would have more pressure to other states worldwide to intensify their contribution and efforts to prevent ongoing global warming.

Technical Appendix to Chapter 3

technological terms and conditions used for the shown approach

temperature losses: An aberration from STC of Δ°C=1 leads to a temperature loss of 0,5% for silicon based cells, as broadly shown in a series of paper (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 less performance seem to be a worse absorption potential of silicon, and another coloration of the light, a variation in wave lengths, which can not 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 approximation[37] 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. If the nominal capacity of the solar power plant is less than 30% of the converter capacity, the degree of efficiency decreases significantly, too.

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. Also pollution through pollen of near plants or the specific micro-climate (wind, wind, heat) affect the system performance.
- Geographic location: Urban areas are more heated than rural areas. Locations near to the sea will benefit from light reflections of the water surface, sand grounds reflect 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 direct impact on the location of their origin,[38] not necessarily affected adversely by urban areas. Metropolitan areas have basically a high level of air pollution by exhaust emissions from traffic and industrial pollution, but reflected global radiation can even increase. So reduction of direct radiation by misty skies can be compensated at least particularly. In contrast, rural areas are more polluted by pollen. Near to the seaside salt particles impact the pureness of skies.

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[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 percental figures. In conclusion one should agree to the simplification done above.

[37] See Häberlin, 2007, 280-289: Converter are designed modular: 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 smaller than the power plant capacity, any operation under full load led to a loss in electricity production due to a too small capacity to convert whole current conduction in the connected strings.

[38] Häberlin, Graf (1998): The not representative survey calculates a 10% loss of generator due to pollution by settled particle on panel surface.

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

- Altitudes: Higher locations are more favourable than valleys, they benefit particularly in month with minor radiance. The exposed positions lead to an advantageous angle between panel and sun, and the way of sun radiation is shorter (the so called "air mass"). Is the sun low, the incoming radiance to fix-mounted panels on mountains is better as in the plain. 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 are cables, leakage currents or occur of minor defects, and a little degradation over the time, but Renken, Häberlin (2003) mentioned no significant effect in the long term survey.

Radiation angle: Useful for the final yield is all penetrating radiance: especially while 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 < 45 ° North the proportion of diffuse radiation can become even more important than the direct normal one, as shown by Quaschning, Geyer (2001).

The installation angle seems to be very tolerant: +/- 20° aberration to the optimised angle just lead to a lost of radiance of round about 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 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 has (and do[41]) to take attention to fit the optimum installation angle, for the macro analysis it is negligible.

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

	optimum installation angle	0 ° angle	loss
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 get warmer in shorter periods and alleviate allocation of clouds.

[40] See Dürrschmidt 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 take 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 round 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 meter of optimised angled roof area for photovoltaics per capita.

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 wavelength[42], 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 the absolute potential of the raw material. Mono crystalline cells consist of purer silicon than the poly cristalline ones, that are based, no doubt were the name is from, on several (=poly) crystals. Poly crystalline cells are little bit less expensive but the efficiency is a little less, too. The modularly assembled cells are the product from wavers - cut slices from heavy silicon cubes. The abstract is much more simple as in the reality, but enough for the moment to understand the fundamentals of how cells are working.

Prices: Where are the system costs from? The biggest costs are coming from the solar panels. Their prices are depending on raw materials, mainly silicon, which is the fundamental component of cells: Häberlin (2007) mentioned, that mass production of panels intend a learning curve which leads to cost reductions of about 20% if the production was doubled.
Round about 8-12% of costs are for installation on initially operation procedure. These costs will increase proportionately with inflation rate. If the degree of efficiency raise up, required space wil be less and costs will reduce in parallelism.
Cable, clamp systems, brackets and other installation materials count for 5% of costs, prices are relatively steady in relative prices. Marginal differentiation caused by installation kind (on roof, on plain) are not noticeable. The one installation needs a little bit more of small parts, the other one more human power. In sum it should be more or less equal.
The converter is the last cost component in the calculation. The prices increased in large scales over the last past years, but remain for 8-12% of total power plant costs. For the whole investment, no more significant reduction is expected, but little reductions are imaginable. Often nobody declares that converters are not expected to have a life span of over 15 years. To take it into account, the following analysis will count converter prices twice, which leads to a huge percentage increase in the costs caused by 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 has to consider if tracking systems are a rewarding investment, because with the same investment sum installable capacity will increase by 20%.

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[42] The cell producer are interested to broaden the useable spectrum. Physical limitations are more or less 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 also other raw materials are able to absorb photons. In the near future they will be used for cells. They are still not ready for the market or to expensive or less efficient to reach a crucial market shares. 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 also uneven surfaces can 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%.

Abbreviations

BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
°C	Degree Celsius
CO_2	Carbon Dioxid
DM	Decreto Ministeriale (it.), Ministerial Decree
GHG	Green House Gases
K_C	Converter Correction Factor
K_G	Generator Correction Factor; modul 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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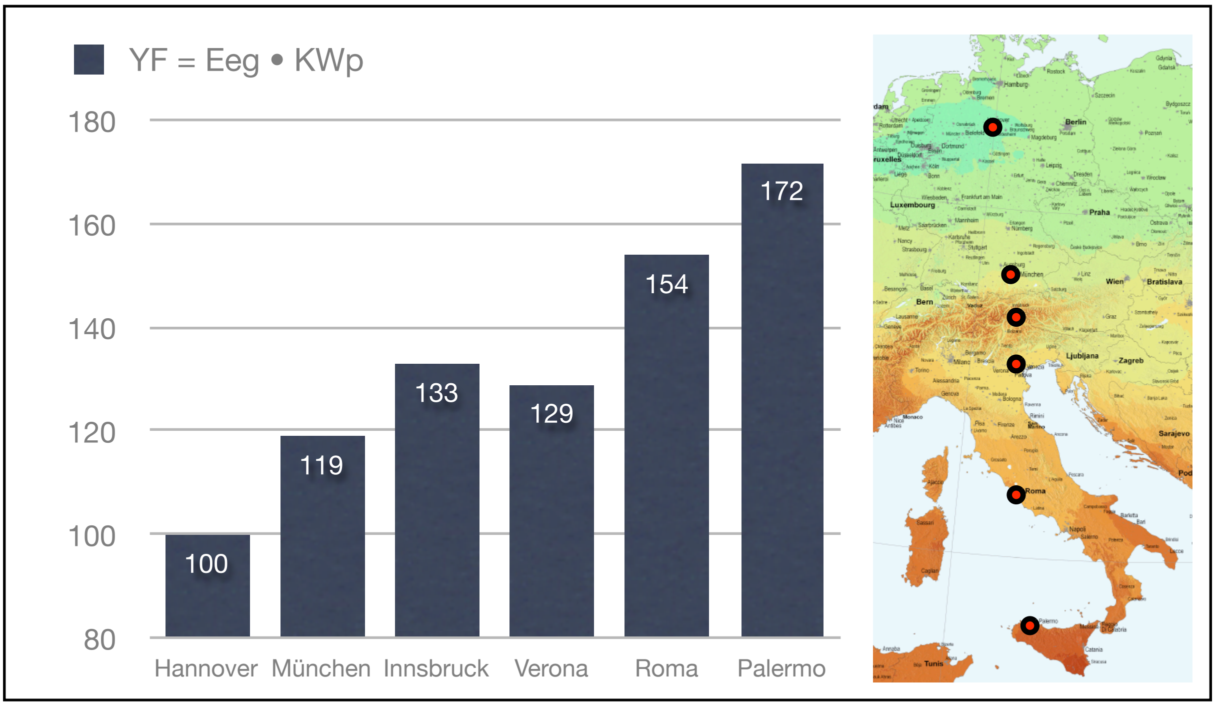
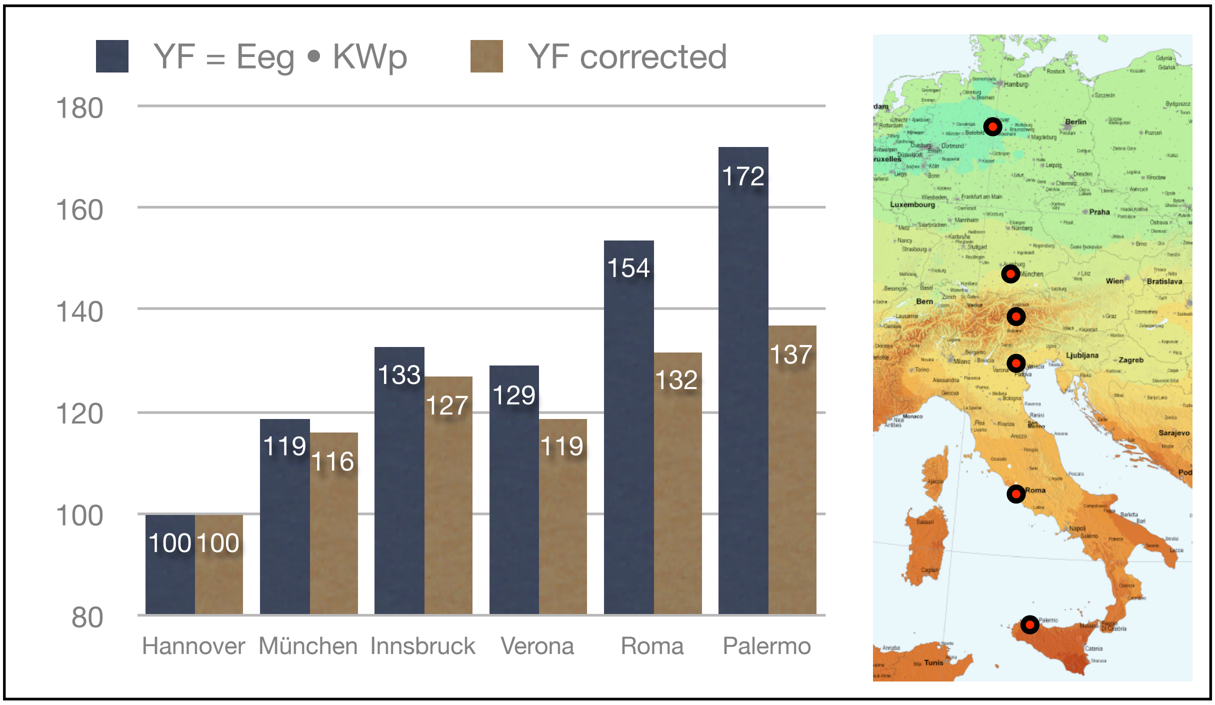
Figures

Figure 1: Expected Final Yield, traditional approach



source: own calculation according PV-GIS

Figure 2: Expected Final Yield, modified approach



source: own calculation according PV-GIS

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