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Environmental Technology & International Affairs

Photovoltaic Dynamic Grid Parity and Austrian Utilities: Where to go from here?

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Univ. -Prof. Dr. Günther Brauner

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Vienna, 10.06.2013

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Affidavit

I, **FELIX VALENTIN MOSER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "PHOTOVOLTAIC DYNAMIC GRID PARITY AND AUSTRIAN UTILITIES: WHERE TO GO FROM HERE?", 90 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 10.06.2013

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Signature

Acknowledgements

I would like to take this opportunity to express my gratitude to Georg Waldner for the inspiration for this Master’s Thesis topic and the motivating words that gave me the impetus to carry on. My supervisor, Professor Günther Brauner, greatly supported me with my work by setting the frame around the topic and helping me not to get sidetracked with unnecessary details as well as by feeding me with fresh ideas to further develop my work; our dialogues were always fruitful. Simon Niederkircher helped me with his practical knowledge in photovoltaic projects to verify my results and keep my feet on the ground when suggesting wonderful new business ideas. Moreover, I thank Wolfgang Anzengruber for the opportunity to interview him on the topic of photovoltaics.

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Picture: Attila Németh, Hungary

1 Famous misquote; the real quote in French “On résiste à l’invasion des armées; on ne résiste pas à l’invasion des idées.”

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Key Findings

- The Austrian photovoltaic market is, to a large extent (90%), driven by the residential sector as the commercial and industrial PV sector are still in their infancies.
- The roof leasing market is in its early stages. With prices for modules plummeting, soon the limiting factor for the deployment of PV system might be suitable roof area.
- On sunny days Lower Austria has enough suitable roofs to cover 115% of its peak load, based on available building roofs.
- Based on the assumptions made, a 100kWp PV system installed in St. Pölten generates electricity at a lower cost than gross residential retail electricity and within the range of net commercial electricity, but still higher than the net industrial electricity price and the generation price of power utilities.
- Consequently, depending on the electricity tariff small and medium enterprises (SMEs) pay, in some cases it is more cost-effective for the SME (considering lifetime costs and savings from electricity substitution) to install a medium size PV system on its own roof than to pay for electricity from the utility (provided the roof is suitable for PV).
- Power utilities risk the loss of market shares in electricity retail and an increase in network maintenance and investment costs if the deployment of PV is not managed pro-actively instead of reactively.
- The profitability of a PV power plant is sensitive to purchasing price, solar irradiation, weighted average cost of capital (WACC), system lifetime, and electricity substitution rate.
- The profitability of a PV power plant is insensitive to operation and maintenance costs, insurance, system degradation, leasing fees, and inflation.
- The risks of investment in a PV power plant are virtually zero because all risks are included within the levelized cost of electricity (LCOE). Being free from any national or regional policy, there is nothing that can generate a loss from the investment made; the WACC therefore should be set lower than 6.5%

List of Abbreviations/Acronyms

BIPV: Building Integrated Photovoltaic System

CdTe: Cadmium Telluride

CIGS: Copper Indium Gallium Selenide

DR: Depreciation Rate

DSO: Distribution System Operator

EEG: Renewable Energy Law (*Erneuerbare Energien Gesetz*)

EVN: *Energieversorgung Niederösterreich AG*

FIT: Feed-In-Tariff

GWh: Gigawatt hour (1,000,000,000 Watt)

IRR: Internal Rate of Return

kWh: Kilowatt hour (1,000 Watt)

kWp: kilowatt peak installed PV capacity

LCOE: Levelized Cost of Electricity

MWh: Megawatt hour (1,000,000 Watt)

O&M: Operation and Maintenance

OECD: (Organization for Economic Cooperation and Development)

OeMAG: *Abwicklungsstelle für Ökostrom* (Austrian clearing house for green electricity)

PV: Photovoltaic System

R&D: Research and Development

T&D: Transmission and Distribution

TSO: Transmission System Operator

USP: Unique Selling Proposition

WACC: Weighted Average Capital Cost

Abstract

The following master's thesis is a photograph of the photovoltaic technology in the Austrian energy and market economy of the years 2012-2013. By analyzing the dimensions in which this technology moves, the author identified the path that lead to the current market situation of overcapacity and dramatic price fall, starting from its invention to the current break-through known as grid parity. The examination of the Austrian electricity market identified opportunities of market penetration for middle scale PV power plants; whereas the detailed analysis of current levelized cost of electricity from PV-systems discerned the most sensible cost factors in order to ensure profitability from a power utility's perspective. The spirit of this thesis is to understand how photovoltaic power plants fit in today's electricity markets and how power utilities can adopt this technology instead of resisting its widespread deployment. The focus was set on the federal state of Lower Austria, as it is the largest PV market of the country.

1. Introduction

1.1. Technology background

In 1954, Bell Telephone Laboratories invented the "solar cell," a device that was able to convert the sun's electromagnetic radiation into electricity with conversion efficiency of approximately 6%. Soon after, the space exploration era demonstrated the applicability of photovoltaic cells as a reliable source of power; the first satellite to be powered by this technology was the Vanguard I launched in 1958 (see Figure 1). The cells that equipped the satellite were such a reliable source of power that NASA's researchers were amazed that they were able to last longer than the built-in batteries.

Figure 1. Replica of the first photovoltaic powered satellite Vanguard I

The space race gave photovoltaics the first push of research and development (R&D). When the first oil crisis hit the global economy in 1973, the second push followed, and PV drew the attention of the major oil companies, which further developed the technology to be used as a power source in remote locations. Due to the remoteness and the lack of long lasting batteries with enough power, photovoltaics were a cheaper solution for applications on land and water (D. C. Jordan, 2011). The first applications were supervisory controls, cathodic well corrosion protection, buoys, oil platform lights, and horns. Upon continuous improvements and innovations, modern photovoltaics developed from a laboratory scale appliance into a modular system expandable to utility scale with conventional power plant technologies. Today, PV is the fastest growing renewable power plant technology (by installed capacity), and it is widely believed that in the future, PV will deliver a large share of global electricity consumption (IRENA, 2012).

1.2. The PV System

Modern PV systems are composed of a set of devices, of which the most important is the PV panel. The PV panel is a compound of cells (usually 60 to 96) that, thanks to the photosensitive characteristic of the material and the chemical treatment it undergoes, is able to convert electromagnetic radiation into electricity. Under ideal conditions[2], one PV panel can generate between 75 and 333 W depending on module surface size and the material it is made of. However, when combined with many other modules, utility scale power plants of up to 200 MWp can be built (U.S. Department of Energy, 2011). The power output density per irradiated area of today's PV panels amounts to 110 to 200 W/m² (Sunpower , 2012)

1.3. Leading PV technologies

Three technologies dominate the PV panel market: mono-crystalline (c-Si), poly-crystalline (p-Si), and thin-film panels. Solar cell technologies differ in the raw materials used in the production of the photosensitive layer and the processes and chemical reactions with which the materials are treated. The first two technologies both rely on high graded silicon as raw material, whereas thin-film panels are made of either amorphous silicon (a-Si), cadmium telluride (CdTe), or copper indium gallium diselenide (CIGS) (PennSun, 2012). The PV cells used in the crystalline silicon based modules (c-Si and p-Si), are manufactured through an energy intensive process in which the silicon first has to be melted and then slowly crystallized in the form of ingots (IPCC, 2012). The thin-film technology on the other hand, is a more energy efficient manufacturing process that requires less material and, therefore, is more cost efficient. The disadvantage of the latter is the inherent lower conversion efficiency of the module during operation (Luque, 2003).

1.4. Motivation of this master's thesis

To answer the legitimate question regarding the relevance of this thesis topic, Figure 2 would suffice. This very simple graph sends an equally simple and daunting message: in Q3 2011 grid parity for residential scale, non-subsidized photovoltaic power plants became a reality in Germany. It is a statistical rather than factual event because it is based on average values and assumptions made, but, nevertheless, this event marked the beginning of a paradigm shift in the way electricity is produced, traded, sold, and even perceived in Germany and all over Europe as well. Since the widespread electrification of nations, the business of electricity generation has been led by few large market actors that profited from natural monopolies; the

2 Standard Test Conditions: 1,000 W/m², 25°C, 1,5 atmosphere thickness and perfectly clean module surface

liberalization of the electricity market followed by the advent of decentralized generation disbanded these monopolies and began eroding companies' profits.

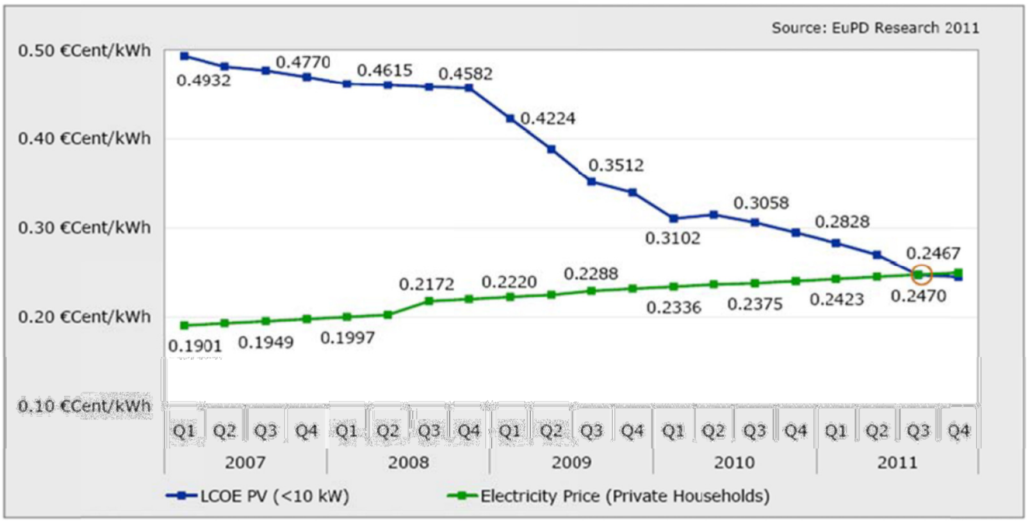


Figure 2. Development of the retail electricity prices of German households and electricity generation costs of small-scale residential PV installations (Wirth, 2012)

From the electricity suppliers' point of view, the event of Q3 2011 prompted mixed feelings. On one hand, thanks to the remarkable decline in electricity generation costs, a new technology became available to the utilities enabling them to generate and sell environmentally sustainable electricity; on the other hand, utilities were aware of the fact that this new technology had a wide range of scalability and could be prevalently conceived for distributed generation, in other words, it had the potential to become a substitute for the their services.

What is therefore the utilities' latitude towards this fantastically simple and yet powerful technology? Shall they hope that the word will not spread? That grid parity stays a German phenomenon that will stop at the border of the alpine nation? This master thesis analyzes the fundamentals of the electricity sale business, preparing decision makers of power utilities with ways to embrace photovoltaics within their power plant portfolio.

2. Methodology

In order to understand the development of PV technology in the European market, **Chapter 3** of this thesis discusses the political and institutional background of the German energy policy. Germany is used as an example due to its role in triggering strong market development of this technology; the phenomenon of the ability of formerly relatively expensive technology to undergo such a swift development over recent decades is in large part due to the sturdiness of German politicians, which will be outlined in Chapter 3. The following section, **Chapter 4**, gives an overview of the global photovoltaic market and the current consolidation phase, which includes the ongoing natural selection of PV manufacturing equipment and solar cell producers. **Chapter 5** analyzes the Austrian PV market and its peculiarities by explaining why the PV market in Austria failed to develop as strongly as it did in Germany. **Chapter 6** examines the Austrian electricity market; the price structure of the three main sectors: industrial, commercial, and residential; and the grid connection policies. As utilities are beginning to play a role in photovoltaic technology, the current strategies of Austrian power utilities participating in this market were also analyzed within this section. The information gathered is based on secondary data such as advertising pamphlets, internet pages, reports, and interviews performed by the author in person (Verbund AG) or via telephone (E-Control, Wien Energie).

In **Chapter 7**, the potential PV deployment in Lower Austria was assessed. To be able to grasp the order of magnitude of the PV potential, secondary data was collected to make an academic estimation of the roof potential and the amount of yieldable energy from the installable PV systems. The results are subsequently discussed and compared to both the electricity consumed in the federal state and the electricity sold by the main regional electric utility during the past fiscal year.

For a better understanding of the cost structure of PV systems, it was deemed necessary to analyze the cash flow of a hypothetical 100kWp power plant installed on a building situated in St. Pölten, the capital of Lower Austria. With the help of Microsoft Office Excel 2010, in **Chapter 8** the levelized cost of electricity of this hypothetical power plant was calculated along with the internal rate of return, and both were subjected to a sensitivity analysis in order to gain relevant information about which factors the company should focus on to guarantee the profitability threshold. This chapter reflects the major focus of this research as the resulting model can be used by the company to assess on a case by case basis whether or not it is profitable to offer the customer an energy service contract and at what electricity tariff.

Based on the findings from the previous sections, **Chapter 9** discusses the possible alternatives for power utilities on how to embrace this technology and include it in its own product portfolio. Finally, in **Chapter 10**, a summary is made and the conclusions are drawn.

3. Political and institutional background

3.1. German subsidy scheme

In 1990, the newly elected coalition of SPD and Bündnis90/Die GRÜNEN[3] marked a fundamental change in Germany's energy policy. Until the late 1980s, renewable energy deployment was supported by a variety of national and federal programs based on research grants and association agreements. Nevertheless, the law did not permit the remuneration for production of renewable electricity with a premium tariff that would cover the higher costs of infant technologies. After German reunification in 1989, a draft law for an electricity feed in act (*Stromeinspeisegesetz* – StrEG) was presented to parliament. The newly elected coalition supported the law, which was unanimously adopted by the Bundestag and entered into force on January 1st, 1991 (Bruns et al., 2011).

3.2. The first feed-in-tariff

The newly adopted StrEG was the first German energy policy that provided financial support and feed-in-tariffs for the production of electricity deriving from renewable energy sources (RES). The main improvement of this law was that the grid operator was obliged to purchase the electricity delivered by the power plant operator. Before 1991, the grid operator decided whether it was possible to connect the new power plants or not, based on given circumstances (like transmission capacity, peak load, and power plant distribution). The new provision deprived the grid operator from this freedom of choice, while at the same time giving the power plant operators the needed investment security in knowing that any investment made in renewable energy technology (RET) will generate the expected revenues.

The inception of the StrEG went unnoticed by power utilities that operated conventional power plants. It was only during the first revision of the law in 1994 that these power utilities began to lobby against the law and the aimed adjustment of compensation rates. By then it was clear that the new law was having the desired effect and the losers were the operators of centralized, fossil-fuelled power plants; power utilities went so far as to call the new law unconstitutional. Nevertheless, the German Federal Court of Justice in 1997 and the European Court of Justice in 2001,

3 SPD Germany's Socialist Party and The Green Party

both ruled that feed-in-tariffs and minimum payment regulations comply with the [German] constitution and [European] law (Bruns et al., 2011).

3.2.1. The Renewable Energy Sources Act (EEG)

The StrEG was successful in supporting the development of RETs, which were still in their infancy[4]. Meanwhile, during the 90s, major developments that were made by the Germans started to carry over to the European and even global levels. In a white paper published in 1997, the European Commission declared its intention to double the European share of energy derived from RES from 6 to 12% by 2010. At the ensuing UNFCCC conference, the emission reduction pledged by the EU within the EU-bubble (an average of -8% between 2008 and 2012 compared to 1990 levels) and the planned measures for the achievement of these goals coincided with the indicative targets of the white paper. Through the doubling of the energy supply from RES by 2010, the reduction in emissions could have been achieved (Pollak et al., 2010).

By the end of the 1990s, the German government was aware of the fact that the current feed-in-tariffs (FIT) of the StrEG were too low to foster the RE deployment necessary to meet the German and European target of doubling the share of RE. A new law was drafted by members of the Greens and the SPD and entered into force on April 1st 2000: the "Renewable Energy Source Act" (EEG). Compared to the StrEG, the EEG brought about the following changes:

- Security of investment was further improved by fixing compensation rates per kilowatt hour independently of the development of the electricity price.
- Remuneration was guaranteed for 20 years, which increased the bankability[5] of RE investments.
- Compensation varied by power plant size and technology.
- Power utilities were allowed to benefit from the FIT.
- Large electricity consumers were granted an exemption from the apportionment of the FIT.

Since its inception, the EEG has been amended twice, in 2004 and 2009, respectively, in order to adapt to changes in market dynamics, technological innovations, and cost reductions due to steep learning curves[6].

4 Compared to today's installed capacity, very few wind, biomass, and photovoltaic power plants existed

5 Bankability of a project expresses the likelihood of receiving loans from commercial banks

3.2.2. Dispute over costs of the EEG

The StrEG and EEG lead to the deployment of large amounts of RET power plants. These power plants were in part imported from other countries and in large part manufactured domestically, driving a fierce innovation and development process. Since the foundation of the first FIT for the support of RET, it was Germany's declared aim to become a world leader in clean technology. This goal was successfully being pursued, as the employment statistic in the RE sector shows (see Figure 3).

Figure 3. German employment figures for the RET sector from 1998 to 2011 (Agentur für Erneuerbare Energien, 2012)

Nevertheless, the strong increase in manufacturing companies was only possible through the subsidization of the industry. The largest amount of subsidies were indirect in nature: the guaranteed remuneration of the produced electricity for 20 years created a large demand for RE technology, which had to be supplied domestically or internationally. The financial resources for these subsidies stem from a levy added to the electricity bill of consumers. In 2010, the redistribution from consumers to producers amounted to € 13.2 Billion (Agentur für Erneuerbare Energien, 2012).

The apportionment of the FIT through the levy that is added to the consumers' electricity bill is not equally distributed. Large electricity consumers are afforded an

6 The learning curve expresses the periodic reduction in manufacturing costs based on the installed capacity. For photovoltaics e.g., there is a 20% decrease in manufacturing costs for each doubling of installed capacity.

increasingly privileged position leading to the situation of consuming 18% of the total electricity produced in 2010 and contributing only 0.3% to the costs (Bundesnetzagentur, 2012). The missing contribution has to be apportioned to the remaining consumers, which, consequently, results in a higher fiscal burden for the latter. In 2006 the electricity tariff amounted to 19.4 ¢€, of which 0.7 cent was levied to pay the FIT for electricity from RES, whereas the remaining costs were unrelated to RE technologies.

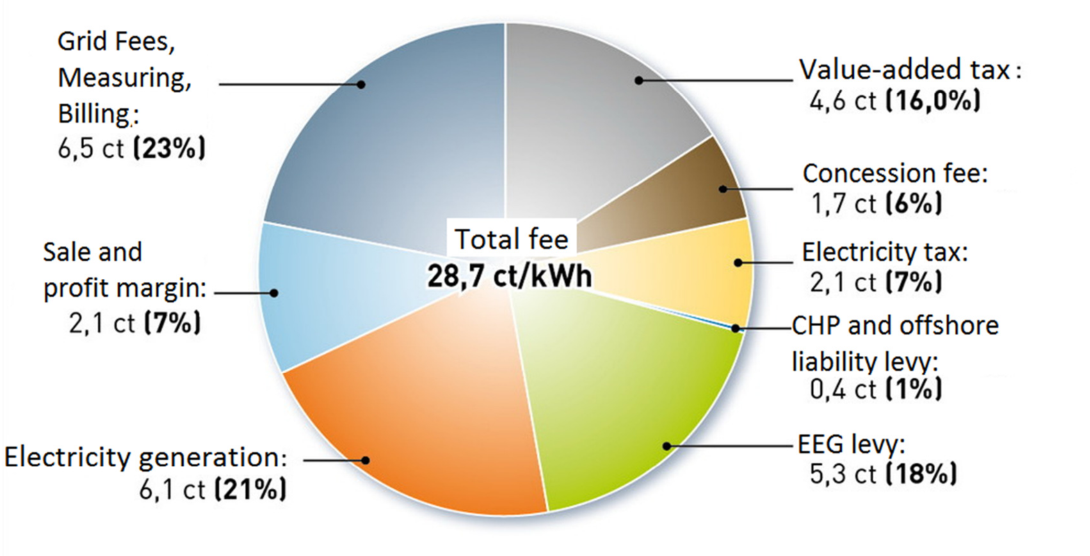


Figure 4. Expected composition of the electricity price for German households in 2013 (Agentur für Erneuerbare Energien, 2013)

In 2013, the cost distribution shifted slightly. The EEG apportionment increased by 4.4 ¢€ to 5.3 cent/kWh[7], whereas the overall tariff for electricity increased by 9.3¢€ to 28.7 ¢€/kW· (see Figure 4). The increase in the FIT apportionment was due to a strong growth in photovoltaic power plant deployment, which earns the highest compensation per kilowatt-hour produced.

7 Estimation, based on the 2012 deployment of new RE power plants

4. Global PV panel market

4.1. The bubble inflating subsidies

During the last decade, PV panel manufacturers experienced fantastic growth rates that turned into a market bubble in the years between 2008 and 2010 (EuPD, 2012). This bubble was driven by generous subsidies offered by regulators of mostly European nations through feed-in tariffs (FIT) and paid for by electricity customers (Bruns et al., 2011). By early 2012, over 65 nations had FIT policies (Greenpeace et al., 2012). Although the energy policies that European member states implemented foresaw *ab ovo* a progressive reduction of the FIT (Wild and Karl, 2012), once these cuts in subsidies became reality, PV panel and solar cell producers and production line manufacturers around the world saw their margin shrink and insolvencies started to spread.

The on-going global economic and financial crisis forced governments to adopt harsh austerity measures. Consequently, national FIT schemes were curtailed more than previously anticipated, and the margins of renewable energy investments started to shrink dramatically. This triggered a downward price spiral of PV system suppliers, which were not able to bring their products to the market without incurring in huge losses. Manufacturers reacted by increasing production capacities in order to drive down unit costs. The austerity measures adopted and the weak conjuncture, nevertheless, reduced the propensity to invest in new PV installations. The result was an overhang in supply that set the customer in the power position of price-setter and turns manufacturers to price-takers. Consequently, margins decreased throughout the whole value chain of manufacturing and installation of PV systems. Today the market is undergoing a consolidation phase in which bankruptcies, mergers, and acquisitions make the headlines every day (Bank-Sarasin, 2011).

4.2. Manufacturers

In 2009, the market for PV modules was dominated by crystalline silicon technologies, which held 80% of market share, whereas the remaining 20% of the sold modules were thin-film PV cells. The major panel manufacturers are located in Germany, the USA, and China. Although 2011 saw the largest increase in newly installed capacity, the PV manufacturing industry is in turmoil and the media sees a solar-industry-Armageddon taking place (Hackhausen, 2012). The undeniable destiny of a market bubble is its inevitable bursting. There are, however, voices of energy experts that see in the current process a "natural consolidation" of the market. In an article by the European Energy Review, Craig Morris points out that although the Chinese competition is fierce and allegedly unfair due to large direct state subsidies, the German market will always profit from the installation of PV modules, whether the installed panels are made in Germany or in China (2012). The argument is based on a study performed by Solarpraxis, which demonstrates that in 2010 the modules made up 50% of the whole PV system costs (including installation), whereas, in 2012 this value decreased to 40%, leaving a total of 60% of the installation costs for locally delivered labor and balance-of-system (BOS[8]) components like cabling, inverters, and frames (Hübner, 2012).

4.3. The consolidation

The market is affected by huge overcapacities on a global scale. In 2011, the annual manufacturing capacity of solar cells (all technologies) reached 60 GWp; according to Morris this capacity was met by a demand for only 29 GW (2012). Therefore, the overhang of supply currently amounts to more than 50%: a toxic environment for any kind of market. The consequences of the consolidation are widespread bankruptcies and a Darwinian environment of "survival of the fittest," whereas the fitness criteria consists of a vertically organized manufacturing process, a broad customer portfolio, and a well-designed cost distribution (Carr, 2012)

4.4. Where is grid parity?

A well-known notion of the current Zeitgeist of energy economics is grid parity. The intended parity refers to the price equivalency between the generation cost of one kilowatt-hour of electricity from a hypothetical PV system on the customer's roof and one kilowatt-hour purchased from the grid at the customer's connection point (corresponding network tier). What this terminology does not refer to is that PV has become competitive in electricity generation. Whether PV technology reaches grid parity or not depends on the levelized cost of electricity (LCOE) of the system, which in turn is linked to a series of site-specific variables.

8 In general BOS comprises everything that makes up a PV system, except the panels

The chart in Figure 5 plots a selection of values for power plant LCOE divided by technology. Bloomberg New Energy Finance defines the LCOE as an economic tool for renewable energy technologies to *"understand how competitive each is with its fossil fuel rivals on something close to an apples-to-apples basis"* (Bloomberg, 2012a).

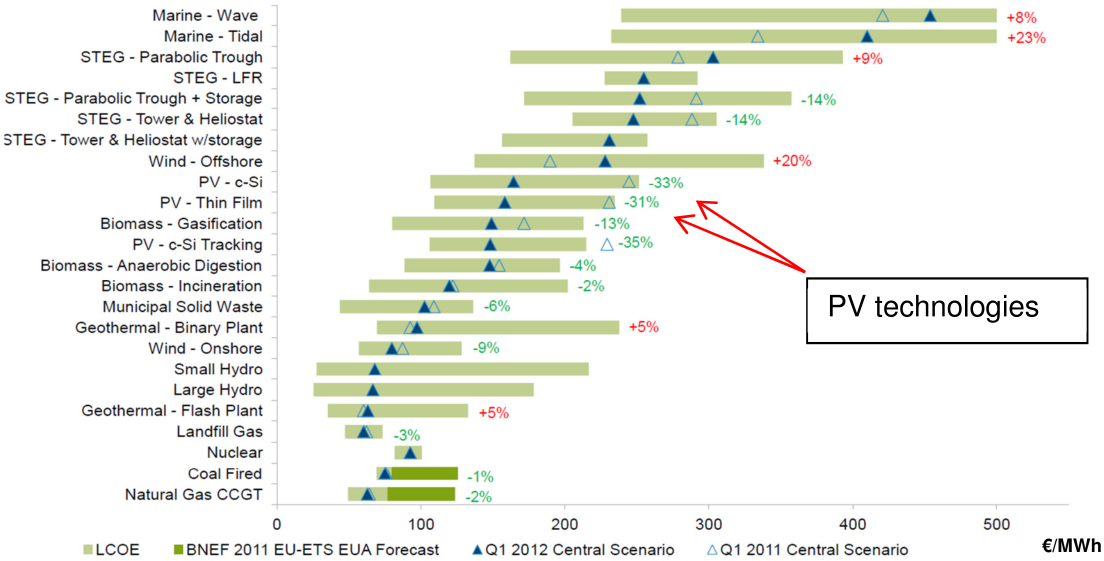


Figure 5. Levelized cost of electricity [in €/MWh] for different generation technologies, Q1-2012 vs. Q1-2011 (UNEP, 2012)

The graph reveals the power of representation that the LCOE has: it allows an investment decision to be made based on a comprehensive lifecycle cost analysis instead of a mere capital expenditure comparison, and it provides the ability to track the LCOE development over time. The graph illustrates the range in generation costs for each renewable energy technology and compares it to costs of fossil and nuclear-fuelled power plants. The costs of renewable energy technologies (RET) mainly depend on the technical equipment chosen and the cost of capital for the investment, as there are no fuel inputs over operation lifetime (except for biomass). The graph further illustrates the change in LCOE between Q1-2011 and Q1-2012[9]. Concerning PV technologies, staggering declines in price of over 30% in only 12 months were registered for electricity generated by crystalline and thin-film PV systems. When compared to the generation price of fossil fuels, the graph suggests that if the price of carbon emission would be included in the generation price

9 Q1 stand for first quarter of the year, i.e. the first three months.

(shaded area of coal and natural gas LCOE range – assumed price is 30€/t), some PV systems (lower range) would be competitive without subsidies.

As previously stated, the LCOE of PV electricity generation technologies is closely linked to the variability of the solar radiation input and the cost for the power plant; this relationship is illustrated in Figure 6.

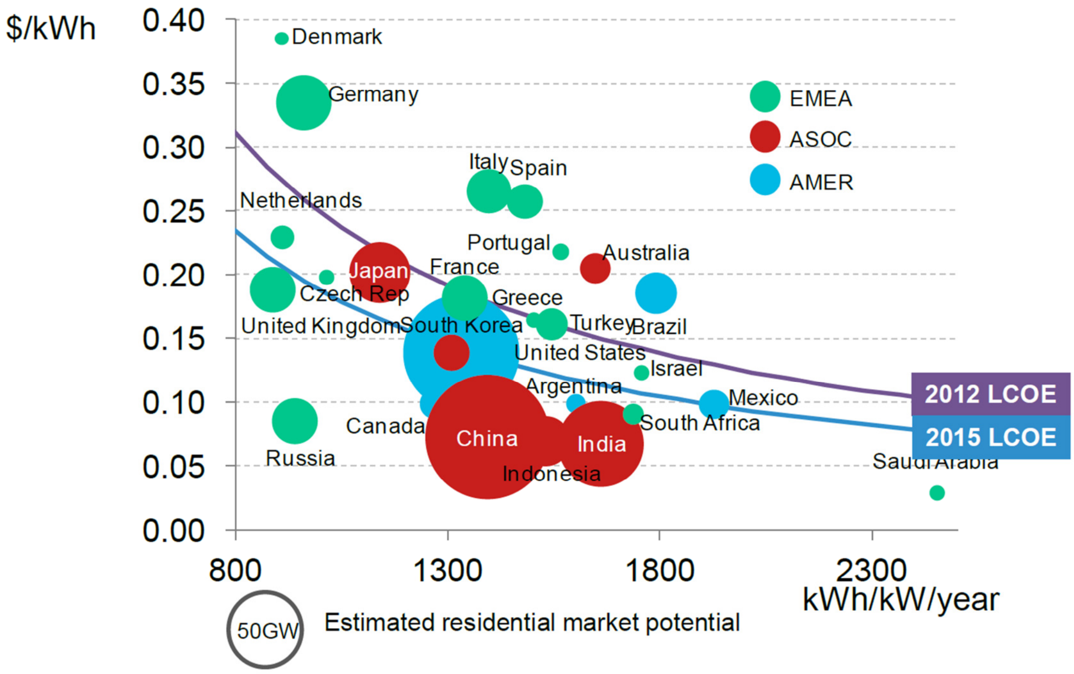


Figure 6. Estimated residential PV price parity in 2012 and 2015, in US$/kWh (UNEP, 2012)

The graph includes four sets of data: the x axis represents the annual global irradiation; the y axis shows the retail price for residential electricity (including all taxes and fees) and the value for the LCOE (same dimension as the electricity retail price which it substitutes); the size of the circle represents the potential for residential PV market in each country (on the bottom left there is a reference size for 50 GWp), whereas the color of the circle identifies the geographical area [Europe, Middle East and Africa (EMEA), Antarctic, Southern Ocean Coalition (ASOC), and the Americas (AMER)]. The fourth and final category of information is the LCOE which is represented by two lines: a purple line for 2012 and a blue line for the LCOE in 2015. These lines are a function of the variables on the x and y axis and represent the threshold for the respective grid parity in each country. According to the graph, for a residential PV system installed in Germany, where 1kWp yields less than 1,000 kWh/p.a. and residential electricity cost just under 0.35 US$/kWh, **grid**

parity is given[10]. The assumptions underlying this statement are 6% WACC[11]; 0.7% module degradation rate; 2,650 US$/kWp CAPEX[12] for 2012 and 2,000 US$/kWp for 2015; annually 1% of CAPEX for operation, maintenance, and insurance (Bloomberg, 2012b).

The stunning and relatively simple message of this chart is that in all countries above the “2012 LCOE” line, the installation of residential PV is profitable without subsidies; this means that for any household to which the assumptions listed above can be applied, it is more profitable to install a PV system on the roof and use as much of the generated electricity as possible than to purchase the electricity at the current average price from a German utility.

A more recent assessment of PV-grid-parity was made by Gerlach and Breyer (2012); the authors looked at the electricity prices and irradiation values of more than 150 countries and made an estimation of the market development in the near future by applying the empirically derived learning curve of the PV-industry. The results of the study on the European market are shown in Figure 7 and Figure 8. The chart is very similar to the one in Figure 6, the differences being that this figure depicts only European countries, differentiates between industrial and residential sector, and the axes have been swapped: on the x axis are the electricity costs for end users and on the y axis the energy yield of a 1kWp power plant. It is important to point out that there is a rapid shift of the grid-parity line that seems to inundate the European electricity market like a Tsunami, leaving out only Russia, and Ukraine by 2020, countries that both heavily subsidize end-user electricity.

Critics to the comparability of Levelized Cost of Electricity

In a paper presented at the International Energy Economics Conference of Vienna in February 2013, Lion Hirth discussed the applicability of the LCOE in the comparison of different electricity generation technologies (renewable and not). Mr Hirth argues that variability, long-term unpredictability of generation and location specificity of RET generate social costs that the LCOE cannot and is not taking into account, therefore, misleading the decision maker and society as a whole into wrong

10 The large dot, which represents the market potential, is positioned where the Germany’s solar irradiation level and Germany’s electricity retail price meet.

11 Weighted Average Cost of Capital

12 Capital Expenditure

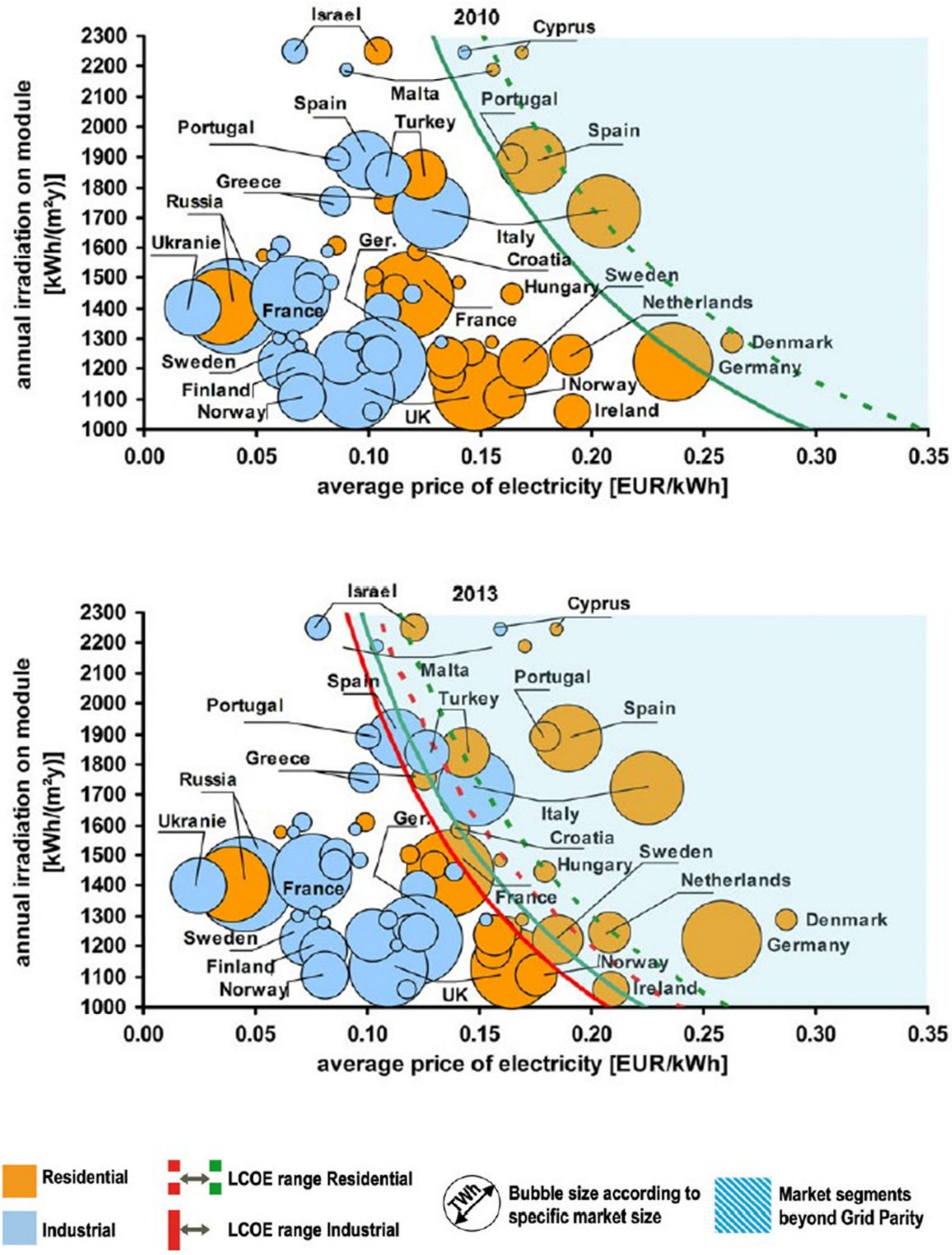


Figure 7. Development of European electricity prices and LCOE of PV in 2010 and 2013 (Gerlach and Breyer, 2012)

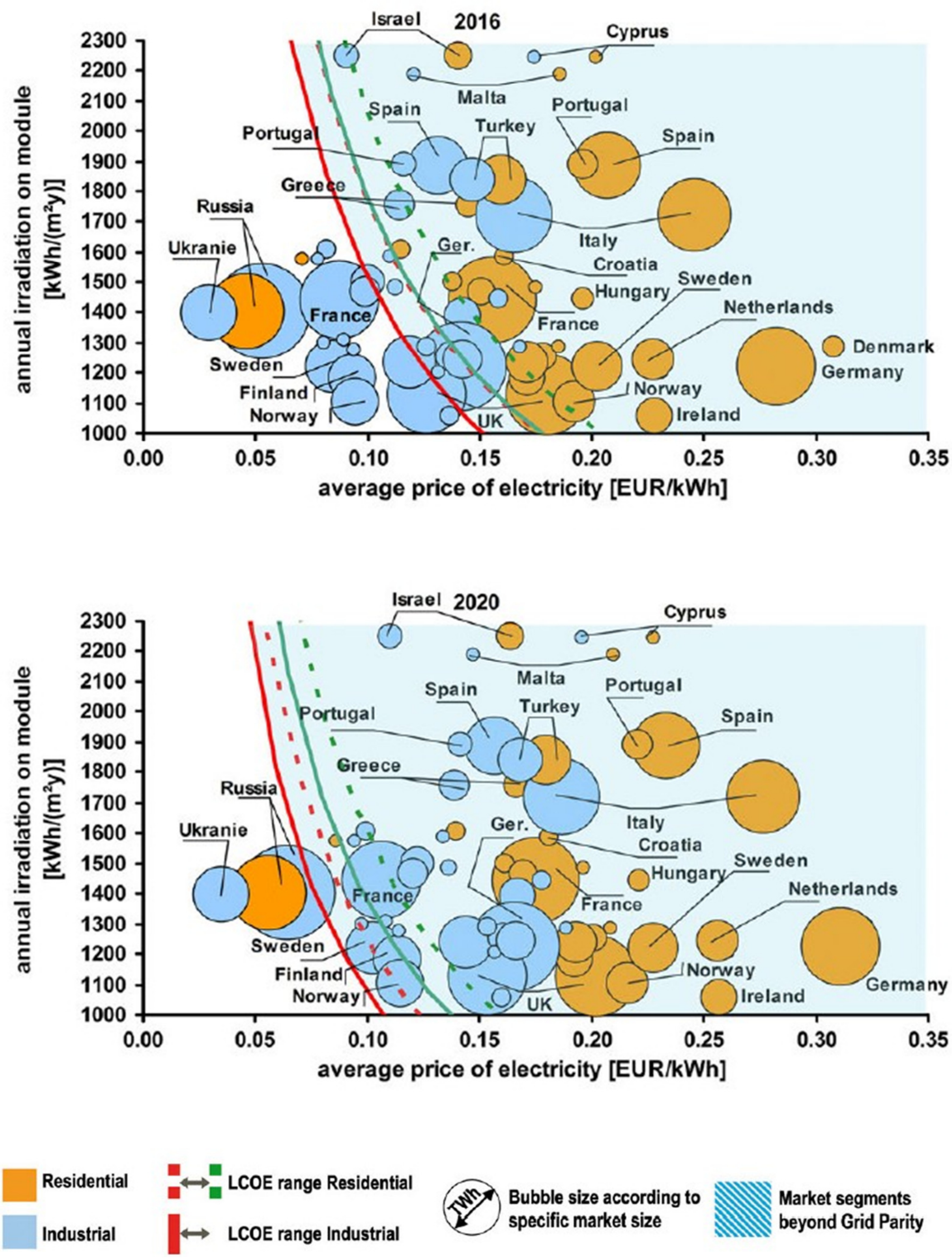


Figure 8. Development of European electricity prices and LCOE of PV in 2016 and 2020 (Gerlach and Breyer, 2012)

decisions about overall technology costs (Hirth, 2013). The political-economic notion of negative externality is the linchpin of the mentioned paper, which indeed raises a significant issue that needs to be addressed. From an energy economics point of view, however, the LCOE represents the most transparent tool at hand. The debate over whether or not it includes negative externalities that may affect the national power system is left in the hands of political economists and will not be further discussed here.

4.5. Austrian Grid parity

The average residential electricity tariff in Austria currently amounts to 19.7¢€ (E-Control, 2012a). The lower price for retail electricity implies that in order to reach grid parity the LCOE of Austrian PV systems has to be lower than in Germany. Keeping the same set of assumptions from Figure 6 and applying the current Austrian electricity tariff, grid parity in the Austrian residential sector might be imminent[13]. This possibility is supported by a research project funded by the Intelligent Energy Europe research fund, PV-Parity, in which residential PV grid parity is forecasted with 65% certainty by 2012, 95% certainty by 2014 and 100% certainty by 2016 (Figure 9). For the grid parity of the industrial sector, the same research group performed a Monte Carlo simulation, which showed that, based on the variables self-consumption, system size, and WACC, the probability that grid parity will become reality is estimated at >90% by 2016 for industries that have their main active period (highest electricity consumption) during the hours 8:00 to 18:00 (Figure 10). Industries that are active during the day and the night usually profit from

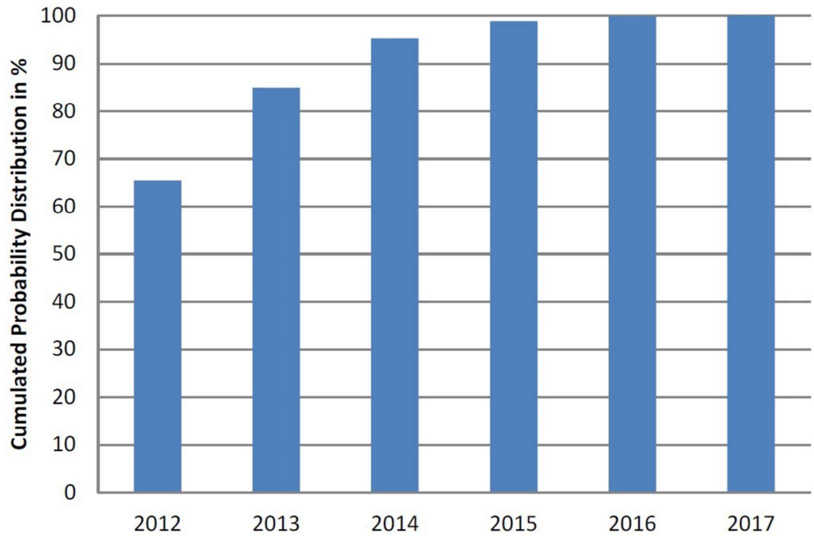


Figure 9. Cumulated Probability Distribution [in percentage] of Austrian residential PV-grid parity (Lettner and Auer, 2012)

13 Current tariff in USD: 0.197€*1.25$/€=0.246$, solar irradiation of 1000kWh/kWp per year

lower electricity tariffs due to their higher consumption. For this consumer category, therefore, due to their lower costs per unit of electricity, grid parity will be reached by 2020 with a 100% certainty (Lettner and Auer, 2012).

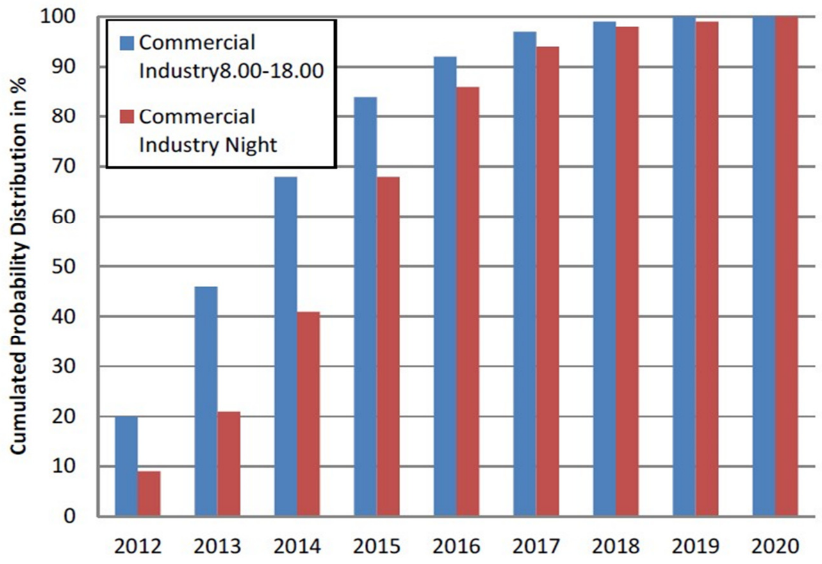


Figure 10. Cumulated probability distribution [in percentage] of industrial PV-grid (Lettner and Auer, 2012)

5. The Austrian PV market

The market penetration of PV in Austria was crippled during the last decade by a frequently changing subsidy policy combined with the introduction of a quota system that poses a yearly limit on subsidized power plants. Consequently, the contribution of PV to the national Total Primary Energy Supply (TPES) can be regarded as insignificantly small (0.1% in 2011). However, the stark fall in module prices for PV-arrays of the last two years, coupled with additional federal subsidies, provoked a high increase in annually installed capacity in Austria. In 2011, the recognized[14] cumulative capacity increased by 105% from 154.4MWp to 316.4MWp; the second year in a row that the capacity doubled[15]. This remarkable market development combined with a renewed amendment of the Austrian Green Electricity Act in 2012 may signal a tipping point for the accelerated development of the Austrian PV market.

5.1. Austria's National Renewable Energy Action Plan (NREAP)

In compliance with the EU directive 2009/28/EC, the Austrian government defined a national energy strategy divided into three pillars: the constant improvement of energy efficiency (i.e. reduction of energy intensity[16]), the increased deployment of renewable energy, and the long-term safeguard of national energy security (Gruber, 2011). The main pillar of the Austrian strategy is the setting of an energy consumption ceiling at 1,100 PJ per year (final energy consumption) and the increase of the RET share of TPES from 23.3% to 34% by 2020. In the National Renewable Energy Action Plan (NREAP) that Austria submitted to the Commission in 2010, the government included a development plan of RET deployment that will allow Austria to reach the 2020 targets (WIFO, 2010).

Based on the forecasted electricity consumption and the agreed upon increase in electricity generated by RET, the production of electricity from RET will have to increase by 26% (using 2005 as a reference) from 41.3 TWh to 52.4 TWh (E-Control, 2012a). The strategy further requires that at least 1,200 MWp of PV panels

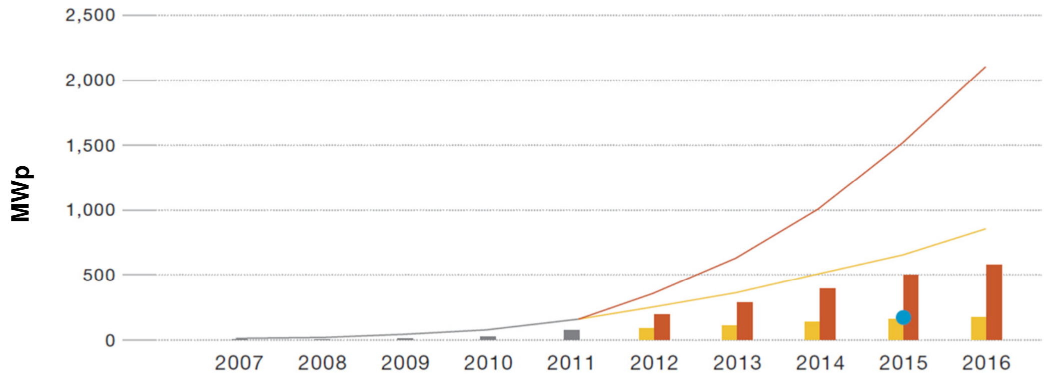
14 The recognized cumulative capacity includes power plants that reached admission status, but have not yet been installed

15 In 2010, the cumulative capacity rose by 116% from 71.3 to 154.4 MWp.

16 Expressed in J per unit of GDP

will be installed, contributing to the national TPES with 1,200 GWh of generated electricity each year.

According to a recent European PV market report published by the European Photovoltaic Industry Association (EPIA), in 2016 the Austrian cumulative installed PV capacity will reach 880 MWp under moderate development (with current policies), and possibly as much as 2,200 MWp with political intervention (see Figure 11). The question is, where will this additional capacity be installed and by whom?



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EPIA Moderate	2	5	20	43	80	100	120	140	160	180
EPIA Policy-Driven						200	300	400	500	600
EPIA Moderate (cumulative)	28	33	53	96	176	280	400	540	700	880
EPIA Policy-Driven (cumulative)						380	680	1,100	1,600	2,200
National target 2015									179	

Figure 11. Historic development and forecast of the Austrian PV market (EPIA, 2012b)

5.2. Austrian PV peculiarities

The Austrian PV market differs from the German market by many aspects. According to the EPIA report, the development of PV is led by the residential sector with almost 90% of the cumulative installed capacity. Only 10% of currently installed capacity resides on industrial or commercial premises and as ground-mounted PV-arrays (see Figure 12). Compared to the other member states of the union, the Netherlands and the United Kingdom show a similar distribution, whereas all the other markets are either more evenly distributed (e.g. Germany, Italy, Hungary, and France) or are predominantly concentrated on ground mounted systems (e.g. Spain and Bulgaria).

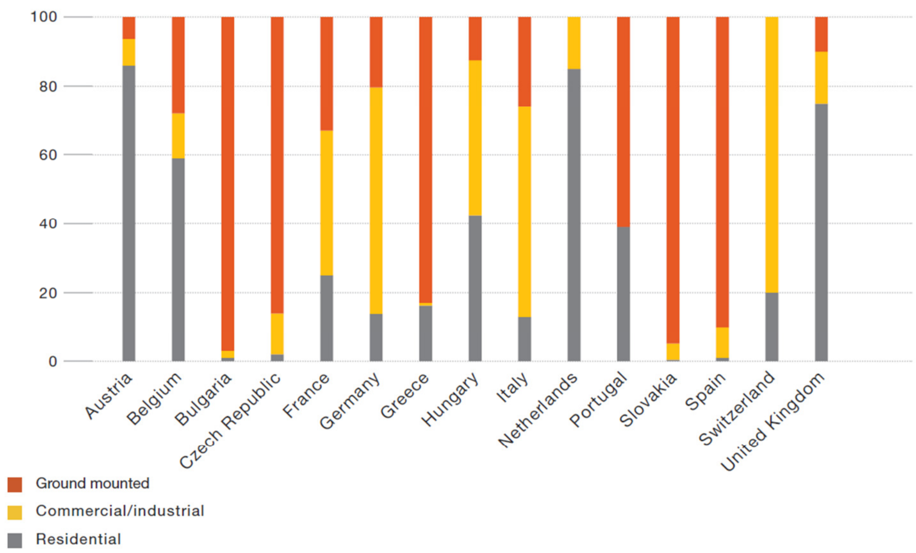


Figure 12. European PV cumulative capacity segmentation until 2011, in percentage (EPIA, 2012b)

According to the Austrian PV-system installation company R-1 Solar, and as stated in the periodiacal Sonnenstrom (2012) one unique feature of the Austrian PV market is its grid regulation laws and the costs implied in them (Niederkircher, 2012). The Austrian Electricity Industry legislation (*Elektrizitätswirtschafts-und-organisationsgesetz* (ElWOG)) and the directive on the system utilization and tariff calculation (SNT VO) (E-Control, 2013a) provide that the property limits of the electricity transmission and distribution grid (T&D) vary depending on grid tier[17] as shown in Figure 13:

- for tier 7 connections, the boundary is the network connection to the low voltage distribution grid.
- for tier 6 connections, the boundary is the client-side of the substation.
- for tier 5 connections, the boundary is the mid-voltage distribution grid.

17 The national grid is divided in tiers (or levels). The highest (1) is the transport tier for long distance electric power transport; the lowest (7) is the distribution tier, which ends with the electric meter of households. Tier 3 and 5 are mid-tension transport and distribution lines. All the even numbers in-between represent the transformers between the tiers: tier 1 has the highest tension; tier 7 has the lowest tension.

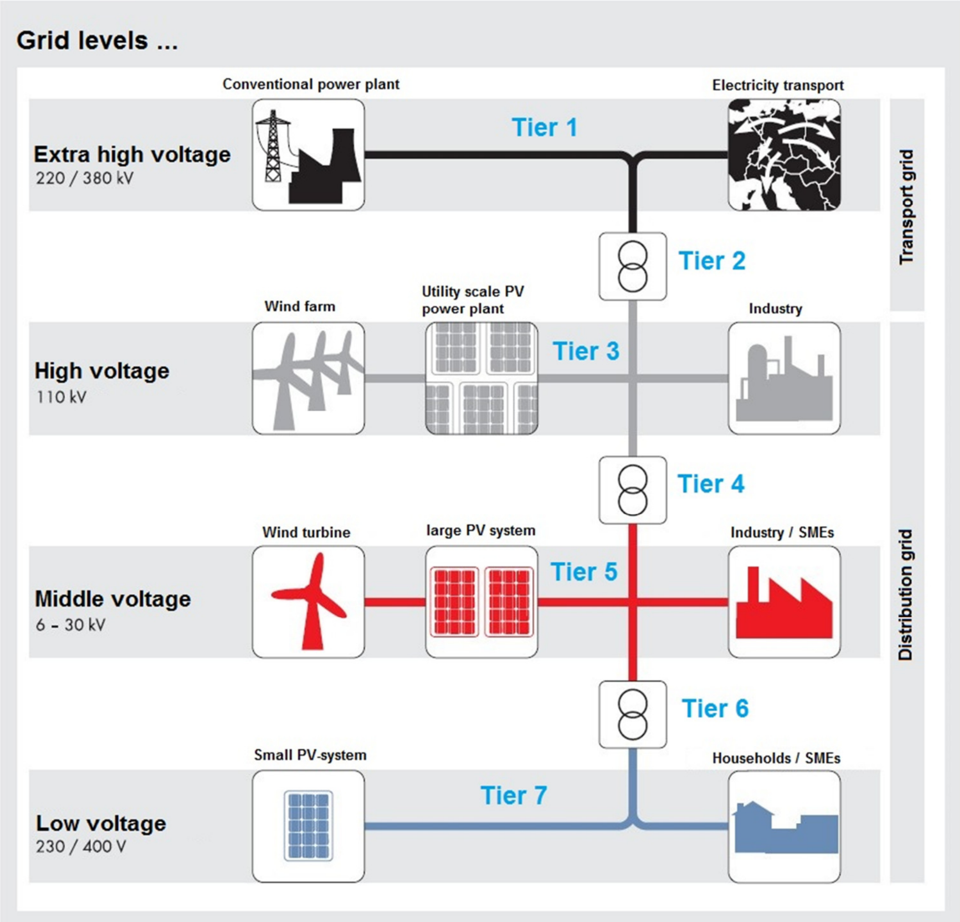


Figure 13. Structure of the Austrian (and German) electric grid; modified after (SMA, 2011)

In the case of tier 7 grid connection which is predominantly the residential sector but also the small business sector, there are no additional investments to make. For PV installations at tier 5 grid connections (consumption >400,000 kWh/a), additional expenses start to shake the cost-effectiveness of the project. For a 100 kWp PV system that needs to be connected at tier 5, depending on grid configuration and distance from the next transfomer (which according to the law is property of the client), up to 40,000€ have to be added to the project investment calculation for the installation of additional transformer capacity, the necessary cable lying, and network services (Niederkircher, 2012).

In contrast, German law spreads the additional costs that distributed RET generate over all consumers via grid fees, hence, socializing the *Energiewende*[18].

18 This German word stands for energy turnaround, and is widely used also in English literature (like the word Zeitgeist) to describe the current transition phase that is taking place in the global energy system

6. Power Utilities

The economics of energy are about to be revolutionized. Power plants of the 20th century are based on fossil and nuclear fuels where chemical energy is first transformed into thermal, then mechanical, and finally into electrical energy. This well-established thermodynamic process, although greatly improved in efficiency, generates a large amount of anergy[19]. Consequently, in order to be cost-efficient these power plants need to be designed as large as possible (100 to 2,000 MW), used in a centralized fashion, and run at full-load for as long as possible. Power plants of the 21st century on the other hand, are based on physical processes that generate little or no anergy during operation. That is why wind turbines and photovoltaic panels are the most promising candidates to push forward the on-going *Energiewende* on a global scale.

In fact, not very long ago, due to the imposing economies of scale of these power plants and the high costs related to this business, European utilities benefitted from quasi-natural monopolies.. In the 20th century, customers looked at electricity as a one-way good: out of the socket. Today, however, thanks to the liberalization of the market (see following paragraph), technological development, and a strong fall in the price of RET, electricity has become a two-way good: from the PV-system to the grid and back. It is clearly a very hard challenge for European utilities to adapt to such a paradigm shift that is overturning any 20th century electricity generation and sale business model, no matter how successful it was in the past.

6.1. The electricity market

The Austrian electricity market began its liberalization process in 1995. Electricity today is a broadly traded commercial good; bought and sold in large amounts either via bilateral contracts or through stock exchange transactions like futures and options, and as a commodity via spot prices on the European Power Exchange (EPEX), a subsidiary of the European Energy Exchange with headquarters in Leipzig, Germany. Any household, commercial business or industry can change the supplier of working power[20]. The electricity fees paid by the clients include the costs

19 waste energy that cannot be employed usefully in any thermodynamic process

20 In order to purchase electricity from the grid the consumer pays for: 1) the grid infrastructure (in € per maximum load and in € per unit of energy withdrawn); 2) the working power, which is the delivery of the electricity itself (in € per unit of electricity); 3) taxes and local/national duties (lump sum and/or in € per unit of electricity)

for working power and for the transmission and distribution network (T&D). The latter are paid to the transmission system operator (TSO) which operates the grid between 110 and 380kV (tier 1 to 3), and to the distribution system operator (DSO) which operates the middle and low-voltage grid (tier 4 to 7). Both TSO and DSO enjoy the status of natural monopolists. The TSO in Austria is APG, a 100% subsidiary of VERBUND AG, whereas the DSO is usually the regional utility (Kleinwasserkraft Österreich, 2008). In Lower Austria, the DSO is EVN Netz GmbH.

Utilities today offer a wide range of services to both the residential and the industrial/commercial sector. The customer portfolio of a typical Austrian utility comprises big customers with large electric throughput (e.g. power supply for manufacturing industry with annual consumption >2GWh), small and medium enterprises with electricity consumptions between 50,000kWh/a and 2GWh/a, and small customers with little throughput (power supply for small family household: <10.000kWh/a). Austrian utilities deliver the working power to their customers independently of their geographical location on the Austrian territory[21], and are responsible for the maintenance of the distribution network in their supply area. Other services offered by utilities are gas supply, telecommunication services, district heating, and potable water.

6.2. Electricity tariffs

In order to assess the market potential for non-subsidized PV installations, the development of the electricity price is of utmost relevance. The unique selling proposition (USP) of a PV system strikes when the life cycle costs of the PV system are lower than the costs accruing in the same period when the same amount of electricity is purchased from the utility[22].

6.2.1. Industrial electricity

The consultancy company A.T. Kearney analysed the Austrian industrial electricity tariff since the liberalization of the market in 1995. As is shown in Figure 14, the liberalization that was undergone achieved the desired effect of increasing

21 In reality, the electrons always follow the path of least resistance, therefore it cannot be said that the utility actually delivers the electricity it has produced. The utility produces a quota of electricity and feeds it into the grid. The electrons use by its customers might come straight from the utility's power plant or from another utility. In the end production and consumption is netted out through accounting, losses included.

22 Expected electricity price evolution over the expected lifetime of the PV system

competition and decreasing prices; the industrial tariff, here expressed in nominal Euros between 1996 and 2009 decreased from a peak of 7.7 ¢€ in 1997 to a low of 4.0 ¢€ in 1999 (working power price). Beginning in 2002, the item "Energy" which hitherto comprised working energy and grid fees, was split in order to allow the customer to differentiate the cost structure of the tariff. Also in 2002, the green electricity fee was introduced (*Ökostromabgabe*). Since 1996, the total price of industrial electricity increased by 42%. A large portion of this rise was due to a strong increase in governmental levies and fees, which soared by 122%, and to a small extent to the increase in working power and grid tariffs, which grew by 22% in the same period (1.56% p.a.). According to E-Control, which monitors Austria's energy fees, the average price for the second half of 2012 amounts to 6.16¢€ (standard deviation: 0.67¢€), lower than the 2009 price shown in Figure 14, for an annual consumption lower than 10GWh, indicating a reversal of the price development trend of the last decade (E-Control, 2013b).

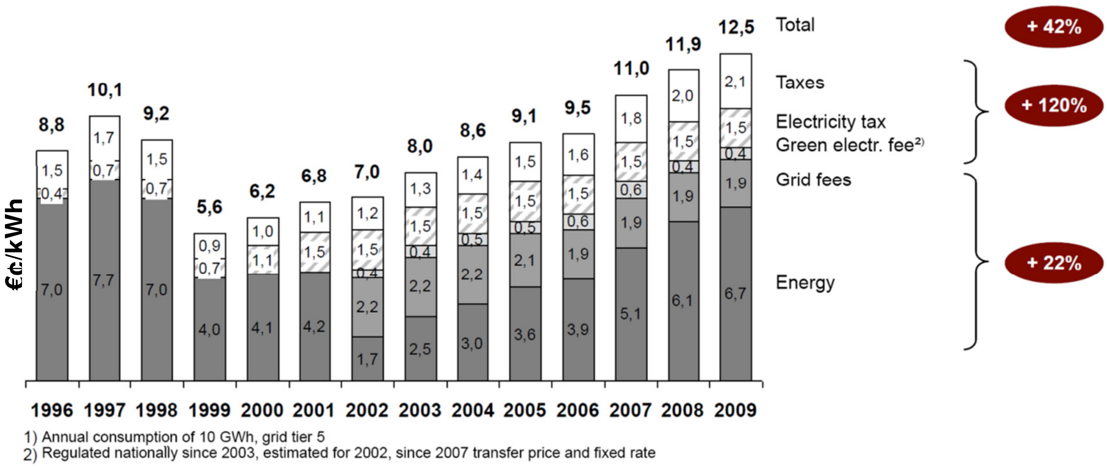


Figure 14. Development of the gross industrial electricity tariff (including VAT) - nominal 1996 to 2009 (A.T. Kearney, 2012)

Electricity tariff forecast for 2020

Although forecasts based on historical data rarely materialize under normal economic conditions, and even less so during economic recessions, in 2009 A.T. Kearney modelled the electricity price for the next eleven years. The electricity levy and the green electricity fee are assumed as constants throughout the period, whereas the grid fees are seen as declining slightly from 1.9 ¢€ to 1.8¢€ (all values are net of inflation). The working energy price on the other hand, is expected to rise within the range of 60-130% from 6.7¢€ to 10.7-14.7¢€ until 2020 (a price increase of 4.3 to 7.4% p.a.). The underlying argument of the consultancy company is that the certificate costs that utilities will have to stem starting from 2013 onward will be rolled over to customers via the electricity bill. Moreover, according to the consultancy company, the rising price of fuels for power plants, especially natural gas which is expected to be dispatched more frequently to compensate the volatility of renewable energy power plants, will offset the merit order effect[23] of renewables on the electricity spot market.

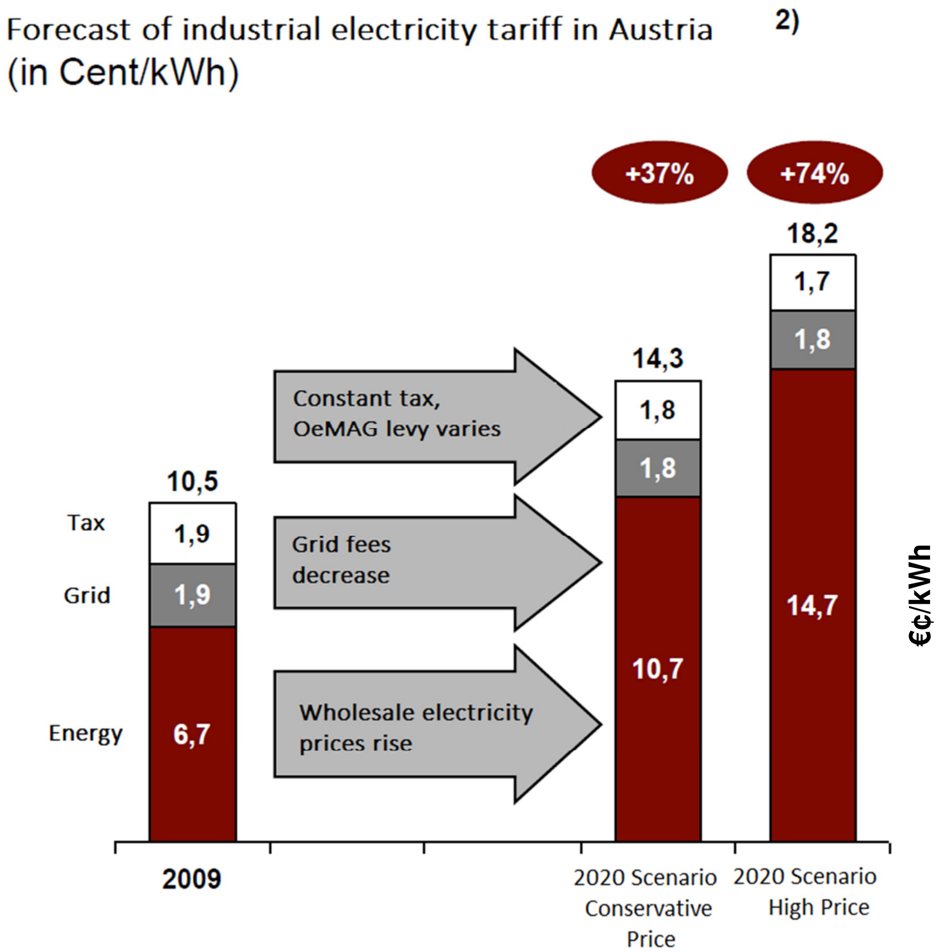


Figure 15. Forecast of the Austrian industrial electricity tariff (A.T. Kearney, 2012)

23 On days with high sun irradiation and high wind speeds, the supply of electricity from conventional power plants is displaced by electricity from RE power plants. In a simplified way, the supply of electricity from RE can be regarded as a diminished demand that has to be met by a lower supply from conventional power plants. The merit-order has the effect of reducing the price paid by consumers for the electricity withdrawn from the grid. This is called Merit-Order Effect. The effect can be so strong that on the 8th of March 2009 for the first time in history the EEX price index, Germans spot market for electricity, went negative (buyer receives money for the purchase of electricity) (Marco Nicolosi, 2009)

6.2.2. SME electricity prices

Working power

Contrary to the household sector, small and medium enterprises (SME) have load profiles[24] that can vary widely within the customer segment. The price that the enterprise pays to the utility prevalently depends on yearly consumption, full-load hours[25], and the peaks of power withdrawn. Table 1 resembles current energy prices paid by SMEs to their suppliers. Any enterprise that consumes up to 100,000kWh, currently pays[26] a tariff between 5.60 and 13.00¢€ (average is 7.21, median is 6.80) for working power, which included the net of network fees, VAT, and taxes.

Table 1. SME working price for electricity in Q1 2013 (E-Control, 2013b)

Working Price Electricity [cent/kWh]			
Low	High	Average	Median
¢€ 5.60	¢€ 13.00	¢€ 7.21	¢€ 6.80

Grid costs

Consumers of electricity pay for the maintenance and extension of the electric grid. According to the grid level to which the consumer is connected, the price for the maximum amount of power that can be withdrawn and the price per unit of energy delivered vary. In Table 2, grid-costs for Lower Austria are listed. Grid utilization fees are composed of a power price, which represent the costs for the connection capacity according to the highest amount of power that can be withdrawn (power price), and the price per unit of energy as a measure of the utilization and wear of the grid and its transformers (grid use). The costs of all three columns vary according to the grid level.

24 The load profile is the statistical data of the consumer's power withdrawal and working power in a 15 minutes interval.

25 The power level (kW) that an enterprise withdraws from the grid varies throughout the day and the year. If the highest level of withdrawable power for instance is 1000kW (1MW) but the average over the year is 100kW, the full load hours of this consumer would be 876 hours at 1000kW (100kW*8760hrs/1000kW)

26 March 29th, 2013

Table 2. Electricity tariff range for SMEs in Lower Austria according to tier connection (E-Control, 2012b)

Grid Level	Grid Connection		Grid Use Summer	Grid Use Winter	Grid losses	ÖFB Power Price	ÖFB Grid use	ÖFB Grid losses
	EUR/kW	EUR/kW	cent/kWh	cent/kWh	cent/kWh	EUR/kW	cent/kWh	cent/kWh
Tier 4	€ 44.09	€ 25.32	€ 0.52	€ 0.67	€ 0.085	€ 8.858	€ 0.189	€ 0.049
Tier 5	€ 101.48	€ 34.92	€ 0.85	€ 1.14	€ 0.115	€ 8.182	€ 0.218	€ 0.046
Tier 6	€ 132.27	€ 30.00	€ 1.16	€ 2.00	€ 0.268	€ 8.542	€ 0.349	€ 0.035
Tier 7	€ 210.65	€ 25.56	€ 2.10	€ 3.33	€ 0.402	€ 9.360	€ 0.537	€ 0.095
Tier 7 (household)	No costs	€ 17.28 (€/a)	€ 4.27		€ 0.402	3.412 (€/a)	€ 1.022	€ 0.095

Retail price

The sum of working price and grid costs give us the range of currently paid electricity tariffs net of VAT[27]. Table 3 shows the grid-tier related electricity price for SMEs in Lower Austria, derived from the information of Table 1and Table 2.

. The lower end of the range, 6.44¢€, is the price paid by large electricity consumers connected to the higher grid, level 4, and characterized by low per unit costs and high base fees. The upper end of the range, 17.36¢€, represents the small electricity consumers with low yearly base fees and high per unit costs. It is within this range that the LCOE of the PV system has to fall in order to be profitable without subsidies.

Table 3. SME electricity retail price for Lower Austria (own calculations)

Electricity Fee range (grid + working power) VAT excl.				
Grid level	Summer	Winter	Base Fee	minimum power
	cent/kWh	cent/kWh	€/a	kW
Tier 4	**€ 6.443**	€ 13.993	€ 205,890.00	5,000
Tier 5	€ 6.829	€ 14.519	€ 22,440.80	400
Tier 6	€ 7.412	€ 15.652	€ 4,174.20	100
Tier 7	€ 8.734	**€ 17.364**	€ 360.20	10

27 Value Added Tax

6.2.3. Residential electricity tariffs

The current average electricity price in the residential sector amounts to 19.7¢€/kWh. A large part of the price difference between the average industrial and average residential tariff is due to higher grid fees and VAT (which is paid only by households, whereas for industries and SMEs it is deductible).

Since 2009, the gross market price of electricity took a completely different path from what was expected; the market price for Austrian electricity decreased sharply from 84.95€/MWh in Q3 2008 to 41.66€/MWh in Q2 2010 (E-Control, 2013c). This highly unsettling development for electricity suppliers bears the risk of delaying the advent of Austrian PV-grid parity. Figure 16 plots the development of the Austrian electricity price from May 2003 to today. Every month, the Austrian Energy Agency calculates the ÖSPI, the Austrian Electricity Price index; the basis year of which is 2006 (2006=100). The index is a black box that depicts a relative movement and not absolute numbers. The standardized calculation assures a stable tracking of the development of the electricity price as only the energy component is considered without any taxes or fees. The values are taken from the EEX electricity stock market of Leipzig and are indicative for the upcoming month because they are based on futures contracts for base and peak load prices.

The development is discouraging by any means; April is the 15th month in a row that the electricity price is receding. In the second half of 2012, power utilities were forced to reduce the electricity tariffs charged to customers as it was no longer justifiable towards the customers to profit from low stock prices on the market while charging the same tariff; further cuts might be imminent. Although this is a desirable event as a consumer, it undermines all efforts to free PV from the handcuffs of subsidies.

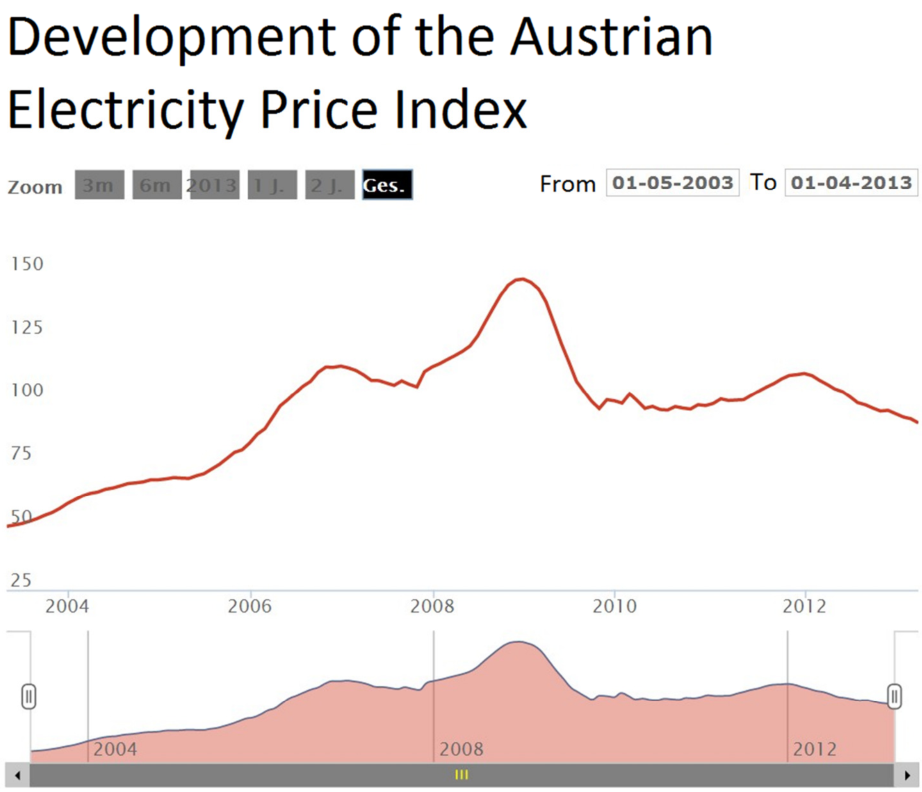


Figure 16. Austrian Electricity Index survey - 2003-2013 (Austrian Energy Agency, 2013)

6.3. Strategies of utilities towards PV

The large portfolios of customers that utilities possess give them the exceptional advantage of being well positioned in a market deemed to grow exponentially in the near future. Because a PV system on a customer's roof competes with the product the utility sells, the working power, there was no incentive from the utility's point of view to incentivize the use of this technology. Nevertheless, as the price per kilowatt peak installed capacity (kW_p) dramatically falls each passing year, grid parity might be behind the corner (see chapter 4.4), hence Austrian utilities are slowly but steadily moving into the PV market themselves and are beginning to offer a variety of products to their customers before other companies beat them to it.

6.3.1. EVN AG

The one-stop-shop solution

In 2009 EVN AG introduced a PV product in its energy service portfolio for the residential sector[28] where it offers the planning, installation, and sale of small scale PV systems. The power plant is dimensioned according to the customer's electricity consumption profile and any excess electricity is bought back from EVN AG at the same tariff (OPTIMA MIDI) for which the company sells the electricity to the customer. The consumer receives a PV system and the feed-in tariff from the same supplier with which it already has a commercial relationship.

Civic participation model

In the spring of 2012, EVN started a civic participation model for the installation of a new PV system on the premises of the Austrian nuclear power plant Zwentendorf. The model foresaw a 3.33% interest, a price of 300.00€ per module, and a limitation of 10 modules to each EVN customer to collect the funding for the erection of a 250kWp PV power plant. The model is very simple and enjoys strong support from the EVN-customers:

- Customer buys modules for 300.00€ (max. 10 pieces)
- Customer gains 22.22 €/module p.a. (equiv. to interest of 3.33%)
- After 13 years the module is sold back to the customer for its residual value of 105€/module.

The model gives EVN customers the possibility to invest in sustainable RET while at the same time, granting EVN access to low cost capital and good publicity (EVN AG, 2012).

6.3.2. Elektrizitätswerke Wels

Since 2010, the electric utility of Wels has been promoting its contracting program in which the roofs of customers are leased to the utility. The promoted product design is a 13-year cession contract for the roof after which the PV system installed by the utility is sold to the customer for its residual value. During the 13-year period, the

28 Only for consumers on tier 7 with a 36 A fuse protection

utility cashes in the FIT from the Austrian green electricity regulator (OeMAG) and an annuity from the customer for the residual value of the PV system after 13 years (around 1/3 of the purchasing price). The contract is tied to a set of conditions such as optimal roof orientation and tilt, no shading, and the regulator's approval for the FIT. By 2011, 450 PV systems between five and 20kWp were installed (ÖGUT, 2012).

Advantage for the utility

The utility profits from the FIT payment made by OeMAG that is conditional to the closing of the contract with the client. Consequently, the client is bound in a long-term contract and is less likely to change suppliers, and the PV system is installed with the participation of the utility.

Advantage for the customer

The customer of the utility that does not have the financial resources to pay for a PV system can install one for a 5% down payment and small monthly rates that will be equivalent to the PV's residual value at the end of the contract (ÖGUT, 2012). Also at the end of the contract, the ownership of the PV system will be transferred to the customer; the PV system will deliver free electricity to the customer for another decade. Nevertheless, any eventual inverter replacement costs (possibly after 15 years) have to be borne by the client.

6.3.3. Wien Energie

In 2012, Wien Energie started its own program of civic participation in PV. The idea was extremely simple and very effective: any citizen of the city of Vienna could deposit money on a Wien Energie bank account (in coupons of 475€) with which the utility would then purchase and install large PV arrays in Vienna (Wien Energie, 2012). In exchange, the creditor receives a fixed interest payment for five to 25 years, (3.1% p.a.) at the end of which the deposited amount is returned to the creditor. However, after the program ran for a few months, the financial market authority (FMA) informed Wien Energie and the other municipalities that followed the same example that this PV promotion model was illegal because they were exerting the function of a bank (without the required banking license) in paying interest on money deposited. Wien Energie had to cancel the running contracts and sell and leaseback the PV panels according to the coupons purchased whereas 475€ entitles a creditor half a panel, and 950€ a full panel (ibid.).

The first PV array under the above-mentioned program went online in Mai 2012 after only two months of promotion. The installed PV system has a rated power of 500 kWp and is composed of 2,100 panels. Each investor can deposit a maximum amount equivalent to 10 panels; hence, this small power plant generated an administrative burden of something between 210 and 4,200 distinct leasing contracts with each one a variable duration between five and 25 years (Wien Energie, 2012).

The new strategy of Wien Energie

The long-term goal of the company is to deploy 70 MWp of PV panels by the year 2020. In order to achieve this goal, the company started a new PV campaign with which it aims to use the roofs of its commercial customers; private customers, on the other hand, are excluded from this offer (Wien Energie, 2012). Besides the civic power plant (BürgerInnen-Solarkraftwerk), Wien Energie now offers the following alternatives:

- Wien Energie installs, operates and profits from the PV system installed on the client's roof, for which the latter earns a leasing fee. No costs for the client. Duration: 25 years.
- Wien Energie installs and operates the PV system; the client pays a leasing fee, uses the produced electricity and gains revenue for any excess electricity fed into the grid, which is remunerated at 7.72 ¢€[29] (Wien Energie, 2012). The client saves money from a reduced electricity bill. Duration: 25 years.
- Wien Energie installs the PV system and sells it to the client; the client operates the PV system, saves money from a reduced electricity bill and earns revenues from excess electricity fed into the grid at 7.72 ¢€. Duration: up to 30 years, depending on PV system component's lifetime.

This new market strategy seeks to reach clients that do not pursue the OeMAG FIT, and try to find a way to reduce their electricity bill instead.

29 Euro cent

6.3.4. Verbund AG

Verbund AG was in the public domain until 1995 when Austria became a member of the European Union (EU). The treaty of the EU foresaw the liberalization of the electricity market; henceforth Verbund could not continue to be a public enterprise and had to be privatized (Pollak et al., 2010). The electric utility nevertheless remains in large part owned by the Austrian state (which possesses 51% of the market shares), and operates through its 100% subsidiary Austrian Power Grid (APG), the Austrian power transmission grid (tier 1 to 4). Furthermore, Verbund AG is the largest owner and operator of hydroelectric power plants in Austria; power plants which were, in large part, built in the period before the liberalization. Thanks to the privileged position the company enjoyed in the 20th century and the large portfolio of already amortized (hence, highly profitable) hydroelectric power plants it inherited, the company can afford the luxury of ignoring the latest development in the energy sector. In an interview with Dr. Wolfgang Anzengruber, the managing director confirmed the company's long-term strategy based on large scale, centralized, and company owned power plants. Photovoltaics on the other hand, are discarded as too expensive due to their low efficiency and high volatility in energy generation and will be ignored by the company in the short- to medium-run (Anzengruber, 2012).

Although the company does not plan to build any PV systems, it offers residential clients that wish to do so the opportunity to install a PV system on their roof, for which the client will receive a FIT. The program, called *“Ich mache Strom”* (I make electricity), stipulates the planning and installation of a PV system by a partner of Verbund AG, and guarantees the purchase of the excess electricity for 10 ¢€/kWh until the end of 2016 (Verbund AG, 2012). Starting in 2017, the FIT will be reduced to the regular FIT, which is indexed to the spot price of the Leipzig electricity stock exchange. Today this tariff amounts to 9 ¢€ and will be paid as a net of the 5.00€/month basic fee[30]. The installed capacity of the PV system cannot exceed 10 kWp, hence it is assumed that the target clients are residential only (Verbund AG, 2012).

More recently, Verbund introduced a new product to the market, which, beside the PV system, also provides a battery for the electrochemical storage of electricity

30 This fee is only charged when the PV system was not installed by a Verbund AG partner

generated by the PV system that cannot be simultaneously consumed by the household. The costs for the whole system are roughly double that of a simple PV system without the battery, and the potential of electricity substitution rises from 30 to 60% of the generated electricity. The remaining 40% is fed into the grid and purchased by Verbund at a preferential rate of 18.00 ¢€ for the first 1,000kWh and 6.95 ¢€ for the 1,001st kWh to the 7,000th kWh.

6.3.5. RWE AG (Germany)

RWE is the second largest power utility of Germany. Until recently, just as Verbund AG, the former CEO tirelessly declared that the subsidization of PV on German territory is a waste of public funds and should be stopped. Since the inception of the new CEO in July 2012, Peter Terium, RWE publicly stated its change of strategy for future power plant investments, which will comprise all renewables, PV included. This diametric change in company policy and investment strategy is justified by the unexpected fall in PV system price per kWp installed (Gassmann, 2012).

In an Interview to the *Manager Magazine Online*, the spokesperson of the RWE marketing subsidiary, Hans-Ferdinand Müller, declared that the company already signed contracts for a potential 200 MWp of optimally orientated commercial roofs, and that it is starting to cooperate with municipalities in order to secure the best roofs (Klooß, 2012). It is the goal of the company to install PV systems that are cost-efficient even without the FIT guaranteed by the regulator, hence, aiming at the commercial and industrial businesses that wish to reduce their electricity bill through the installation of PV systems. In order to achieve cost-efficiency, the company plans to optimize the PV system according to the consumption profile of the client. How this will be achieved remains a company secret of course, but the main criteria will be to focus on South-European countries and those regions in Germany with the best irradiation statistics. For 2012, the goal was to install 1,000 MWp of new PV capacity: a herculean endeavour by any standard.

Hans-Ferdinand Müller further states in the interview that the increasing number of small producers of electricity represents a challenge for a company specialized on the operation of centralized, utility scale power plants. This endorses the view that today's utilities have to restructure themselves in order to accommodate renewable energy technologies.

Development of the solar activities

As of today, PV power plants are nowhere to be found in the statistics of RWE and the renewable energy subsidiary RWE Innogy. During a press briefing on the annual results of 2011/2012, the press spokesperson announced that the 1 billion € recently invested in RET will be reduced to half in the near future due to a tightening capital situation (Marksteiner, 2013). Moreover, the share of electricity generated by RET did increase in the past financial year, although prevalently due to a strong increase in the wind energy sector. The article does not mention PV, which allows us to deduce that not much happened in that area.

6.3.6. Linz AG

The utility of Upper Austria's capital, Linz AG, was the first utility to implement the model of civic participation in the installation of a PV system. The program promotes "Silver sunrays" and "Golden sunrays" with which the client can purchase a share of 300 € and 600 €, respectively. For each client, who must be a private person, a limit of 10 Golden Sunrays is set. The municipality has already erected four power plants with funds raised through the program (OÖ Nachrichten, 2011).

6.3.7. Conclusion utilities' strategy

It appears that the utilities' preferred business model for embracing PV technology is the civic participation program. All major utilities are offering customers from their supply region (usually the federal state territory in which they operate) the possibility to participate in the design of the regional energy supply. Despite the media coverage of these projects, the energetic contribution to the regional energy supply is negligible.

Civic participation

From the utility's perspective, the civic participation model provides the opportunity to implement an environmentally sound power plant investment at low-cost debt-capital (usually around 3% p.a.) and very effective publicity thanks to the frequent contact with the participants. New models of civic participation take legal risks into consideration and offer legal safety thanks to business structures that allow the company to make payments to the participants in a very similar way to the forbidden scheme where interests were paid on a yearly basis.

On the down side, the high number of long-term contracts clearly represents an administrative burden, and the company should ponder if it has the necessary human resources for it. Moreover, it is not clear how profitable such projects are due to theses administrative costs.

Leasing of roofs

Wien Energie and Germany's RWE very recently started a new strategy that might turn out to be key for a potential future market. As PV systems become cheaper, the limiting factor for profitability will be suitable area and not whether an FIT is paid or not. Wien Energie is already "flirting" with Viennese commercial and industrial roofs, offering a variety of contract alternatives. RWE on the other hand is securing contracts in south European regions. Early movers like these two utilities will have the opportunity to close very advantageous contracts as the market is still developing and the competition for good roof surfaces is weak. The success of these strategies is not assessable now, but both companies are particularly quiet about their PV strategies since their almost simultaneous roll out in spring 2012.

7. Photovoltaic potential in Lower Austria

In 1993, the International Energy Agency (IEA) started the Photovoltaic Power System Program. Within this program, the members of the agency perform a variety of R&D projects concerning PV technologies. One of these research programs was led by Task 7, which is comprised of 21 OECD members[31] (Organization for Economic Cooperation and Development). In 2002, Task 7 of the IEA published a report on the potential PV roof and façade area of each IEA member, Austria included. The estimation made was used to evaluate the potential PV market in Lower Austria.

7.1. GIS supported roof charting

It would be extremely costly to measure the roof surface of every building of a city, let alone of a federal state like Lower Austria as a whole. With the aid of geographic information systems (GIS) which are based on satellite pictures and aerial photography, it is possible to reduce the costs for an approximate assessment. The German federal state of Hessen, for example, began such an assessment and already charted 1,000 km² of non-adjacent area (FH FFM, 2012). The charted area represents only 4.8% of the Hessen's total area; nevertheless, the presented results are remarkable. The aim of the project was to create an assessment tool for citizens in order to deliver independent and reliable information about the solar (photovoltaic and thermal) energy potential on site. The developed GIS software enables the users to pinpoint their own house, evaluate the roof according to PV suitability, and calculate the annual electricity yield based on the site conditions. For a project cost of 290,000.00 € (Gießener-Allgemeine.de, 2012), the consortium individually analyzed 586,102 buildings and evaluated them according to orientation, roof type, roof tilt, shading through trees and other objects, and annual mean global irradiation: 52,517 have a very good, 132,343 a good, and 54,262 a restricted suitability for PV. In sum, **41%** of the analyzed buildings were suitable for the installation of a PV system on the roof. Moreover, of the suitable surfaces, 25% were characterized as flat roofs (FH FFM, 2012).

31 Australia, Austria, Canada, Denmark, European Commission, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States

7.2. PVPS rules of thumb

Coming back to the PVPS Task 7 project, the assessment made by the consortium has to be considered as an academic guess of the real world. Here is an excerpt of the methodology:

"An assessment of the BIPV[32] Potential starts with a determination of the total roof and façade area, which is subsequently corrected for architectural suitability for solar utilisation […]. BIPV potential calculations are based on ground floor area figures, which are transformed into roof and façade surface figures. The BIPV potential can subsequently be calculated by applying factors for solar yield and architectural suitability to the gross roof and façade surfaces. […] Architectural suitability includes corrections for limitation due to construction (HVAC installations, elevators, terraces, etc.), historical considerations, shading effects and use of the available surfaces for other purposes. Solar suitability takes into account the relative amount of irradiation for the surfaces depending on their orientation, inclination and location as well as the potential performance of the photovoltaic system integrated in the building." (PVPS-T7-4, 2002: 4)

Based on these assumptions, the rule of thumb to estimate the PV potential of a whole country was to allocate 0.4m² of suitable roof area for PV for each m² of ground floor occupied by a building. This figure only considers roofs of buildings without historic importance, suitable envelope, no shading, and with a sufficient solar yield (which is given when solar input is 80% of maximum local annual solar radiation). Because there is no statistical assessment of Austrian building ground floor area, (Germany has it) the potential has to be estimated indirectly:

"The ground floor area can be aggregated, e.g. for Central Western Europe. A typical statistical building for a person living in Central Western Europe has about 45 m2 of ground floor area. Half of it is used for residential purposes, 7 m² for the primary sector, 6 m² each for the secondary sector and for the tertiary sector and the rest for other purposes. Applying the corresponding overall utilisation factor of 0.4 for roofs and 0.15 for façades (for the building stock), the solar-architecturally suitable building roof and façade areas per capita are calculated for Central Western Europe." (PVPS-T7-4, 2002: 5)

32 Building Integrated PV Systems

Subsequently, the report explains how the resulting 18m² are divided into separate sectors and then multiplied by the current population of selected IEA countries. The results for Austria are shown in Table 4:

Table 4. Austria roof area potential for the installation of PV - modified after (PVPS-T7-4, 2002)

BIPV area potential (in km²)		*Residential buildings*	*Agriculture buildings*	*Industrial buildings*	*Commercial buildings*	*Other buildings*	*All buildings*
Austria	Roof	85.65	17.13	15.19	17.45	4.20	139.62
	Façade	32.12	2.14	5.70	8.73	1.58	52.36

As stated before, this is only an educated guess based on a series of assumptions. Nevertheless, it is a very cost-efficient method to be able to grasp the order of magnitude[33] of the Austrian PV potential. The total roof area suitable for PV installations in Austria amounts to approximately **140 km²**. The façade area will be ignored in this work.

Based on the methodology applied by the IEA Task 7 members, the potential for Lower Austria was analogously calculated. Because the calculation is based on a per capita building area, the first step was to calculate the share of population that lives in Lower Austria (21%). This value was then multiplied by the suitable roof area of Table 4 to find the corresponding value of suitable roof area of each sector in Lower Austria based on the national distribution. Table 5 lists the results of the calculations. It should be noted that the focus of this work is on non-residential, roof-mounted PV; this excludes ground mounted PV systems and all buildings with

Table 5. Estimation of roof surface potential based on statistical building areas per capita - own representation based on data from (PVPS-T7-4, 2002)

Area category		Austria	Lower Austria
Agriculture roof	km²	17.13	3.66
Industrial roof	km²	15.19	3.25
Commercial roof	km²	17.45	3.73
Other buildings	km²	4.20	0.90
	km²	53.97	11.55
Inhabitants		7,547,027.03	1,614,661

33 The scope of this "guestimation" exercise is to get an idea about the order of magnitude of the market potential in Lower Austria, i.e. find out whether it is 100MWp or 1000MWp or 10GWp.

prevalent residential use. Consequently, the result of the roof estimation for Lower Austria is **11.55 km²** of potentially available surface.

The next step was to assess the maximum of potential electricity that can be generated on the available surface area. Photovoltaic panels differ in their electricity output according to the materials they are made of. In order to reach a power output of 1kWp, fewer efficient mono-crystalline modules are needed but are more expensive than thin-film modules with a lower efficiency per m² and a lower price per module. Being that modules are all the same size regardless of their composition or efficiency, a more efficient module translates to a lower roof area coverage. In other words, when the roof area is given, the amount of power (and energy) achievable depends on the module technology chosen[34].

For that matter, in order to assess the potential installable power in Lower Austria, the efficiencies of the PV systems have to be gauged. The module efficiency of the best PV products for the main three technologies available on the market has been used[35] and multiplied with the performance ratio of the balance of system (BOS) efficiency, which comprises all the system losses from the module connectors, through wiring, to the output of the inverter. The value of 80% is a conservative value; better efficiencies have been documented and are not exceptional. The resulting overall efficiency of the PV system expresses what portion of the energy that irradiates 1m² of the PV surface is transformed into AC electricity fed into the grid:

$$C_P = \frac{A}{\frac{1}{\eta_{SYS}}} \qquad [1]$$

In equation 1, $\boldsymbol{C_p}$ is the highest installable PV peak capacity per available surface area [kWp/m²], ***A*** is the surface area available [m²], and $\boldsymbol{1/\eta_{SYS}}$ gives the energy density of 1m² of PV modules according to its overall system efficiency[36]. The higher the efficiency of the system the lower its footprint on the building's roof will be (see Table 6).

34 Another decisive factor for the choice of the technology is the temperature coefficient of the panels: crystalline solar cells have higher temperature coefficients than thin film (-0.45%/°C for C-Si vs. -0.2%/°C for e.g. CdTe), meaning that in regions with higher temperatures thin film lose less efficiency and perform better even though under STC the efficiency is lower.

35 Due to the on-going R&D, and the focus on future market development of this work, it is assumed that what today counts as top performance, very soon will evolve into state of the art

36 A ηSYS of 17.3% results in 5.8 m² for 1kWp of installed capacity. Dimensionless quantity.

7.3. Results

The result of the estimation is the potential PV deployment expressed in kW_p that could be installed in Lower Austria if all suitable roof area would be developed with one of the available technologies. In the next step, the development potential was

Table 6. Estimation of Lower Austria's maximum installed capacity potential on non-residential buildings with reference to the values in Table 5 - own representation

Sector	Roof [km²]	Unit	PV technologies		
			Mono-crystalline	**Poly-crystalline**	**Thin-Film**
Austrian PV market distribution in 2011[37]		%	45%	46%	9%
Module efficiency[38]		%	20.4%	16.0%	11.0%
Performance ratio[39]		%	80%	80%	80%
Overall efficiency		%	16.3%	12.8%	8.8%
PV system footprint on roof		m²/kWp	6.1	7.8	11.4
Value from literature[40]		m²/kWp	6 - 7	7.5 - 10	9 - 20
Irradiation[41]		kWh/m²	1,384	1,384	1,384
Agricultural potential	3.28	MWp	535	420	289
		GWh	741	581	399
Industrial potential	2.91	MWp	475	372	256
		GWh	657	515	354
Commercial potential	3.34	MWp	545	428	294
		GWh	754	592	407
Other potential	0.80	MWp	131	103	71
		GWh	182	142	98
Total	10.33	MWp	1,686	1,322	909
		GWh	2,334	1,830	1,258
By market share		**MWp**	**759**	**608**	**82**
		GWh	**1,050**	**842**	**113**
Overall total (adj. to avg. market distribution)				**MWp 1,449**	
				GWh 2,005	

37 (Energy Economics Group, 2012)

38 (Sunpower , 2012)

39 (Harvey, 2010)

40 (The German Energy Society, 2005)

41 (Solar GIS, 2012)

adjusted by the current market share of the three main panel types. Depending on the technology used, the potential amounts to 759MW$_p$, 608MW$_{p,}$ and 82 MW$_p$ for mono-crystalline, poly-crystalline, and thin-film solar cells, respectively. These values were then multiplied by the overall efficiency and the reference annual global irradiation, which amounts to 1,384 kWh/m², according to the latest estimation made by Solar GIS (2012) for St. Pölten. The result is the maximum electricity yield for the whole federal state of Lower Austria.

In 2010, the electricity consumption of the state amounted to 10,543 GWh (NÖ Landesregierung, 2012). Dividing the whole surface by the mentioned technology distribution, the maximum installable PV capacity would be 1,449 MWp and the maximum electricity yield would be 2,005 GWh per year, which represents 19% of the electricity consumption of 2010.

7.3.1. EVN

The local utility, EVN AG, supplies the largest share of the approximately 810,000 customers in Lower Austria. In the fiscal year 2010/2011 the company sold 7,754 GWh of electricity. The results of the previous chapter suggest that, potentially, more than 25% of EVN's market share could be curtailed if the cost of the technology continues to develop in the current direction (yearly price fall of 10%). Nevertheless, the past development did not pose a real threat to the company as yet, because by the end of 2011, only 96 MWp of PV were installed within the jurisdiction of Lower Austria (E-Control, 2013c). The PV power plants owned by EVN and from which EVN purchases electricity amount to 3.6 MWp and delivered less than 3.5 GWh in 2011, which is 0.2% of the estimated potential of 2,005 GWh and less than 0.05% of the electricity sale of EVN (NÖ Landesregierung, 2012).

7.4. Conclusions on Lower Austria's PV potential

The peak electricity load in 2010 of the federal state of Lower Austria amounts to 1.3 GW. According to the estimation made in chapter 7.3, therefore, the state's territory has at its disposal enough suitable roof area to cover up to 115% of the state's electricity consumption with electricity generated by distributed PV systems (on sunny days). Whether or not this potential will ever be exploited remains to be seen. However, the vision of a 100% renewable electricity supply (even if not constant throughout the year) makes one grasp the potential in possible fossil fuel savings, as each kilowatt hour produced by PV systems saves many kilowatt hours of fossil primary energy that laboriously has to be converted into electricity by undergoing a laborious set of extractions, pre-processing, conversions, filtering of emissions, et cetera.

As desirable as this scenario might be, it cannot be achieved without careful planning. The distribution grid has its limits in capacity, and these limits have to be managed to remain cost-effective and to accommodate the desirable amount of renewable energy power plants. Chapter 9.2 will further elaborate on the grid capability issue.

8. The Model

To better understand the generation cost of Austrian PV systems, an excel sheet was set up in which costs, electricity yields, and revenues were juxtaposed. This model can be used as a tool to identify on a case-by-case basis if the **dynamic grid parity** on the roof of a certain building has been reached (via the LCOE) and whether or not the installation of the PV system is profitable without an FIT (via the IRR). The dynamic grid parity has been defined as follows: *"Dynamic grid parity is defined as the moment at which, in a particular market segment in a specific country, the present value of the long-term net earnings (considering revenues, savings, cost and depreciation) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid."* (EPIA, 2011c).

8.1. Levelized Cost of Electricity

The assessment of power plant generation costs is crucial by any standard, even more so when subsidies are not provided. To assess how much one kilowatt-hour of electricity generated by a PV system will cost, the instrument of choice is the Levelized Cost of Electricity (LCOE). This well established and widely applied energy economics tool assists the decision maker in the evaluation of different electricity generating technologies in that it divides the costs for installation and maintenance by the amount of electricity generated during the whole lifetime of the power plant (see equation 2).

$$LCOE = \frac{Lifecycle\ cost}{Lifetime\ electricity\ production} \qquad [2]$$

In order to do so, a discounted cash flow analysis is performed in which annual costs are summed, discounted, and successively divided by the amount of the discounted annual generation of electricity. This translates into the following formula (adapted from (You et al., 2011)):

$$LCOE = \frac{INV + GRID + \sum_{n=1}^{N} \frac{(O + I + L + R) \times (1 + r)^n}{(1 + DR)^n}}{\sum_{n=1}^{N} \frac{Y \times (1 - SDR)^n}{(1 + DR)^n}} \qquad [3]$$

where ***INV*** are the incurred investment costs for the PV system in period '0'[€/kWp], ***GRID*** are the costs for grid connection[€/kWp], ***N*** is the lifetime of the power plant [years], ***n*** is the period in which the costs and generated electricity accrue, ***O*** is the operation and maintenance costs [% of INV], ***I*** is insurance cost [% of INV], ***L*** is leasing costs for the roof [% of INV], ***R*** is the replacement cost of the DC/AC inverter [% of INV], ***r*** is the annual inflation rate [% p.a.], ***DR*** is the real discount rate (net of inflation) [% p.a.], ***Y*** is the annual electricity yield [kWh/a], and ***SDR*** is the system degradation rate [% p.a.]. The annual costs ***O,I,L,R*** are adjusted to inflation at the end of each period. The same inflation rate is netted out from the WACC used to compute the discount rate (see chapter 8.1.8). The LCOE is expressed in €/kWh.

As seen in equation 3, the annual electricity yield is also discounted to the net present value (NPV). This is necessary because it is not possible to discount the price of the electricity produced, since it is the variable being calculated. However, it does not matter that the formula discounts a non-monetary value because the revenues accruing from the sale of electricity are the result of the multiplication between the amounts of kWh sold, times the revenue per kWh (Harvey, 2010).

8.1.1. System price

The cost structure of PV systems is continuously changing. Due to the harsh competition from East Asia and the financially tight conjuncture, prices literally plummeted in the last few years. If PV panels made up 80% of the power plant's costs 10 years ago, today the panels account for less than 50% (Niederkircher, 2012). As stated in chapter 4.2, PV modules of PV systems installed in Germany today constitute only 40% of the PV system.

The German PV industry association, BSW, constantly monitors the price development of the market and regularly publishes the results. Figure 17 illustrates the overwhelming price development of the average German PV system smaller than 100 kWp[42] (VAT excl.) from 2006 until the first quarter of 2013. The average price of 1,684€/kWp signals that, for utility scale PV systems, significantly lower prices are achievable today.

42 Because the reference for the price is kWp, it does not matter which solar cell technology is installed, whether thin-film, mono- or poly-crystalline, as this would considerably affect the footprint of the PV system but not the price. The prices given here are an average over all installed technologies.

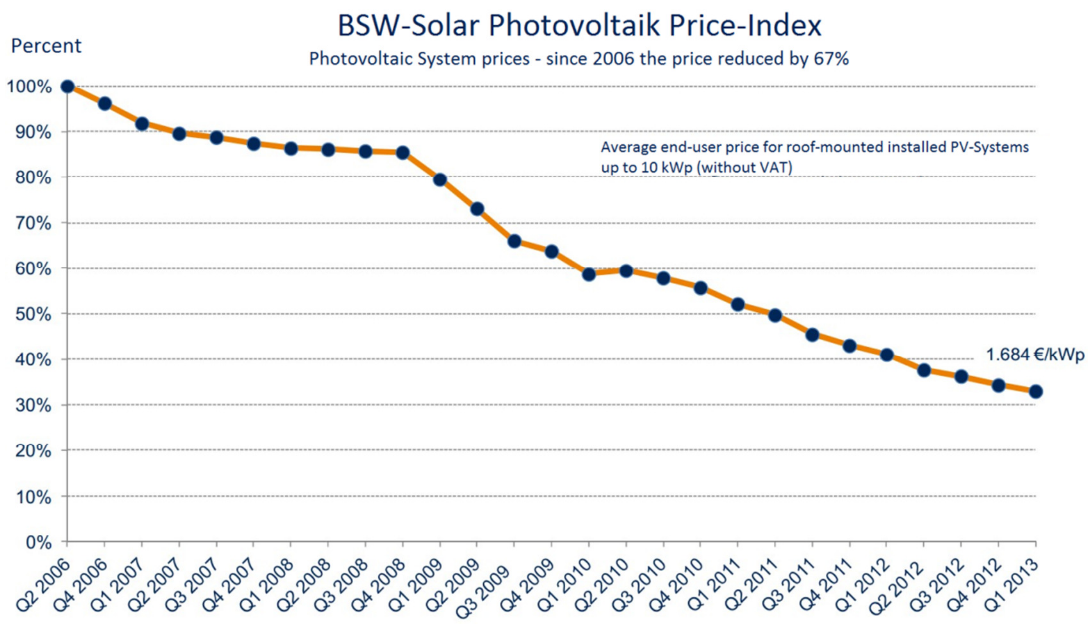


Figure 17. Average price monitoring for PV systems < 10kWp, w/o VAT (BSW, 2013)

The Energy Economics Group of the Technical University of Vienna performed similar price monitoring in a study commissioned by the Austrian ministry of transport innovation and technology. In this study the average price for a PV system larger than 10 kWp, amounts to 2,528€. The range of prices, nevertheless, spans between 1,400 and 3,500€/kWp (Energy Economics Group, 2012). The data are derived from a survey made by Technikum Wien, which elaborated information from 26 system installation companies. The lower range of 2011 prices, 1,400€/kWp, confirms that the average price for PV systems has symbolic value; utility sized PV systems with positive returns to scale can obviously achieve prices far below average. For the simulation in this work a turnkey price of **1,600€/kWp** was assumed. In fact, according to the price development pictured in chapter 4.4, lower prices would be realistic for medium-scale PV systems installed in 2013; nevertheless, a conservative value was chosen, and successively a sensitivity analysis was performed to assess the influence of system price on the LCOE.

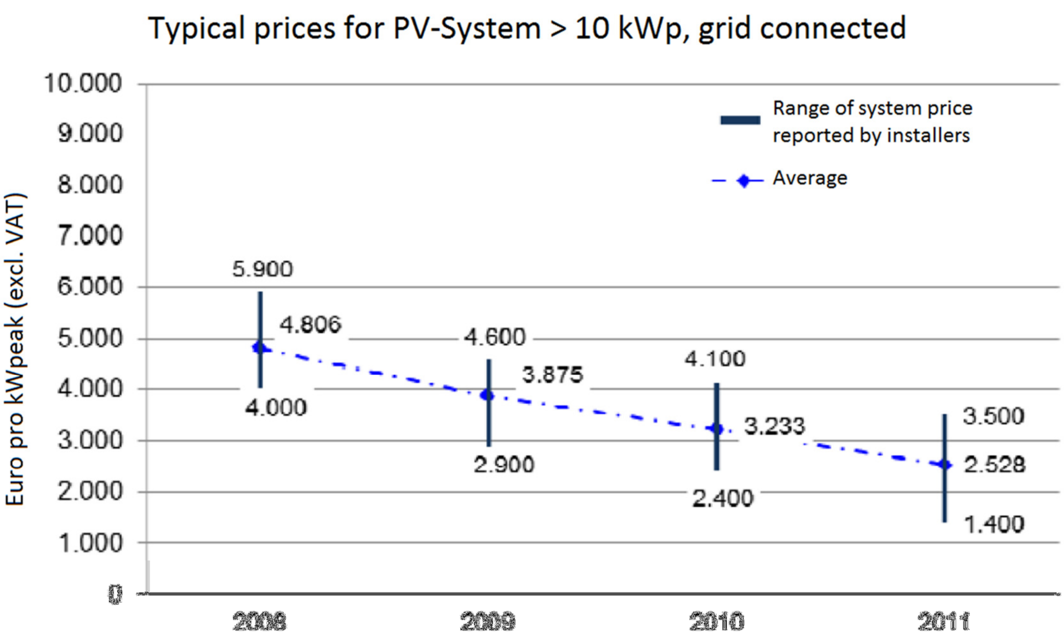


Figure 18. Average and range of system prices for a PV system > 10 kWp, grid connected, w/o VAT (Energy Economics Group, 2012)

8.1.2. Grid connection costs

As explained in chapter 5.2, Austrian law provides that the PV project owner bear any incurring grid connection costs in case additional transformer capacity is necessary to feed the electricity generated from the power plant into the grid. The price for the connection varies according to the grid level to which the PV system will be connected to (see Table 7).

Table 7. Grid connection costs for Lower Austria (E-Control, 2012b)

Grid level	€/kWp
Tier 3	€ 22.40
Tier 4	€ 44.09
Tier 5	€ 101.48
Tier 6	€ 132.27
Tier 7	€ 210.65

When the PV system is installed on the roof of an active consumer like a manufacturing enterprise, it is highly unlikely that the available roof area allows the building owner to install a PV system the capacity of which surmounts the installed transformer capacity for the withdrawal of electricity by the very same consumer. Only in cases where this unlikely scenario occurs do the fees of Table 7 apply (E-Control, 2012b). For ground-mounted PV-systems for instance, the fees always apply. Because the current model only focuses on roof-mounted PV, grid connection costs will be ignored in the base case and will only be considered in the sensitivity analysis. The costs listed in Table 7 represent the standardized connection fees that are charged by the DSO for the additional burden the installed system will put on the higher grid tiers; it does not include the costs for purchase and installation of the transformer and the laying of the cable.

8.1.3. Lifetime of a PV system

The PV system is composed of many non-movable long-lasting components that have very little wear-off. Although a large part of the currently installed capacity was deployed during the last decade, and therefore, accurate data will only be available by the year 2020, some research has already been done on the topic of PV durability. The literature mentions values between 20 and 40 years of operation after which the efficiency of the system drops below 80% of the initial performance. Solar cells degrade through time under the weathering effect of their environment (light induced deterioration, corrosion, oxidation, and thermal stresses). The economic life of a power plant is defined as the point in time at which the system is replaced or

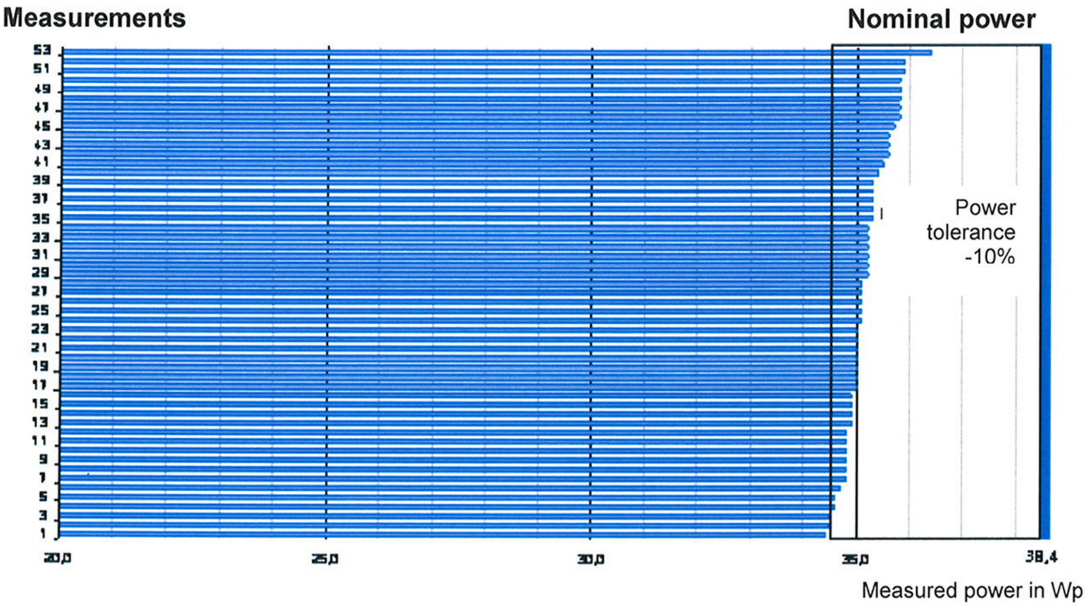


Figure 19. Measured nominal power of 53 Schott Solar modules after 26 years of operation, accuracy ± 3% (SCHOTT Solar, 2010)

refurbished because O&M costs exceed revenues. Therefore, the economic lifetime of a PV system depends on the energy output that the system delivers that is still considered acceptable.

An established reference value for good system performance at the end of the system's life is 80% of its initial output. Given a degradation rate of 1% p.a., the 80% threshold is reached after 20 years of operation. Nevertheless, a research study performed in 2009, on the performance of field-aged PV installations, demonstrated that more than 65.7% of the panels had degradation rates below 1% (average was 0,88%/p.a.). This proves that if the 80% performance threshold is assumed as the criteria for the end of life of a PV system, PV systems installed between 1982 and 1986 had an average lifetime of 24 years (Skoczek et al., 2009). It is therefore fair to assume with a high degree of confidence that through the improvement in material stability and endurance from corrosion and thermal stresses, average economic lifetimes of up to 30 years are becoming the rule rather than the exception. Moreover, many manufacturers nowadays guarantee a performance of 80% after 25 years of operation (degradation <0.8%), and 90% after 10 years (degradation <1.0%) of operation (Sunpower , 2012).

A report commissioned by the PV cell manufacturer Schott Solar to the Fraunhofer Institute for Solar Energy Systems (ISE) published in 2010 attested the durability of 53 PV panels, which after 26 years of operation all had a residual performance of 90% resulting in a degradation rate of 0.38% p.a. Figure 19. This survey further supports the argument that the 20-year lifetime is obsolete, and lifetimes up to 30 years should be used for cost assessments.

In the model, a lifetime of **25 years** was assumed, with a conservative residual performance of 85%. The resulting annual degradation amounts to 0.6%/p.a., a value that resides within the range 1.0% (highest ever recorded degradation)to 0.2% (lowest ever recorded but realistic long-term development). A similar study to this master thesis made by the Fraunhofer Institute ISE, used the value 0.2% for all LCOE calculations (Fraunhofer ISE, 2012).

8.1.4. Operation, Maintenance and Insurance costs

Once the PV system is up and running, the power plant requires very little attention from the owner. Large PV systems are generally monitored remotely to constantly evaluate their performance. The required maintenance mostly consists of periodic visual inspections of the panels, the inverter, and the BOS. Sometimes, it is necessary to clean the panels, but rain usually does the job. The inverter is a known weak point of the PV system, but this is linked to the normal functioning of the system, and not to a lack of maintenance. For large PV arrays, it might be useful to perform a thermography analysis after some years of operation in order to identify any malfunctioning solar cells, modules, or module strings (Figure 20). In the event of mechanical damage or any cause for malfunctioning, the cells tend to overheat.

The expenses for a thorough thermographic analysis are decreasing thanks to cheaper cameras; the resulting yield gains over the lifetime of the PV system in the event of identified damages might therefore be covered manifold.

Insurance of the PV system covers all possible damages, which are not caused by the owner voluntarily.

The O&M and insurance costs

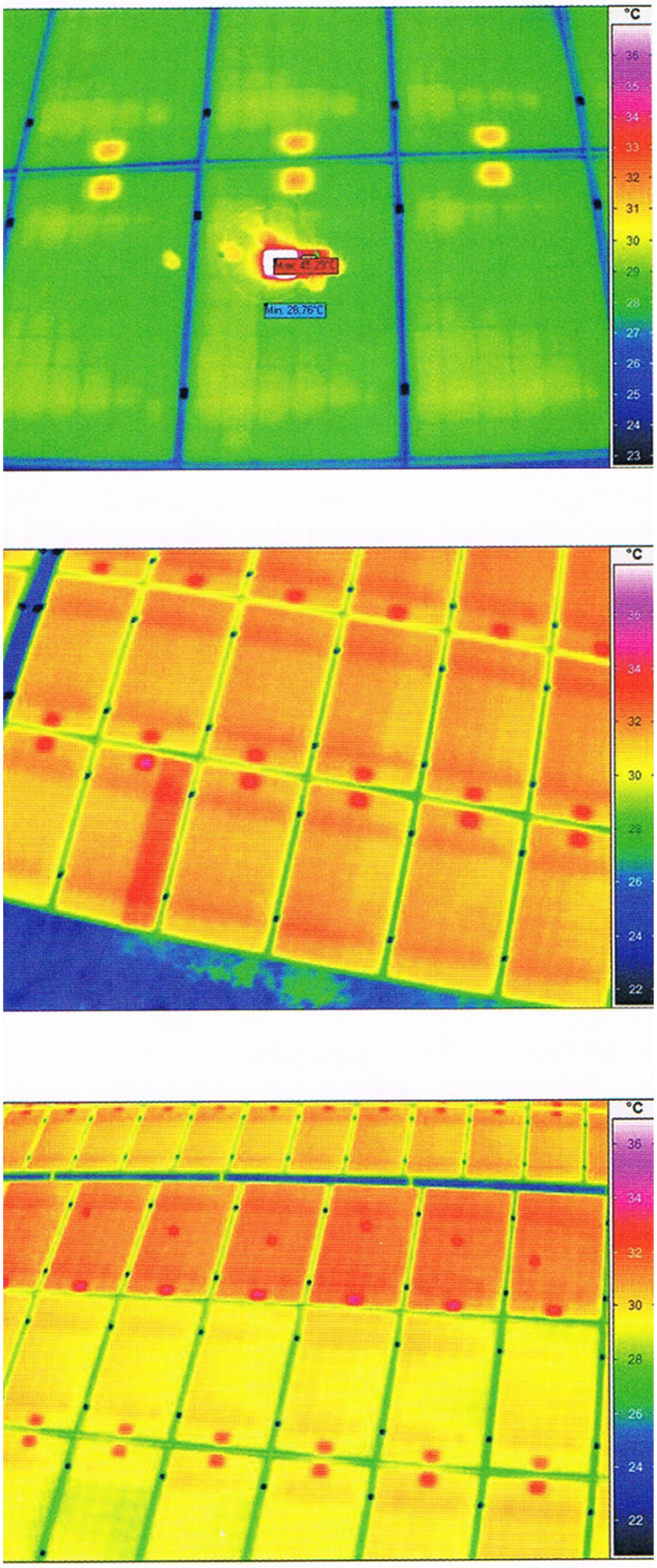


Figure 20. Helicopter based thermography for the identification of faulty cells (upper image), cell strings (middle image), module strings (lower image) (Faltermeier, 2012)

are indicated as a percentage value of the total system costs and range between 0.25% and 1% p.a., depending on the country in which the system is installed and the insurance contract signed. For the simulation, **0.5%** was assumed for both O&M and insurance (Konstantin, 2009).

8.1.5. Leasing of roof

The focus of this work is the calculation of PV projects as roof mounted PV systems, and for this reason, ground-mounted PV systems will not be covered. As stated earlier, the Austrian market is driven by the residential sector, which leaves a large potential of "untapped" commercial and industrial roofs. The industrial or commercial enterprise that possesses a suitable roof for the installation of a PV system, but that does not wish to do so by itself, due to lack of capital or any other reason, can easily lease the unused surface of its premises to any investor or utility that is looking for suitable buildings. This is a win-win-situation for the owner of the building and for the investor. The simulation will demonstrate to what extent the leasing fee for the roof impacts the LCOE of the PV power plant.

There is a variety of contracts being used by roof owners and PV system investors in order to secure the profitability of both parties to the agreement:

- lump-sum leasing fee – as a percentage share of total system costs, paid up-front in period "0"
- annual leasing rate – as a percentage share of total system costs, adjusted to inflation
- share of the FIT (where applicable)
- leasing fee per kWh produced (independently of FIT)
- PV system is entitled to roof owner after a certain period of operation (13 - 20 years)

A thorough assessment of which model best suits the interests of the utility goes beyond the purpose of this work. For the simulation of the base case scenario, the assumption is that no leasing fees are paid for because the building owner closes an energy service contract with the utility and purchases the electricity produced by the PV system. Nevertheless, in cases where such a contract is not concluded and the electricity is sold somewhere else, an upfront leasing fee of **7%** of the installation cost has been assumed. Alternatively, annual payments at an initial **0.6%** annual leasing rate of system costs (annually adjusted for inflation) were also tested to verify its influence on the LCOE.

Examples of roof leasing contracts are known for Germany and Italy. In Germany the company Vario Green Energy Concept, which is specialized in renewable energy investments, mediated a pool of investors and a roof owner into a 450,000€ project. The PV system has a rated capacity of 200kWp and will generate around 51,000€ of revenues each year. The leasing fee for the roof was paid up-front and amounted to 31,000€ (6.9% of 450,000€). Alternatively the roof owner could have chosen the yearly payment of 2,700€ (0.6% of 450,000€). The owner chose the up-front payment alternative, and invested the money in a small PV system for his own house (Vario Green Energy, 2012).

The same company is offering similar projects to other investors. The leasing rates for the roofs on which these projects are planned are indicated as up-front payments that vary between 13 and 16% of the investment volume (Vario Green Energy, 2012).

Besides the amount paid for the leasing fee, the most important requisite of a leasing contract is the agreed upon compensation in case of premature termination of the contract by the roof owner for compelling reasons. It is unreasonable to prohibit the owner from making any changes to the roof if he so wishes; nevertheless any contractual partner of the power utility will agree to the fact that it just as unreasonable to expect the utility to install a PV power plant on a roof without any financial safeguard in case the roof owner changes his mind. It is therefore wise to conclude a leasing contract that safeguards the utility's financial interests and at the same time makes the roof owner aware of the responsibility.

8.1.6. Replacement of the inverter

The weak point of the PV system is its inverter, which enables the system to feed the electricity into the distribution network and to the electrical devices of the system owner that function with alternate current (AC) in compliance with the prevailing grid codes. The inverter transforms the direct current (DC) electricity from the PV modules (set of panels) into 50hz, 230V[43] AC. The efficiency ratio of this transformation varies between 92 and 98% (Fraas and Partain, 2010). The loss in

43 If fed into the tier 7 distribution grid

electricity is transformed into waste heat that has to be extracted via cooling fans; inverter's life expectancies vary widely according to manufacturer and the installation environment. Due to the heat generation, only open-air installations, and well-ventilated enclosures are allowed to prevent overheating which would further decrease efficiency. For inverters installed in 2007, EPIA specifies a lifetime of 10 years, after which the inverter has to be replaced. For 2010, EPIA's indication rose to **15 years** (EPIA, 2011a). This is the standard value for estimated inverter life expectancy today and is the value used in the model.

The costs of replacement are assumed at 15% of the initial PV system price paid in period 0, indexed by inflation and paid for in period 15.

8.1.7. Inflation

In order to make calculations that, although based on a set of assumptions, shall depict probable future developments, any cost that accrues in the future has to be indexed for the expected inflation. In this work, a low inflation of **2%** is assumed as the starting value. This value is in line with current very low interest rates and sovereign bond yields (reference value for safe investment margins) which are yielding negative real interest rates[44].

8.1.8. Discount rate

The notion of time plays an important role when costs and revenues accrue at different points in time; when they are compared, these figures have to be weighted. Costs incurred today or next year cannot be valued the same as costs or benefits accruing 20 years from now. The discount rate in this case expresses the value that present generations give on present gains and future losses and vice versa. A small discount rate of 1%, gives a higher weight on future gains/losses than a 10% discount rate, making an astronomic difference in the calculation of the net present value (NPV) of an investment[45]. It is therefore necessary to choose the discount rate wisely, and where possible, to perform a sensitivity analysis by applying different rates.

44 German 10 year bonds yield 1.5%, inflation for July 2012 was at 1.7%= real interest rate -0,2%

45 1,000,000€ in costs incurred 20, 50 and 100 years from now, if discounted at 8%, will result in net present values of 214,500€, 21,300€ and 454€, respectively. At 1% however the same amount results in net present values of 819,544€, 608,038€ and 369,711€, respectively.

The discount rate used in this work is given by the weighted average cost of capital net of the expected inflation. The result is the exact **real discount rate**[46], which is calculated by the following equation:

$$DR = \frac{(1 + i_n)}{(1 + r)} \qquad [4]$$

where i_n is the nominal WACC (Konstantin, 2009). Hence, the discount rate used in the simulation, as the result of the composite WACC and the expected inflation, is **4.41%**.

8.1.9. Electricity yield of the PV System

The location selected for the simulation is the capital of Lower Austria, St. Pölten. The annual mean solar irradiance in the city center is 1,384kWh/m². This value is strongly linked to the geographic location of the building on which the PV system will be installed. There are already large databanks which deliver the mean solar irradiance of virtually every spot of land on earth based on values that range from the '70s to 2012. The value given above is the mean irradiation of the years 1994-2010 as measured by the satellite "Meteosat". The uncertainty of the annual horizontal irradiation ranges between ±3 and ±5% (Solar GIS, 2012).

The annual irradiance is the highest amount of solar energy that reaches any surface at the indicated coordinates. Therefore, contrary to conventional power plants, the energy input of the PV power plant is fairly stable over the years and cannot be varied at will. This being so, it is up to the technology used to transform as much irradiative energy as possible into electricity. PV installers use the performance ratio of PV systems instead of the surface-based efficiency value to compute the efficiency of the power plant; the performance ratio (79.8% in this model) expresses how much electricity of a PV system with a rated power of 1kWp is lost during operation due to conversion inefficiencies compared to standard test conditions (STC[47]).

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46 Another way to calculate the real interest rate would be to simply subtract the inflation rate from the interest rate. The result though, is an approximate interest rate instead of the "exact" interest rate calculated here.

47 Standard test conditions: vertical irradiance E of 1000 W/m²; cell temperature T of 25°C with a tolerance of ± 2°C; defined light spectrum (spectral distribution of the solar reference irradiance according to IEC 60904-3) with an air mass AM =1.5 (The German Energy Society, 2005).

Table 8. System losses and performance ratio (R1 Solar, 2012)

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1385	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1385	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	1343	-42	-3.0	97.0	97.0
4. Conversion to DC in the modules	1230	-113	-8.4	91.6	88.8
5. Other DC losses	1162	-68	-5.5	94.5	83.9
6. Inverters (DC/AC conversion)	1133	-29	-2.5	97.5	81.8
7. Transformer and AC cabling losses	1116	-17	-1.5	98.5	80.6
8. Reduced availability	1105	-11	-1.0	99.0	79.8
Total system performance	**1105**	**-280**	**-20.2**	**-**	**79.8**

The assessment for St. Pölten was made by R1 Solar with the pvPlanner tool. This software allows for the estimation of the yield of a PV power plant independently of the available or needed surface; the outcome of the calculation is a value expressed in kWh/kWp, which then has to be applied to the suitable roof area for the installation of panels. The items listed in Table 8 are parameters that vary according to the specifications of the PV modules used, the location of the roof and its surroundings, and the orientation of the roof. At the power plant's location of this sample, no shading is assumed (item #2); a small portion of the irradiated energy is reflected back to the atmosphere by the panel glass, hence reducing performance by 3% points (item #3). The highest loss takes place within the mono-crystalline PV modules. This value, 8.4%, represents the influence of the environment on the PV panels, which is the performance deviation from their STC. The temperature of the atmosphere at the power plant's location has the largest influence on its performance, because solar cells on average lose 0.4% of efficiency points for each ℃ over 25℃ (Fraas and Partain, 2010). Item #5, "Other DC losses", expresses the energy loss due to interconnectors' heat development, cables, dirt, snow, self-shading, etc. The energy loss from the inverter, 2.5%, is an average value from the higher end range of inverters, hence, a rather optimistic value. The overall system performance amounts to 79.8%, resulting in a mean annual electricity yield of **1,105 kWh** for each kWp installed capacity at a global irradiation of 1,384kWh/kWp (for further details on the R1 Solar yield assessment, see Annex II).

If roof area would be a limiting factor for the calculation, than the panel type would have to be chosen accordingly in order to reach the desired energy density (kWh/m²). Depending on the technology chosen, the installed rated power per covered surface varies between 110 and 200 W/m² (Sunpower , 2012). These values are directly proportional to the panel's efficiency values, which for today's top-performing thin-film, poly- and mono-crystalline panels amount to 11.1, 14.7 and 20.4%, respectively (Vario Green Energy, 2012) (Sunpower , 2012). In the model, the value 1,105 kWh/kWp was used for the base scenario as an efficiency factor that is multiplied by the rated power of the power plant being installed.

8.1.10. System degradation rate

The last factor of equation 2 that influences the LCOE is the degradation rate of the PV panels throughout their lifetime. As stated in chapter 8.1.3, PV cells gradually deteriorate in performance due to the influence of the environment. The degradation rate varies depending on climatic condition and manufacturing quality at rates between 0.3 and 1%/p.a. (Fraas and Partain, 2010). In this simulation, the assumed degradation was set at **0.6%**. In a recent study of the Fraunhofer Institute for Solar Technology in which the LCOE of RET was compared, the institute applied the degradation rate 0.2% for all the calculations. The more conservative rate is justified by the variety of qualities of PV panel available on the market; due to market constraints the cheapest will most likely be purchased, therefore higher rates might materialize.

8.2. Internal Rate of Return

The internal rate of return is a financial mathematic tool used in project evaluation (Bhattacharyya, 2011). The IRR is closely linked to the NPV, and is computed via the NPV as that exact discount rate, which at the end of life of the power plant returns an NPV=0. The IRR is determined by the amount of capital employed and the sum between depreciated revenues (positive values) and depreciated costs (negative values). This is done via equation 5:

$$NPV = I_0 - \sum_{n=0}^{N} \frac{(R_n - C_n)}{(1+r)^n} = 0 \qquad [5]$$

where $\boldsymbol{I_0}$ stands for initial investment for the PV system, ***R*** is the revenue from the sale of the electricity in period ***n***, ***C*** is the costs in that same period, and ***N*** is the lifetime of the PV system (total number of periods). Excel iteratively[48] computes the ***NPV*** until it finds an ***r*** (IRR), that satisfies the condition ***NPV*=0**.

Costs and revenues on the other hand are calculated via equation 6:

$$R_n - C_n = (FIT_C + FIT_G) - (O_n + L_n + R_n + T_n) \qquad [6]$$

where ***FIT_C*** are the revenues from the sale of electricity to the customer and ***FIT_G*** are the revenues from the sale of electricity to the grid, period 0 for the PV system), ***O*** are operation and maintenance costs and insurance, ***L*** is the leasing fee for the roof (upfront paid in period 0 or yearly payment), ***R*** is the replacement cost for the inverter in period 15, and ***T*** is the amount of tax paid on the taxable amount (see equation 7). All factors in equation 6 correspond to values in Table 9 that, beginning with period 1, have been indexed to the assumed inflation rate.

The amount of tax paid is based on the calculation of the taxable amount multiplied by the corporate tax rate ***t*** (25%). See equation 7.

$$T_n = [(FIT_n) - (AfA + O_n + I_n + L_n + R_n)] \times t \qquad [7]$$

where AfA is annual depreciation of the PV system over a period of 20 years[49].

The resulting rate of return is then juxtaposed to the **desired** rate of return of the investor (in this case 6.5%). If the IRR is equal to or higher than the desired rate, then the investment is considered profitable.

8.3. Results

In the first part of this chapter, the LCOE will be calculated based on current cost factors that originated either from pertinent literature or expert interviews. In the second part, the internal rate of return (IRR) will be calculated to evaluate the profitability of the investment according to current costs. Further, in chapter 8.4, a sensitivity analysis will test the solidity of the assumptions made and the variance of the results when single factors are changed by a relative value of ± 50%.

48 In a trial and error process, excel calculates the NPV of the cash flows, until the sum of all NPV periods, results 0.

49 According to the current Austrian tax law 20 years is the longest period for the calculation of the depreciation

8.3.1. LCOE

Table 9 lists all the factors used in the LCOE calculation, and current ranges, which vary according to technology chosen, geographic location or customer dependent circumstances.

Table 9. Input data for the simulation of the LCOE- own representation

Variable		Unit	Simulation	Range from literature
PV System	System price	€/kWp	**€ 1,600.00**	€ 800.00 - € 2,400.00
	Efficiency factor (Austria)	kWh/kWp	**1,100**	900-1,400
	Rated power	kWp	**100**	3-1,000
	System degradation	%p.a.	**0.60%**	0.2-1.0%
	Inverter Replacement frequency	years	**15**	10 - 20
	Lifetime of system	years	**25**	20 - 30
Yearly costs	Insurance	% of System price	**0.50%**	0.25-1.00%
	O&M	% of System price	**0.50%**	0.25-1.00%
	Yearly increase in costs	% (inflation)	**2.00%**	1-5%
	Leasing of electric meter	€/kWh	**€ 600.00**	€ 26,16 - € 900.00/a
Roof leasing	Leasing fee-upfront	% of System price	**7.00%**	0.0-16.0%
	Leasing fee-annual (indexed)	% of System price	**0.60%**	-
Financing	WACC	% p.a. nominal	**6.50%**	2.00-12.00%
	Inflation	% p.a.	**2.00%**	1.00-3.00%
	Resulting DR	% p.a. real	**4.41%**	3.00-10.00%

By applying the input values from Table 9 (column "Simulation") in equation 2, the resulting LCOE amounts to **0.1335€/kWh**. This value expresses the total cost of each kWh generated by the PV system over its expected lifetime of 25 years. What the LCOE does not show is whether the investment earns a profit or loss (this will be evaluated via the IRR). Based on current working power tariffs of 5.1 to 8.0¢€/kWh paid by customers to Austrian utilities, it is clear that PV systems of this size (100kWp) that are located in St. Pölten, are too expensive to generate electricity for direct sale by the utility; other business models have to be applied than the standard large scale power plant model.

8.3.2. Internal Rate of Return

The values in Table 9 were also used in the computation of the IRR. Therefore, in addition to the costs of the power plants, the revenues have to be taken into account. For this purpose the model assumes an electricity sale price of 14.00¢€/kWh[50]. The yearly increase in the electricity price was set at 2%, a relatively moderate value that forecasts a low future inflation, therefore reproducing a rather conservative outcome with a reserve potential for higher margins.

Table 10. Input data for the computation of the IRR - utility's perspective – own representation

Variable		Unit	Simulation	Range from literature
Earnings	Sale of electricity to customer	€/kWh	**0.140**	€ 0.070 - € 0.210
	Sale of electricity to grid	€/kWh	**0.045**	€ 0.020 - € 0.068
	Yearly increase in el. Price	%	**2.00%**	1.00 - 3.00%
	El. Substitution Share	%	**100%**	60-100%
Costs	As in Table 9			
Tax	Corporate tax	%	**25%**	-

Applying the costs in Table 9 and Table 10 in equations 5, 6, and 7, the IRR is calculated with the help of the excel sheet. The resulting IRR amounts to **6.32%.**

8.4. Sensitivity analysis

The results in chapter 8.3 hide a set of assumptions that bear the risk of being slightly, very, or dramatically wrong, depending on how the future unfolds. For this reason, it is wise to perform a sensitivity analysis on the variables that are part of the equations in order to identify which factors are the most influent in changing the LCOE and the IRR. The sensitivity analysis is performed with the help of statistical tools. In this particular case the linear regression function is applied to identify the relationship between the dependent (LCOE or IRR) and independent variables. In an additional excel sheet all the independent variables were listed and new values were generated varying the independent variables by -50%, -25%, +25% and +50% from the base scenario (see Table 11). Subsequently the model input data were changed accordingly by varying one independent variable at a time within the range and by keeping all other variables at

50 Current average retail price for electricity

Table 11. Values for the sensitivity analysis

Variable		Base	-50%	-25%	0%	25%	50%
System price €/kWp	€	**1,600.00**	800.00	1,200.00	**1,600.00**	2,000.00	2,400.00
System degradation	%	**0.60%**	0.30%	0.45%	**0.60%**	0.75%	0.90%
Electricity FIT	€/kWh	**0.140**	0.070	0.105	**0.140**	0.175	0.210
El. FIT increase/a	%	**2.00%**	1.00%	1.50%	**2.00%**	2.50%	3.00%
Insurance	%	**0.50%**	0.25%	0.38%	**0.50%**	0.63%	0.75%
O&M	%	**0.50%**	0.25%	0.38%	**0.50%**	0.63%	0.75%
WACC	%	**4.00%**	3.25%	4.88%	**6.50%**	8.13%	9.75%
Inflation	%	**2.00%**	1.00%	1.50%	**2.00%**	2.50%	3.00%
Leasing fee roof annuity	%	**0.00%**	0.30%	0.45%	**0.60%**	0.90%	0.75%
Leasing fee roof upfront	%	**0.00%**	3.50%	5.25%	**7.00%**	8.75%	10.50%

base value (e.g. system price at 800/1200/2000/2400€ and same lifetime, efficiency factor, SDR, et cetera). This way a new table was generated, that listed all the new values for LCOE and IRR according to the changed input. Then, to identify the magnitude of influence on the dependent variable, an algorithm was applied to compute the correlation coefficient of the linear regression of the results (excel function: SLOPE):

$$b = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2} \qquad [8]$$

b is the slope of the linear regression line (y=a+**b**x), ***x*** is the independent variable, $\bar{x}$ is the arithmetic average of all known x's (+50% to -50%), ***y*** is the dependent variable, $\bar{y}$ is the average of all known y's (resulting values for LCOE or IRR). The slope quantifies the strength of the relationship between the dependent variable (LCOE or IRR) and the independent variable (Cohen and Cohen, 2003).

8.4.1. LCOE sensitivity analysis

The results of the sensitivity analysis are listed in Table 12 and plotted in Figure 21. The chart plotted in Figure 21 illustrates two very important sets of information. First, it shows how strongly the LCOE depends on the variation of the factor listed (range of -0.02€ to +0.18€/kWh). Secondly, it states whether this relationship is positive or negative. The strongest relationship exists with the *"system price."* This positive

Table 12. LCOE sensitivity analysis - own representation

LCOE SENSITIVITY ANALYSIS	Slope	-50%	-25%	0%	25%	50%
System price €/kWp	**0.1335**	0.0668	0.1001	0.1335	0.1669	0.2003
System degradation	**0.0083**	0.1295	0.1315	0.1335	0.1357	0.1378
Insurance	**0.0096**	0.1287	0.1312	0.1335	0.1360	0.1383
O&M	**0.0096**	0.1287	0.1312	0.1335	0.1360	0.1383
WACC	**0.0612**	0.1053	0.1188	0.1335	0.1495	0.1665
Inflation	**-0.0120**	0.1403	0.1367	0.1335	0.1307	0.1283
Leasing fee roof annuity	**0.0104**	0.1393	0.1422	0.1451	0.1509	0.1480
Leasing fee roof upfront	**0.0073**	0.1371	0.1389	0.1407	0.1425	0.1444

relationship means that when the price of the system doubles (+100%), the LCOE increases by 0.1335€/kWh. Analogously, if the purchasing price of the PV system were to decrease by 10% (1,600€ -10%=1,440€) the LCOE would decrease by 0.01335€/kWh[51] and come down to 0.1202€/kWh. The second most relevant variable affecting the LCOE is the WACC. When the WACC is increased by 100%, from 6.50% to 13.0%, the LCOE increases by almost double the base value indicating a non-perfect linear regression (0.1947 €/kWh instead of 0,2034€/kWh). Other variables that have a strong impact on the LCOE have not been listed due to their non-linear regression which makes them incomparable within the same chart. They will be discussed in chapter 8.4.3.

The remaining independent variables clearly do not heavily influence the outcome of the LCOE. Such variables are the "system degradation rate," "insurance," "O&M costs," and most importantly, "leasing fee for the roof." This result indicates that if these variables are changed dramatically within a range that includes realistic extremes, the LCOE will only vary slightly. The larger impact of the yearly leasing fee compared to the upfront payment is noticeable here (a difference of 0,0043€ or 0,43¢€). Overall, however, there is no intrinsic risk in making a price forecast with these variables, as the impact is very low.

51 0.1321€/kWh multiplied by 1/10

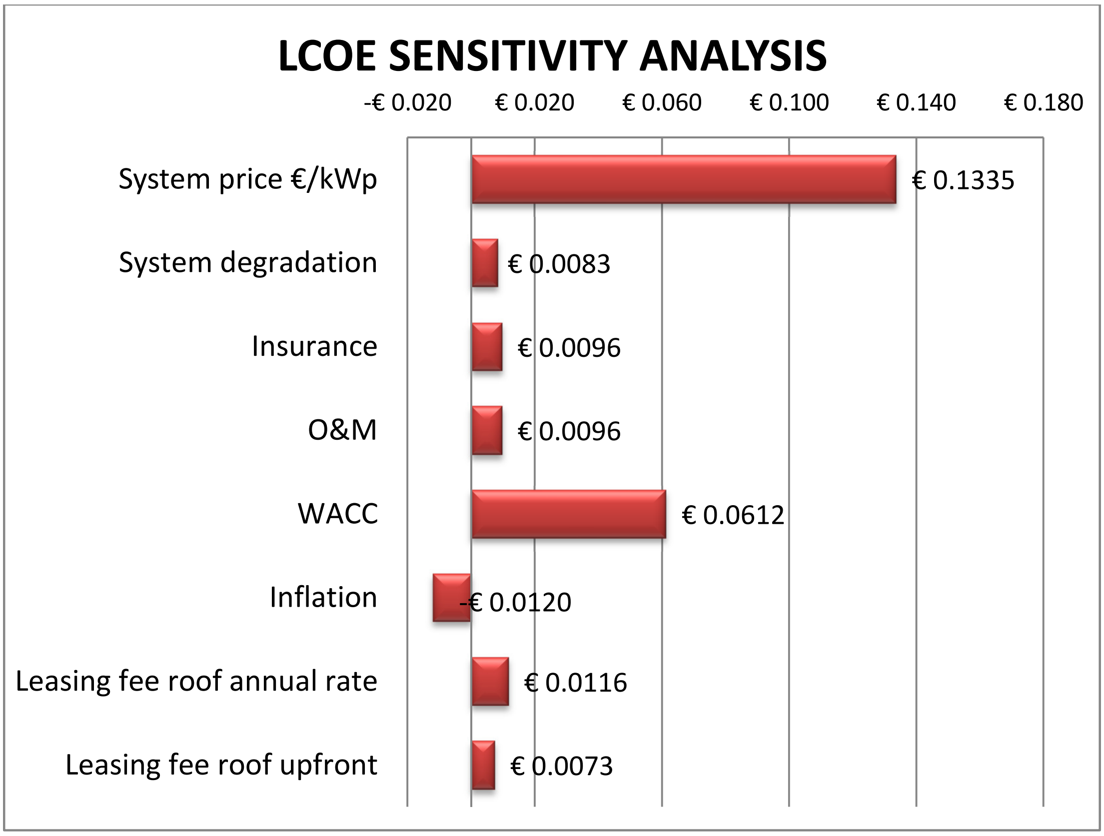

Figure 21. LCOE sensitivity analysis results – the values indicate the strength of the relationship between the LCOE and the independent variable in €/kWh which have to be added or subtracted from the base case value 0.1335€/kWh

8.4.2. IRR sensitivity analysis

The resulting IRR indicates that 6.32% is the upper limit of cost of capital; as long as the project is financed at a WACC lower than 6.32%, the project will be profitable (Bhattacharyya, 2011). Yet, what is more significant than the single value of the IRR based on the assumptions is the information about which factors most influence the IRR. Table 13 and Figure 22 provide exactly this information. The relationship between the dependent variables IRR and the independent variables are non-linear. The result of the slope algorithm is indicative of its order of magnitude but cannot be used as a correlation factor.

The results of Table 13 have been plotted in Figure 22. The figure suggests that the largest influences on the profitability of the PV system are given by the total costs of the investment, the price that the utility can charge for the electricity sold to its

Table 13. IRR Sensitivity analysis data

IRR SENSITIVITY ANALYSIS	Slope	-50%	-25%	0%	25%	50%
System price €/kWp	**-0.1305**	15.61%	9.73%	6.32%	3.97%	2.18%
System degradation	**-0.0070**	6.66%	6.49%	6.32%	6.14%	5.96%
Electricity FIT	**0.1059**	-0.48%	3.32%	6.32%	8.92%	11.28%
El. FIT increase/a	**0.0228**	5.17%	5.75%	6.32%	6.89%	7.45%
Insurance	**-0.0061**	6.62%	6.47%	6.32%	6.16%	6.01%
O&M	**-0.0061**	6.62%	6.47%	6.32%	6.16%	6.01%
WACC	**0.0000**	6.32%	6.32%	6.32%	6.32%	6.32%
Inflation	**-0.0046**	6.53%	6.43%	6.32%	6.20%	6.07%
Leasing fee roof annuity	**0.0076**	5.19%	5.38%	5.57%	5.76%	5.95%
Leasing fee roof upfront	**0.0060**	5.29%	5.45%	5.61%	5.96%	5.79%

customers, and, to a minor extent, the yearly increase (in percentage) of this price. Whereas, "system degradation," "insurance," "O&M," "leasing fee of the roof," "equity capital," and "WACC," barely affect the profitability of the investment.

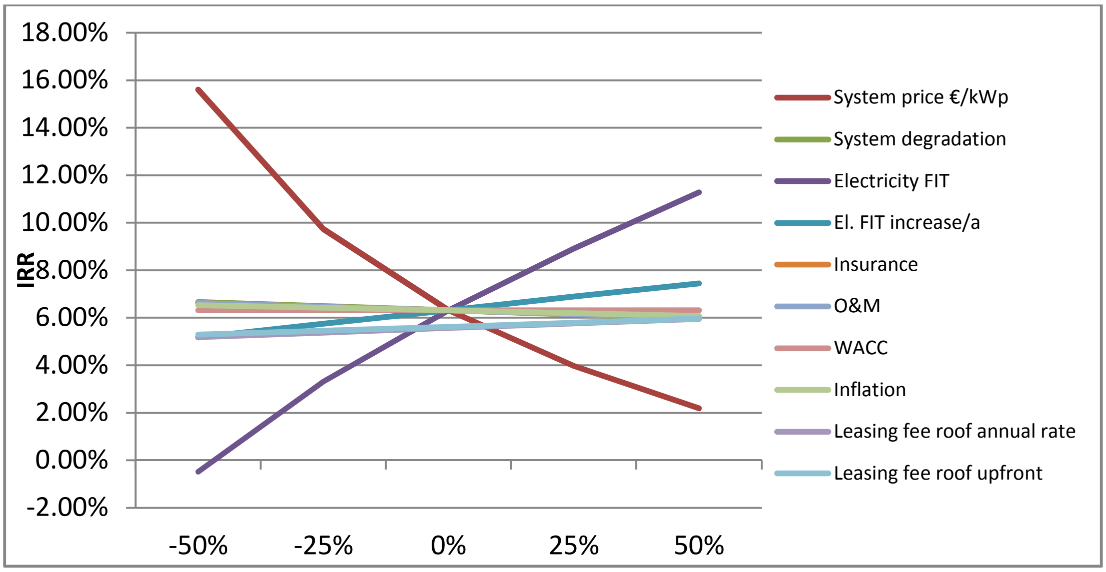

Figure 22. IRR sensitivity analysis plot

The non-influence of WACC on the IRR

What appears to be a "bug" in the model is in fact a compromise for the gain of simplicity against overwhelming complexity. The WACC used in this model is simultaneously used to calculate the real depreciation of money and the amount of electricity generated over the lifecycle of the power plant. Being that the cash flow of the IRR is dependent on the depreciation rate used this depreciation rate is applied on both sides (costs and revenues), changing the WACC does not affect the resulting IRR. The author defends the legitimacy of this assumption with the argument that WACC and depreciation rate are closely linked, and changing the one without adapting the other would be unrealistic because it would give money (spent and earned) different values.

The influence of inflation on the IRR

Why does inflation influence the IRR of the power plant? Because the inflation rate of 2% (in the base case) affects the real depreciation rate just as the WACC does, but additionally, it is used to index all operation costs that are incurred during the lifecycle of the power plant. This leads to slight changes in the IRR.

8.4.3. Sensitivity analysis of non-linear regression functions

The following variables have been treated separately because of their non-linear regression or because of a relative variation that differs from the -50% to +50% used previously.

Efficiency factor

A strong relationship exists between the "Efficiency factor" and both the LCOE and the IRR. The plotted results in Figure 23 illustrate that an improvement in the efficiency by 25% (higher insolation, higher system performance, et cetera) improve the IRR by 2,64% points and lowers the LCOE by 0,0271 €/kWh. What the figure also suggests is that with increasing efficiency, there is a slight reduction of increasing marginal profitability.

Table 14. Sensitivity of the LCOE and the IRR to the efficiency factor

Efficiency Factor	0.55	0.83	1.10	1.38	1.65
LCOE impact	0.267	0.1769	0.1335	0.1064	0.089
IRR impact	-0.48%	3.38%	6.32%	8.96%	11.28%

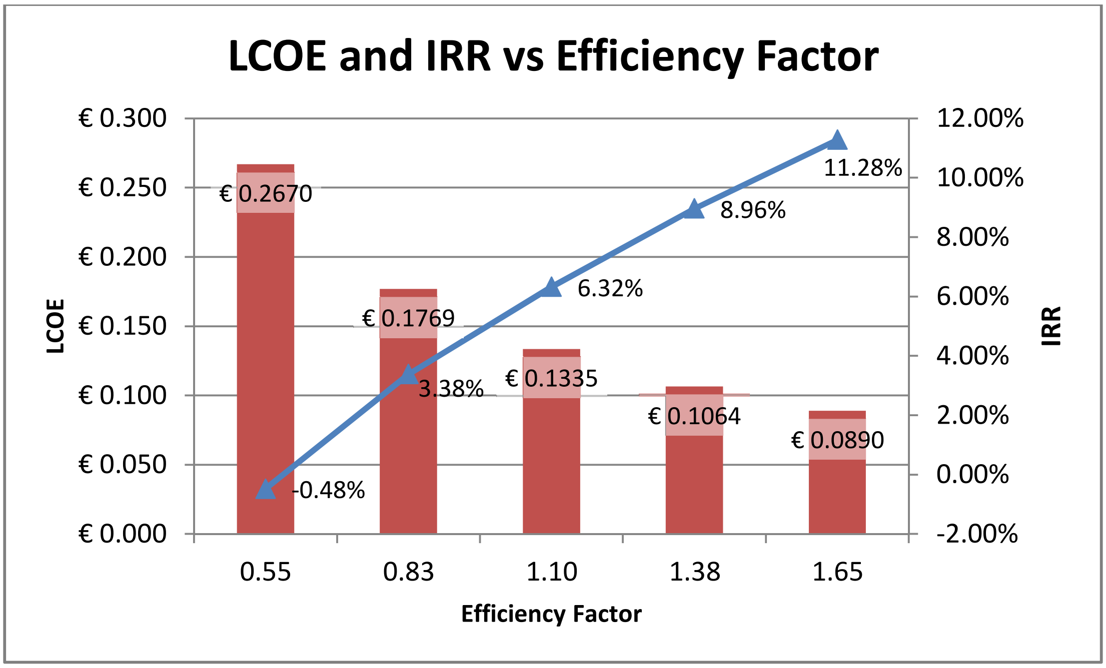

Figure 23. LCOE sensitivity analysis for the efficiency factor

Lifetime of the PV system

As discussed on page 49, the lifetime of PV modules depends on the photo-degradation of their solar cells as well as on the BOS components. In calculating the sensitivity to lifetime, the system degradation rate has been kept constant, which leads to an end of life efficiency that differs between the five cases (from 91% to 79%). Most importantly, the inverter replacements have been varied too. In the case of a 15-year life expectancy of the PV system, the replacement of the inverter will not take place. In the case of a 30 year life expectancy, the second replacement will not take place, but if the PV system is assumed to last 35 years both replacements will take place (one replacement around 15 years and the second around 30 years). The results are listed in Table 15 and plotted in Figure 24.

Table 15. Sensitivity of LCOE and IRR to the Lifetime of the PV System

Sensitivity of LCOE and IRR					
Lifetime in years	15	20	25	30	35
Inverter Replacement	none	once	once	once	twice
SDR	0.60%	0.60%	0.60%	0.60%	0.60%
Efficiency at life end	91%	88%	85%	82%	79%
LCOE impact	0.1573	0.1474	0.1335	0.1251	0.1263
IRR impact	3.75%	4.94%	6.32%	7.09%	7.32%

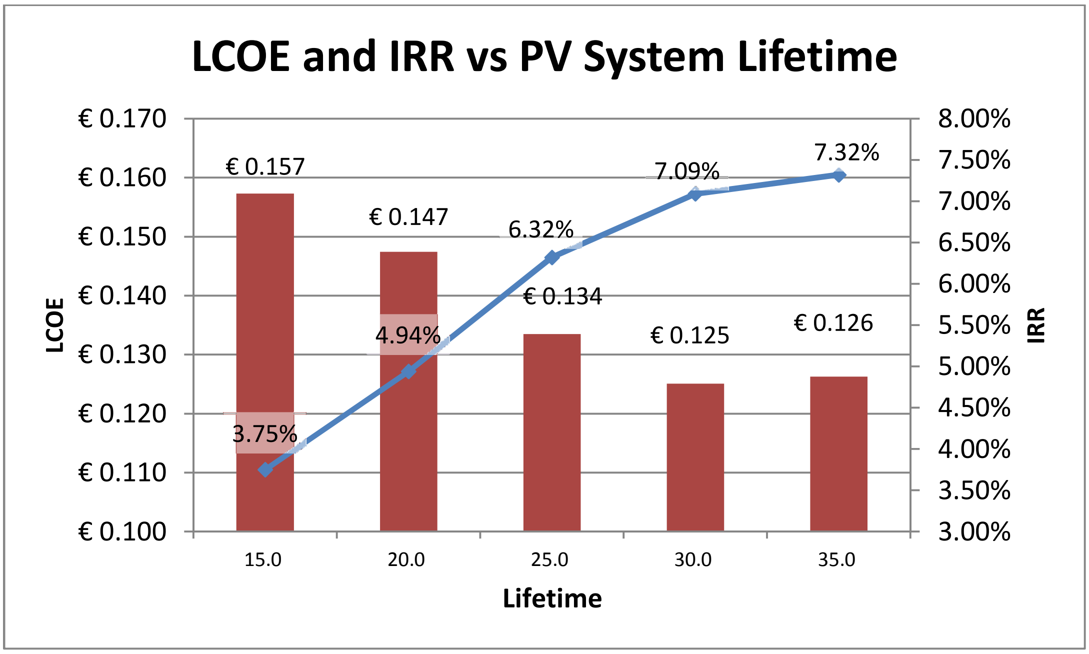

Figure 24. Sensitivity of LCOE (red columns) and IRR (blue line) to the Lifetime of the PV System

What is remarkable is that after the second replacement of the inverter, the LCOE begins to increase again after an almost linear decrease every five years. The IRR rises linearly between the scenarios 15 to 25 and then shows strong reduction in increasing marginal profitability, which suggests that a lifetime of 30 to 35 years might be the optimum lifetime of a PV system.

Grid connection costs

For the eventuality, that the PV project is designed in a way that requires the installation of additional transformer capacity, the impact of grid connection costs according to the grid level has been calculated (cost details and explanation in chapter 8.1.2).

Table 16. Sensitivity of LCOE and IRR to grid connection costs

Grid level	7	6	5	4	No Costs
LCOE impact	0.1511	0.1445	0.142	0.1372	0.1335
IRR impact	4.99%	5.46%	5.65%	6.02%	6.32%

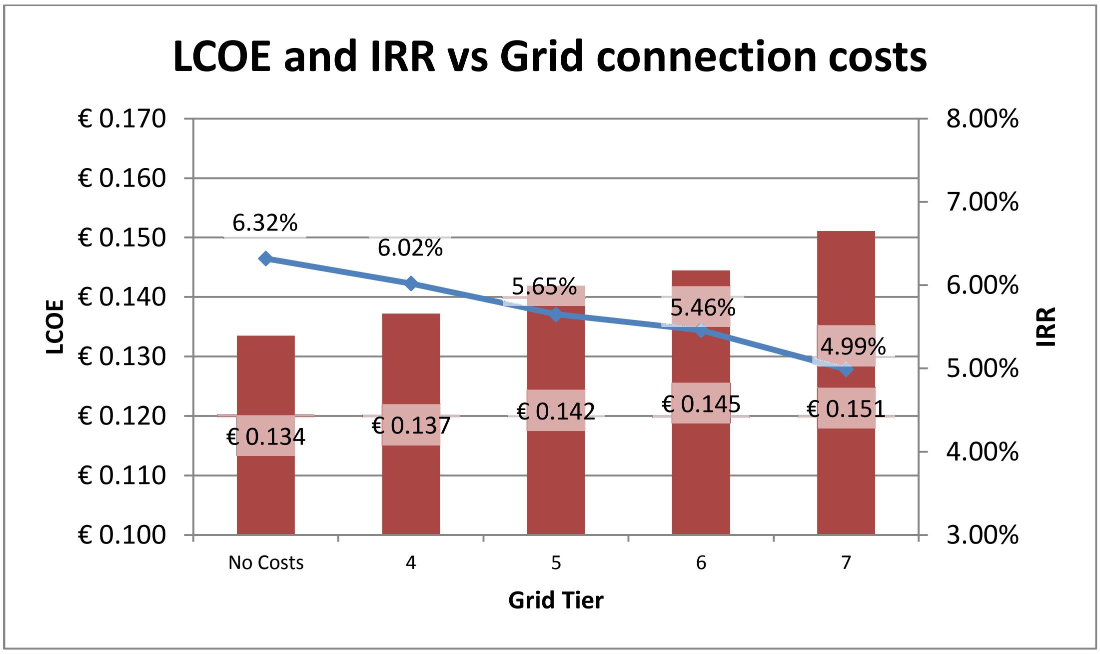

Figure 25. Sensitivity of LCOE and IRR to grid connection costs

As can be seen in Figure 25, whether or not grid connection costs are incurred, affects the profitability of the PV system and is decisive for the achievement of grid parity. In order to establish a grid connection for the PV system, a service contract has to be concluded with the DSO which usually generates costs in the same order of magnitude. Because these costs are evaluated by EVN Netz GmbH on a case-by-case, basis they have been ignored in this evaluation.

Electricity substitution share

In the base case scenario it is assumed that all the electricity generated by the PV power plant can and will be sold at the preferential price of 140€/MWh to the contractor. There are, however, special cases in which this fortunate condition does not apply due to the lack of simultaneity between generation and consumption and the assumption that the customer will not install batteries in order to store the electricity. One example of missing simultaneity could be a wonderful sunny 1st of May workers day where the PV system would most likely work at its peak performance values thanks to high sun irradiation and relatively low temperatures, coinciding with a national holiday where all manufacturing machines stand idle. Most likely, on this day, the electricity will be fed into the grid at the current market price of (today) approximately 45€/MWh (1/3 of the preferential price). If the condition of simultaneity is frequently broken, the profitability of the PV system starts to shrink. Figure 26 plots the decreasing IRR depending on the share of electricity that is being substituted by a power plant on the roof of the contracting customer. It is daunting that a decrease of 10% in the electricity sold at the preferential price each year strongly decreases the profitability of the power plant by almost one percentage point.

The electricity substitution rate does not affect the LCOE.

Table 17. Impact of decreasing electricity substitution rates on the IRR

El. Subst. Share	100%	90%	80%	70%	60%
IRR impact	6.32%	5.52%	4.69%	3.81%	2.87%

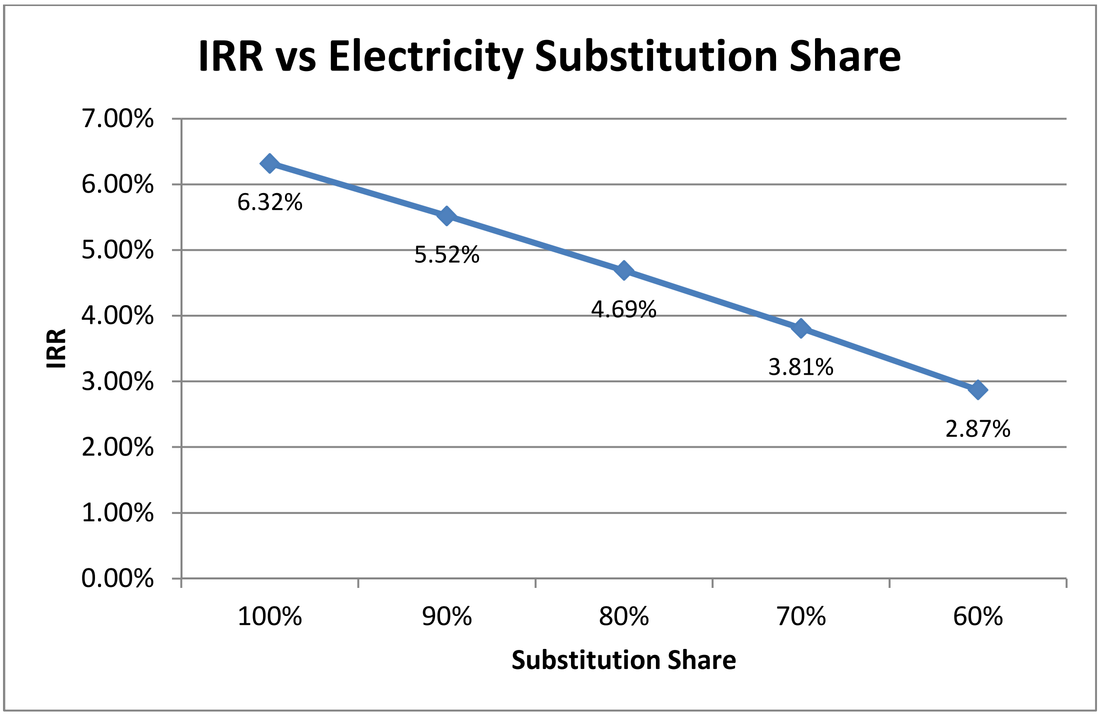

Figure 26. Impact of decreasing electricity substitution rates on the IRR

8.5. SME's perspective

8.5.1. LCOE

SME customers consume different amounts of electricity depending on their business activity and have an electricity tariff that usually resides between the residential and the industrial sector. With a net electricity purchasing price range of 6.44 to 17.36¢€/kWh, the resulting LCOE for a medium scale PV system of 13.35¢€ should call the attention of many SMEs that wish to reduce their electricity bills and improve the image of their businesses. Based on the current model and under the assumption made, any commercial enterprise that consumes over 400,000 kWh per year and that pays more than 13.35¢€/kWh (VAT excl.) is better off if it would install a 100kWp PV system on its own roof than to purchase the electricity from the utility!

8.5.2. Internal Rate of Return

Any enterprise that seeks to reduce its own electricity bill can invest in a PV system in order to do so. The capital invested in this power plant, however, incurs the opportunity cost of not being able to earn revenues (interest) if employed in another investment. It is therefore misleading to think that the SME's WACC is close to 0% as long as the price of the electricity saved equals the LCOE of the PV system. It is for this reason that the author rejected the idea of expanding the LCOE model by adding the SME's point of view (or better, it has been done, with no discernible differences recognized).

8.6. Discussion of the results

The main goal of this master thesis was to gather all the relevant information necessary to assess whether PV systems have reached the state of grid parity or not under specific circumstances. Furthermore, the resulting model, which is based on the broadly used Windows® PC operating system, can be employed as a decision making tool for the evaluation of the profitability of PV projects. The model is in many ways adaptable to real projects and depicts all the necessary variables that flow into the calculation of both the LCOE and the IRR of a hypothetical power plant. With the aid of scrollbars for the variation of the variables, it was possible to seek out optima and verify incongruences and errors (Figure 27). Its applicability has been tested at the company level; the results are comparable with models that calculate the IRR via different itineraries but with increased complexity (in order to fulfill company standards).

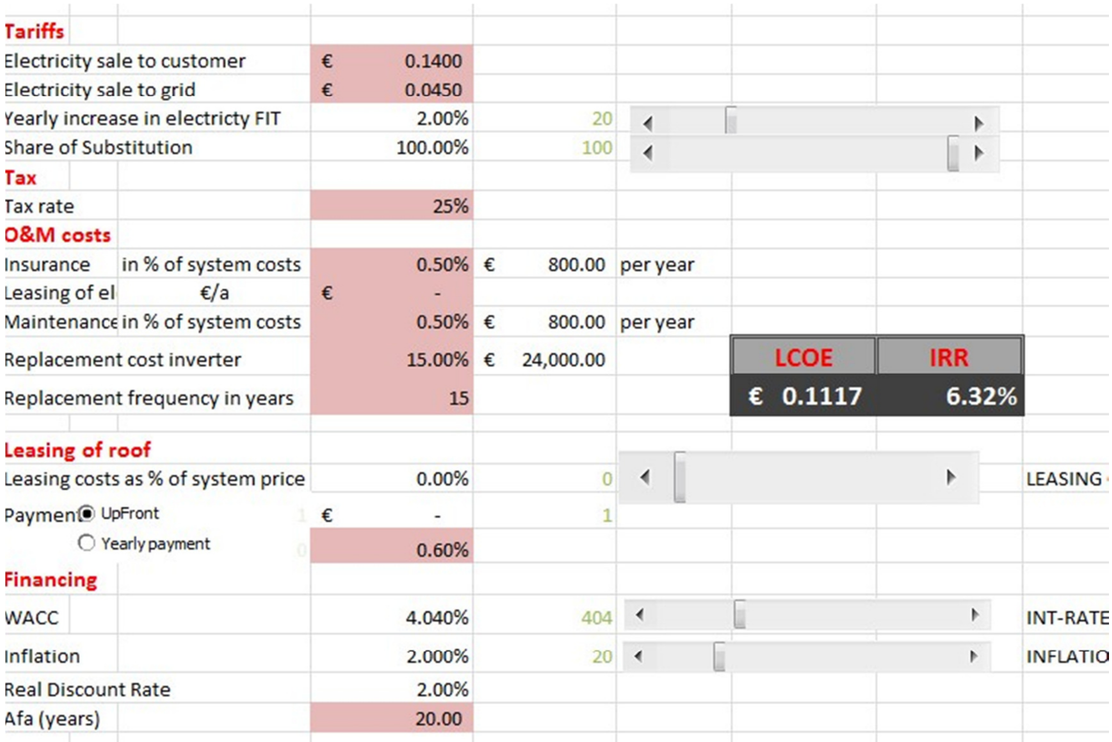

Figure 27. The model interface with the example of a calculation; the scroll bars aid the user to find optima

Thanks to the sensitivity analysis performed, it was possible to identify which factors the attention of the utility should be concentrated upon. Important findings of the model are:

- The efficiency factor and the PV system costs are by far the most influential variables. All other variables, however, have a decisive impact on the profitability of the project when WACC requirements are high.
- The considered lifetime of the PV system should be extended from 25 years (in some cases 20 years are applied) to 30 years. The very low rates of photo-degradation for new PV systems and the fact that the IRR and LCOE include the cost for the inverter replacement in period 15 justify the prolongation of the calculation period. The longer lifetime of the PV lifecycle improves the IRR and reduces the LCOE.
- The PV system has to match the electricity consumption of the contracting customer. Ceteris paribus[52], a reduction of the electricity substitution by 10% can push the IRR of the power plant below the company profitability threshold.

52 Latin for all things equal

- There are no connection costs as long as the PV system does not feed more power into the grid than the available transformer can take. Therefore, an over-dimensioning of the PV system does not make economic sense due to additional investment costs that increase the LCOE of the PV plant by up to 12%.
- The system degradation rate of the PV panels (between 0.3% and 0.9%) plays a marginal role over the PV system lifecycle.
- In the case of a different contractual relationship than the electricity contracting suggested in this work, the roof on which the PV system will be installed will include a leasing fee. Whether this fee is paid upfront or throughout the power plant's lifetime has very little influence on the economics of the PV system, although the payment upfront is more advantageous for the utility (if the yearly leasing is indexed by inflation).

9. New strategies

Market revolutions take place when innovations occur. The invention of the photovoltaic cell goes back as far as 1950, but only recently could this invention be turned into a mass product, and only in recent years has this product reached cost-effectiveness without financial subsidization. Therefore, it can be said that the innovation took place only recently: the cost reduction was (and will be) key to the widespread adoption of a 60 year old invention.

What role should a utility play when PV systems crowd the roofs of their customers? The toughest challenge of this master thesis was to find the link between the customer's interest (affordable and reliable electricity) and the interest of utilities (sustainable profits). Luckily, for Austrian utilities, revolutions do not take place overnight; that is why they have the chance to adapt to a new potential market, and if they keep pace with the changes in their sector of influence, the game will have no losers. To adapt to the new market setting short- and long-term strategies were outlined.

9.1. Short term strategies

As previously stated, the pivotal factor for the cost effectiveness of PV installations in the future will be the availability of suitable roofs. It is therefore paramount for electricity suppliers to enter the market as early adopters and secure the "low hanging fruits" of available roofs by focusing on medium to large-scale PV systems where the highest scale economies are possible. It is important that the utility gathers experience and that it positions itself in the market in order to get the chance to secure future surfaces (as a market participant the gathering of strategic information about key developments becomes easier). As shown by the model, the leasing fee does not greatly influence the LCOE of the PV system, and therefore, a variety of contracts can be signed without posing a risk to the long-term profitability of the power plant.

9.1.1. Leasing of roofs

The "no-brainer" strategy would be to participate in the developing roof-leasing market and sign contracts with companies such as large animal farms, supermarket chains, or logistic warehouses that possess large roofs and do not plan to invest in

PV system of their own. For the leasing of roof there are standardized contracts that secure a safe business relationship for both parties of the agreement with most eventualities covered. The market is still developing and therefore the first to adopt this strategy will profit from nonexistent competition that grants lower leasing fees. The issue with this business model is that the sale of electricity on the market will not be profitable as long as the LCOE is higher than wholesale electricity prices. The possibility of achieving an OeMAG FIT is discarded as highly unlikely in this work. This strategy could be pursued if a the utility finds a way to sell the electricity to local consumers at a preferential tariff that is higher than the LCOE but lower than the tariff paid by the customer.

9.1.2. Electricity Contracting

The utility that wishes to enter the PV market in an aggressive way can grant the roof owner an electricity rate that is close to the price the client pays and therefore gives the roof owner an incentive to sign an electricity-contracting contract with the utility that binds the client over the lifetime of the PV system. A contract secures both partners. The utility gains from

- free access to roof area it does not possess,
- securing the roof area and customer for a long term;

The client gains from

- long-term foreseeable electricity tariff for leasing a roof it was not using anyway,
- an image improvement thanks to a visible endeavor to a sustainable future,
- but, loses the future opportunity to install a PV system of its own.

The strategy would be easy to implement, the profitability thereof depends on the bulk price of the modules bought, on the roof architecture of the potential customers, on the business model for the installation of the PV systems (outsourcing vs. own business branch), and on the price reduction granted to the customer as an incentive to close a long-term contract.

9.2. Long term strategies – Managed, incentivized, extensive PV deployment

To maintain a functioning electric grid is an expensive business, to build a new one even more so. The extensive deployment of renewable energy technology strains the capacities of the T&D electricity network of EVN Netz AG. According to grid management common sense of distribution networks, even though the maximum capacity for each household connection is usually 10kVA[53], the real maximum capacity allocated for each household at the tier 6 level[54] (transformer 10kV → 400 V) amounts to 25% of the sum of the maximum individual capacity. For reasons of cost-effectiveness, it is not reasonable to install the full transformer capacity at tier 6 that would correspond to the sum of each individual household maximum capacity because it is highly unlikely that all households will withdraw the full capacity simultaneously. Nevertheless, in a scenario in which many households decide to install a PV system on their roofs (on tier 7), the electricity fed into the grid (depending on PV system size) will greatly exceed by the electricity withdrawn. Therefore, in a distribution network where the average per-household transformer capacity amounts to 1kVA of withdrawal, at noon in April or September[55] there might be a per-household required transformer capacity of 5kVA or higher due to the electricity fed into the grid by the PV systems.

The utility that wishes to deploy large amounts of PV systems by incentivizing its own customers to install PV systems on their roofs should do so while taking into consideration the limitations of its own grid. The aim of the utility should be to incentivize the installation of small PV systems and find a way to prevent the installation of large systems on tier 7. This concerns only the residential sector. SMEs and industrial enterprises in Austria have to pay for additional transformer capacity when changes on their premise's power load-profile take place.

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53 kVA is the dimension of transformers, used to distinguish between apparent and real power.

54 The tier 7 level of the distribution network is divided in sectors which are connected to the medium tension grid (tier 5) through the transformers (tier 6). This way the maximum current capacity that can be withdrawn in tier 7 depends on the maximum capacity available at the transformers (tier 6).

55 Due to the temperature coefficient of PV cells that decrease performance with increasing cell temperature, the best performances of PV systems are registered in April and September thanks to lower air temperatures (cooling effect) and comparatively analogues solar irradiation.

9.2.1. The ideal development – controlled deployment of PV

Maximum PV capacity per household

Each household does not withdraw more than 1kW of power on average from tier 6 through the tier 7 network. This means that with almost absolute certainty the distribution grid can handle a maximum average power capacity of 2.5 kW withdrawal per household at any point in time[56]. From the transformers' perspective, it is irrelevant in which direction the electricity flows, the installed capacity is what matters. A maximum transformer capacity of 2.5 kVA per household combined with an average withdrawal of 1 kW, results in a trouble-free average installation capacity of 3.5 kWp per household. One kilowatt peak will be consumed directly from the household's appliances and a maximum of 2.5 kWp will be fed into the grid, a capacity that is met by an already available tier 6 transformer capacity. No further investments in grid development are necessary.

Because the figures mentioned above are average values, when a pool of households decides not to participate in the utility's strategy, precious resources might stand idle (roof area). In this likely eventuality, either the utility or other households could lease their roofs and install PV systems. Alternatively, with some additional administrative work, household "A" could install a larger PV system than is permitted on its own roof and find a settlement with household "B" that does not wish to install a PV system to cover for the extra capacity. Household "B" would have to guarantee that it will not install a PV system in the future. This way, grid stability would be guaranteed.

Intelligent inverters

New inverters from the leading manufacturers have a built-in function that enables the inverter to monitor the grid's voltage and in case of a hazardous increase in grid voltage[57], reduce the electricity fed into the grid up to the point where it shuts down completely. The utility can make the granting of favorable terms for the installation of a PV system conditional to the use of an inverter with this functionality. As a result,

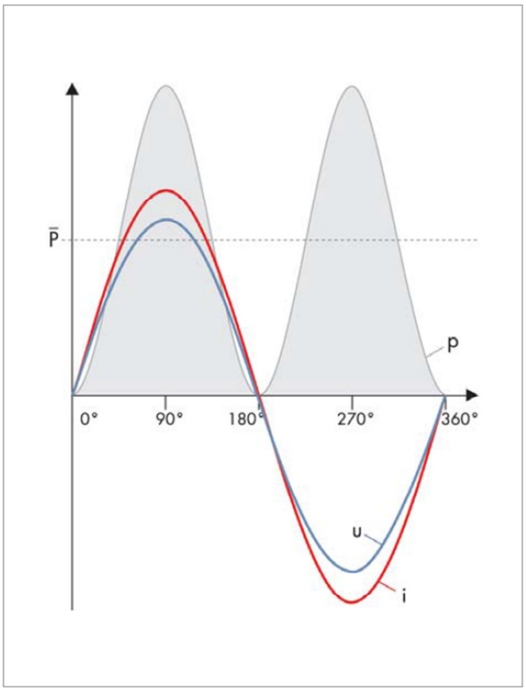
[56] 25% of installed capacity

57 This happens when there is a mismatch between generation and consumption of electricity: a household that is far away from the next tier 6 transformer generates electricity in excess, the grid's tension from the household to the tier 6 transformer can reach levels as high as 120% of nominal tension. This can disrupt electric appliances of the households that are connected between the generating PV system and the tier 6 transformer.

when the capacity limit of tier 6 is reached, the inverters connected to the subordinated tier 7 will reduce the power load: a self-healing process.

Reactive power

The current that flows in the tier 7 distribution grid is a three phase current at 400 V. If a resistive load is connected to the grid (e.g. an incandescent light bulb), the product of voltage (400 V) and current (e.g. 6A) equals the power that can be withdrawn. Nevertheless, in reality there are loads connected to the grid that, due to their characteristics, can shift the sinusoidal phases of current and tension from each other (e.g. like asynchronous motors). This is called “phase shifting” and is defined as *cosinus phi* (cosφ). Because the grid’s power capacity is the product of voltage and current, this phase shifting causes a reduction of real power that is able to be withdrawn from the grid by electric appliances.



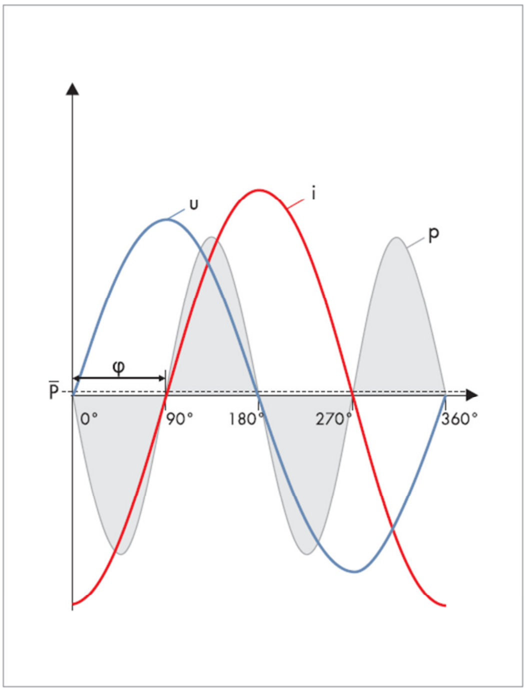


Figure 28. Left picture - voltage and current are in phase, apparent power equals real power (power always positive); right picture – due to capacitive loads, current shifts by 90°, power is equally positive and negative, the result is that apparent power equals reactive power, no real power available (SMA, 2011)

Through the active provision of reactive power that counteracts this effect, it is possible to reverse the shifting or deliberately provoke it in order to either release grid reserves (power is available on the grid but cannot be withdrawn due to the phase shift) or balance a temporary increase in voltage (Schwarzbruger, 2012).

In a report published by Fraunhofer Institute for Wind and Energy System Technology (2012) commissioned by the German Federal Association of Solar Industry, the institute analyzed the consequences of an extensive deployment of PV systems on German grid stability. The institute made a techno-economic assessment of the grid's capacity to accommodate large capacities of PV on the tier 7 grid. In the assessment, five different strategies were evaluated according to their cost-effectiveness, deployability, and policy effort. The strategy that satisfies all criteria is the provision of additional reactive power through the inverters of PV systems. Through inverters that are able to provide extra reactive power (a novelty on the market), the voltage of tier 7 grid can be held in check. Figure 29 roughly illustrates the functionality of such an inverter. When the voltage (black line) exceeds the voltage's threshold of 1.03 p.u.[58], the inverter's reactive power (green line – invers scale) is increased to Q= Qmax. Consequently, the real power (blue line) decreases, and the voltage on the grid decreases too. When the threshold of 1.03 is undercut, the apparent power is reduced to Q=0.

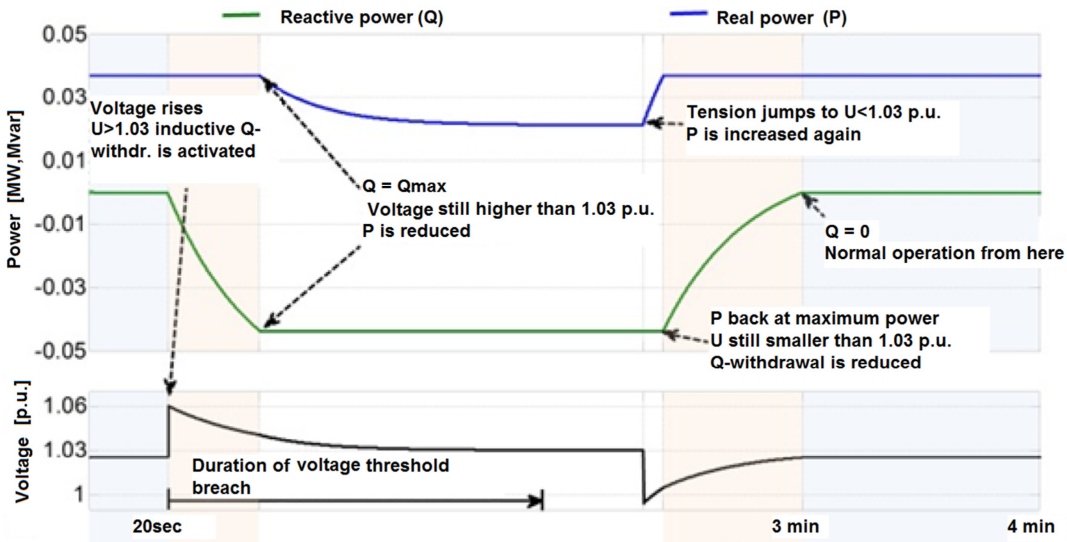


Figure 29. Functionality of an inverter with automatic voltage regulation – modified after (Stetz et al., 2012)

58 p.u. stands for per unit and expresses a relative change of a defined base unit quantity (Glover et al., 2012)

9.2.2. Advantage for the utility

In the current liberalized market, it is difficult to make the interests of power utilities and DSOs converge. In an ideal world (or the status quo before 1995), the interests of these two players were identical, whereas today they are almost diametrically opposite concerning future investments (congruent in maximizing the sale of electricity units). Before the unbundling of grid operator and electricity generator was enforced, the convergence of interests would make it possible to deploy large amounts of PV power plants in accordance with everybody's interests. Even though the following scenario does not fulfill the criteria of current market structure, it helps to illustrate where the problem resides.

Assuming every household has installed a PV system on its roof, or on tier 7 for every household on the grid connection an average 3,5kWp PV system feeds electricity into the grid, the utility will have saved money from the avoided expansion of grid capacity and power plant installations. The lost revenues from the sale of electricity would be compensated by higher grid fees which will be paid not for a higher use of the grid (according to current legislation, only the consumer of electricity pays for grid use not the producer), but for the supply of grid capacity. In other words, the customer pays a higher monthly fee regardless of consumption, or pays a higher per unit fee, to compensate the fact that grid capacity is provided for when needed.

In today's unbundled electricity sector, investment saving of DSOs do not influence the investment decisions and company policies of the electric utility regarding which power plant to install, hence the conflict of interests persists and the market regulator (E-Control) has to intervene to guarantee electricity generation profitability and grid stability.

The scenario depicted above would also be in the interest of the utility's customers that installs the PV system at their own costs, or lease their roof to the utility or other households. The utility gives its customers an economic incentive to make the investment in a PV system. The management of the extensive deployment of PV systems represents an economic advantage for the customer as well because, in the end, any expenses made by the utility have to be paid for by consumers; therefore, any euro not spent in infrastructure is a euro that the utility does not have to charge the consumer through the electricity bill.

10. Conclusions

The development of PV system costs and electricity tariffs in Europe throughout the last decade prepared a fertile ground for the widespread deployment of non-subsidized PV system for residential and commercial electricity consumers. The market might not yet be at the point of dynamic grid parity in each segment and on average throughout the whole segment (residential or commercial), but this tipping point is certainly not far away.

Power utilities all over Europe are struggling when confronted with this technology: the inconvenient truth is that they do not really know what to do with it because it is not meant for them. Photovoltaic power plants that generate electricity at practically zero marginal costs become a disruptive technology within an established electricity market as soon as the investment costs start decreasing dramatically. This has been the case for the last 5 years (50% cost reduction). Power utilities that underestimate this powerful technology that magnificently works in harmony with nature's cycles, risk losing large chunks of revenues to prosumers[59] and other market players that are more innovative and flexible.

The simple message of this master's thesis is that dynamic grid parity is imminent, the question is not whether power utility customers will get a PV power plant on their roof or not, but who will install and who will own this power plant. The undeniable consequence of this development is that for each household and each SME that adopts PV, the power utility on average loses 30% of the revenues.

The moment in which utilities start to take PV more seriously and adopt this technology, they will become forerunners instead of filibusters. The most important criteria for the achievement of their own profitability are the following:

- The efficiency factor and the PV system costs are by far the most influential variables. All other variables, however, have a decisive impact on the profitability of the project when WACC requirements are high.
- The considered lifetime of the PV system should be extended from 25 years (in some cases 20 years are applied) to 30 years. The very low rates of photo-degradation for new PV systems and the fact that the IRR and LCOE

59 A prosumer is a consumer that produces as well. This neologism was introduced to identify those households and SMEs that participate in the electricity generation market as facilities that not only withdraw electricity but also - partly - feed electricity into the grid.

include the cost for the inverter replacement in period 15, justify the prolongation of the calculation period. The longer lifetime of the PV lifecycle improves the IRR and reduces the LCOE.

- The PV system has to match the electricity consumption of the contracting customer. Ceteris paribus, a reduction of the electricity substitution by 10% can push the IRR of the power plant below the company profitability threshold.
- The connection costs are not due as long as the PV system does not feed more power into the grid than the available transformer can take. Therefore, an over-dimensioning of the PV system does not make economic sense due to additional investment costs that increase the LCOE of the PV plant by up to 12%.
- The system degradation rate of the PV panels (between 0.3% and 0.9%) plays a marginal role throughout the PV system's lifecycle.
- In the event of a different contractual relationship than the electricity contracting suggested in this work, the roof on which the PV system will be installed will be charged a leasing fee. Whether this fee is paid upfront or throughout the power plant's lifetime has very little influence on the economics of the PV system, although the payment upfront is more advantageous for the utility (if the yearly leasing is indexed by inflation).
- The WACC used by the power utility for the calculation of the IRR should be chosen wisely. This economic indicator expresses the intrinsic risk of investing in a particular technology (PV, Wind, or CCGT[60]) in a specific country (OECD or emerging market). Due to their access to low interest financial resources, power utilities could aggressively occupy the PV market by adopting lower WACC (meaning expecting less return on investment), therefore expanding the portfolio of profitable projects and becoming one of the most important market players. The risks of this investment are virtually zero because they are completely priced-in within the LCOE. Being free from any national or regional policy there is nothing involved that can generate a loss from the investment made.

The time has come for fossil fuels to go back to where they came from: six feet under.

60 Combines cycle gas turbine, nowadays the most efficient fossil fuel power plant available

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ANNEX I

Comparison of RET shares in electricity production of the EU-27 MS in 2009 (E-Control, 2012)

Country	Total generation	%	Electrcity generation from Renewables (gross) in the EU in 2009 in GWh and %											
			Total Renewables	%	Hydro	%	Wind	%	Biomass	%	SOLAR	%	Geothermal	%
BE	91.225	100%	4.611	5,1%	328	0,4%	996	1,1%	3.121	3,4%	166	0,18%		
BG	42.964	100%	3.710	8,6%	3.470	8,1%	237	0,6%	0		3			
CZ	82.250	100%	4.643	5,6%	2.429	3,0%	288	0,4%	1.837	2,2%	89	0,11%		
DK	36.364	100%	9.032	24,8%	19	0,1%	6.721	18,5%	2.288	6,3%	4	0,01%		
DE	592.464	100%	87.814	14,8%	18.660	3,1%	38.639	6,5%	23.918	4,0%	6.578	1,11%	19	0,0%
EE	8.779	100%	265	3,0%	32	0,4%	195	2,2%	38	0,4%				
IE	28.242	100%	4.039	14,3%	902	3,2%	2.955	10,5%	182	0,6%				
EL	61.365	100%	8.069	13,1%	5.258	8,6%	2.543	4,1%	218	0,4%	50	0,08%		
ES	293.847	100%	72.788	24,8%	26.331	9,0%	37.773	12,9%	2.666	0,9%	6.018	2,05%		
FR	542.345	100%	67.483	12,4%	57.138	10,5%	8.048	1,5%	2.125	0,4%	171	0,03%		
IT	292.641	100%	66.267	22,6%	49.138	16,8%	6.543	2,2%	4.568	1,6%	676	0,23%	5.342	1,8%
CY	5.227	100%	16	0,3%	0		0		12		4	0,08%		
LV	5.569	100%	3.557	63,9%	3.457	62,1%	50	0,9%	49	0,9%				
LT	15.358	100%	684	4,5%	424	2,8%	158	1,0%	102	0,7%				
LU	3.878	100%	242	6,3%	106	2,7%	63	1,6%	53	1,4%	20	0,52%		
HU	35.908	100%	2.893	8,1%	228	0,6%	331	0,9%	2.333	6,5%	1			
MT	2.167	100%			0		0							
NL	113.502	100%	9.190	8,1%	98	0,1%	4.581	4,0%	4.465	3,9%	46	0,04%		
AT	68.989	100%	46.257	67,0%	40.293	58,4%	1.967	2,9%	3.959	5,7%	35	0,05%	2	0,003%
PL	151.720	100%	8.678	5,7%	2.375	1,6%	1.077	0,7%	5.226	3,4%				
PT	50.207	100%	18.001	35,9%	8.284	16,5%	7.577	15,1%	1.796	3,6%	160	0,32%	184	0,4%
RO	58.016	100%	15.604	26,9%	15.534	26,8%	9	0,0%	61	0,1%				
SI	16.401	100%	4.906	29,9%	4.713	28,7%	0		189	1,2%	4			
SK	26.155	100%	4.888	18,7%	4.368	16,7%	6	0,0%	514	2,0%				
FI	72.062	100%	21.386	29,7%	12.686	17,6%	277	0,4%	8.418	11,7%	5	0,01%		
SE	136.717	100%	78.436	57,4%	65.852	48,2%	2.485	1,8%	10.091	7,4%	7			
UK	375.665	100%	23.713	6,3%	5.262	1,4%	9.304	2,5%	9.127	2,4%	20	0,01%		
EU 27 total	3.210.027	100%	567.173	17,7%	327.385	10,2%	132.823	4,1%	87.355	2,7%	14.057	0,44%	5.547	0,2%

[Source: eurostat, eurobserv'er]

Annex II

R1 Solar yield assessment of a hypothetical 1kWp PV system located at the coordinates of St. Pölten. Created with the pvPlanner software and based on SolarGis data from 1994 to 2010.

solargis | pvPlanner

YIELD ASSESSMENT OF THE PHOTOVOLTAIC POWER PLANT

Report number: PV-109-1208-1213
Issued: 17 August 2012 13:41 CET (GMT +0100)

1. Site info

Site name:	Sankt Pölten Sankt Pölten, Niederösterreich, Österreich
Coordinates:	**48° 12' 12.71" N, 15° 38' 17.41" E**
Elevation a.s.l.:	269 m
Slope inclination:	0°
Slope azimuth:	304° northwest

Annual global in-plane irradiation: **1384 kWh/m^2**
Annual air temperature at 2 m: **9.6 °C**

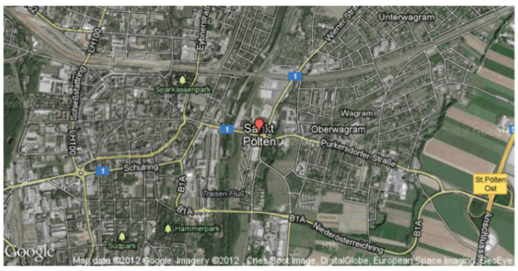
2. PV system info

Installed power:	**1.0 kWp**
Type of modules:	crystalline silicon **(c-Si)**
Mounting system:	**fixed mounting, roof installed**
Azimuth/inclination:	**180° (south) / 30°**
Inverter Euro eff.:	97.5%
DC / AC losses:	5.5% / 1.5%
Availability:	99.0%

Annual average electricity production: **1105 kWh**
Average performance ratio: **79.8%**

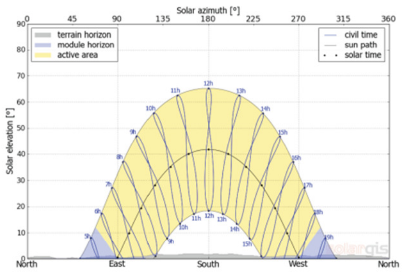
Location on the map: http://solargis.info/imaps/#loc=48.20353,15.63817&tl=Google:Satellite&z=14

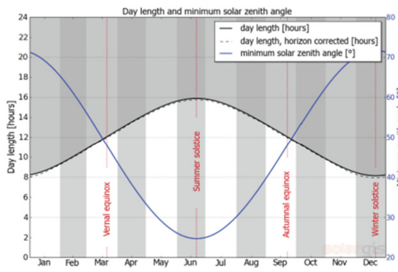
3. Geographic position



Google Maps © 2012 Google

4. Terrain horizon and day length



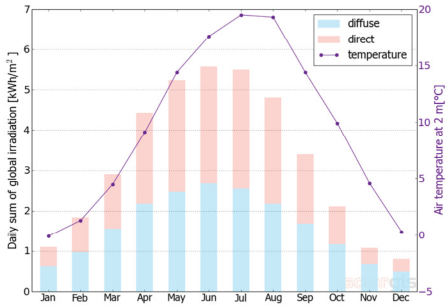


Left: Path of the Sun over a year. Terrain horizon (drawn by grey filling) and module horizon (blue filling) may have shading effect on solar radiation. Black dots show True Solar Time. Blue labels show Local Clock Time.

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

5. Global horizontal irradiation and air temperature - climate reference

Month	Gh_m	Gh_d	Dh_d	T_{24}
Jan	34	1.10	0.62	-0.1
Feb	52	1.84	0.97	1.3
Mar	90	2.90	1.56	4.5
Apr	133	4.43	2.18	9.1
May	162	5.24	2.48	14.4
Jun	167	5.57	2.68	17.6
Jul	170	5.49	2.55	19.5
Aug	149	4.81	2.18	19.3
Sep	102	3.40	1.68	14.4
Oct	65	2.11	1.17	9.9
Nov	32	1.08	0.67	4.6
Dec	25	0.80	0.49	0.3
Year	**1181**	**3.24**	**1.61**	**9.6**



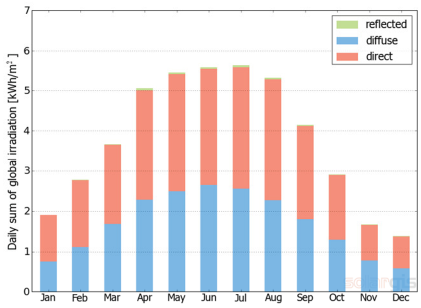
Long-term monthly averages:

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

6. Global in-plane irradiation

Fixed surface, azimuth 180° (south), inclination. 30°

Month	Gi_m	Gi_d	Di_d	Ri_d	Sh_{loss}
Jan	59	1.91	0.74	0.01	0.1
Feb	78	2.78	1.11	0.02	0.1
Mar	114	3.67	1.68	0.02	0.0
Apr	151	5.05	2.28	0.04	0.0
May	169	5.44	2.49	0.04	0.0
Jun	167	5.58	2.64	0.05	0.0
Jul	174	5.62	2.55	0.05	0.0
Aug	165	5.31	2.27	0.04	0.0
Sep	124	4.15	1.80	0.03	0.0
Oct	90	2.91	1.30	0.02	0.0
Nov	50	1.67	0.76	0.01	0.0
Dec	43	1.39	0.57	0.01	0.1
Year	**1384**	**3.79**	**1.69**	**0.03**	**0.0**



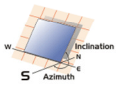
Long-term monthly averages:

Gi_m Monthly sum of global irradiation [kWh/m^2]
Gi_d Daily sum of global irradiation [kWh/m^2]
Di_d Daily sum of diffuse irradiation [kWh/m^2]
Ri_d Daily sum of reflected irradiation [kWh/m^2]
Sh_{loss} Losses of global irradiation by terrain shading [%]

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

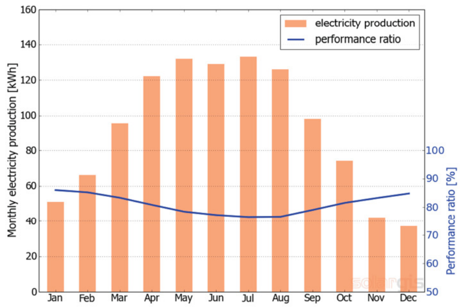
	kWh/m^2	relative to optimally inclined
Horizontal	1182	85.0%
Optimally inclined (37°)	1391	100.0%
2-axis tracking	1758	126.4%
Your option	**1385**	**99.6%**

Site: Sankt Pölten, Österreich, lat/lon: 48.2035°/15.6382°
PV system: 1.0 kWp, crystalline silicon, fixed roof, azim. 180° (south), inclination 30°



7. PV electricity production in the start-up

Month	Es_m	Es_d	Et_m	E_{share}	PR
Jan	50	1.64	51	4.6	86.0
Feb	66	2.37	66	6.0	85.2
Mar	94	3.06	95	8.6	83.3
Apr	122	4.08	122	11.1	80.8
May	132	4.27	132	12.0	78.4
Jun	129	4.31	129	11.7	77.2
Jul	133	4.30	133	12.1	76.5
Aug	126	4.07	126	11.4	76.6
Sep	98	3.28	98	8.9	79.0
Oct	73	2.37	74	6.7	81.5
Nov	41	1.38	42	3.8	83.2
Dec	36	1.18	37	3.3	84.8
Year	**1105**	**3.03**	**1105**	**100.0**	**79.8**



Long-term monthly averages:

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

8. System losses and performance ratio

Energy conversion step	Energy output [kWh/kWp]	Energy loss [kWh/kWp]	Energy loss [%]	Performance ratio [partial %]	Performance ratio [cumul. %]
1. Global in-plane irradiation (input)	1385	-	-	100.0	100.0
2. Global irradiation reduced by terrain shading	1385	0	0.0	100.0	100.0
3. Global irradiation reduced by reflectivity	1343	-42	-3.0	97.0	97.0
4. Conversion to DC in the modules	1230	-113	-8.4	91.6	88.8
5. Other DC losses	1162	-68	-5.5	94.5	83.9
6. Inverters (DC/AC conversion)	1133	-29	-2.5	97.5	81.8
7. Transformer and AC cabling losses	1116	-17	-1.5	98.5	80.6
8. Reduced availability	1105	-11	-1.0	99.0	79.8
Total system performance	**1105**	**-280**	**-20.2**	**-**	**79.8**

Energy conversion steps and losses:

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

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

Site: Sankt Pölten, Österreich, lat/lon: 48.2035°/15.6382°
PV system: 1.0 kWp, crystalline silicon, fixed roof, azim. 180° (south), inclination 30°

9. SolarGIS v1.8 - description of the database

SolarGIS is high-resolution climate database operated by GeoModel Solar s.r.o. with geographical extent covering Europe, Africa and Asia. Primary data layers include solar radiation, air temperature and terrain (elevation, horizon).

Air temperature at 2 m: developed from CFSR data (© NOAA NCEP); years: 1991 - 2009; recalculated to 15-minute values. The data are spatially enhanced to 1 km resolution to reflect variability induced by high resolution terrain.

Solar radiation: calculated from Meteosat satellite data; years: 1994 - 2010; 15-minute or 30-minute values at 90 m spatial resolution - global horizontal and direct normal irradiance; the uncertainty of annual global horizontal irradiation typically ranges between ±3% and ±5%; 99% data coverage for the analysed time period.

This estimation assumes year having 365 days. Occasional deviations in calculations may occur as a result of mathematical rounding and cannot be considered as a defect of algorithms. More information about the applied data and algorithms can be found at: http://solargis.info/doc/pvplanner/.

10. Service provider

GeoModel Solar s.r.o., Milana Marečka 3, 84107 Bratislava, Slovakia; Registration ID: 45 354 766, VAT Number: SK2022962766; Registration: Business register, District Court Bratislava I, Section Sro, File 62765/B

11. Mode of use

This report shows solar power estimation in the start-up phase of a PV system. The estimates are accurate enough for small and medium-size PV systems. For large projects planning and financing, more information may be needed:
1. Statistical distribution and uncertainty of solar radiation
2. Detailed specification of a PV system
3. Interannual variability and P90 uncertainty of PV production
4. Lifetime energy production considering performance degradation of PV components.

More information about full PV yield assessment can be found at: http://solargis.info/doc/pvreports/.

12. Disclaimer and legal information

Considering the nature of climate fluctuations, interannual and long-term changes, as well as the uncertainty of measurements and calculations, GeoModel Solar s.r.o. cannot take full guarantee of the accuracy of estimates. The maximum possible has been done for the assessment of climate conditions based on the best available data, software and knowledge. GeoModel Solar s.r.o. shall not be liable for any direct, incidental, consequential, indirect or punitive damages arising or alleged to have arisen out of use of the provided report.

13. Contact information

This report has been generated by R1 Solar s.r.o., Eurovea Central 1, Pribinova 4, 811 09 Bratislava, Slovakia, http://www.r1solar.sk