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Comparison of support policies for residential photovoltaic systems in the major EU markets through investment profitability

L. De Boeck^a, S. Van Asch^b, P. De Bruecker^c, A. Audenaert^d

^aFaculty of Economics and Business, KU Leuven, campus Brussels, Research Centre for Quantitative Business Processes, Warmoesberg 26, 1000 Brussels, Belgium, liesje.deboeck@kuleuven.be, tel: +3226098272, fax: +3222176464 (corresponding author)

^bSia Partners Belgium, Henri Jasparlaan 128, 1060 Brussels, Belgium, siemen.vanasch@sia-partners.com

^cFaculty of Economics and Business, KU Leuven, Research Center for Operations Management, Naamsestraat 69, 3000 Leuven, Belgium, philippe.debruecker@kuleuven.be

^dUniversity of Antwerp, Faculty of Applied Engineering & Faculty of Applied Economics, Rodestraat 4, 2000 Antwerp, Belgium, amaryllis.audenaert@uantwerpen.be

Abstract:

In this paper a comprehensive evaluation of the support policy for photovoltaic installations in the residential sector of the major European markets (Flanders (Belgium), Germany, Italy, Spain and France) is carried out. To this end, the economic viability of a household investment in a photovoltaic installation is studied, employing a model based on the discounted cash flows of the installation over its lifetime. The results indicate that Italy's support system has been the most profitable out of the countries studied since 2010. In general, under current support policies, residential installations are still profitable in most cases, despite decreasing support levels, except for Spain. Furthermore, the paper demonstrates that self-consumption can significantly increase profits, especially in Spain and Germany. However, Flanders' policy has no effect on levels of self-consumption. Finally, a comparison of past and present policies shows the varying levels of success countries have enjoyed in keeping the profitability of investments stable over the years, depending on the efficiency of their support policy. Germany's support system might be considered the most balanced one over the last five years.

Keywords: profitability; residential photovoltaic installations; support policy in European Union; self-consumption

1. Introduction

In recent decades renewable energy sources have gradually come into the spotlight because of numerous factors such as rising energy prices, pollution and depletion of fossil fuels. Their rise to prominence accelerated in the last decade because of political agreements made on an international level, starting with the Kyoto protocol. The European Union has always been a frontrunner for a more ecological and sustainable world. In 2007 it established the target of increasing its share of renewable energy in total production to 20 % by 2020 (European Commission, 2007). Photovoltaic (PV) solar panels are an essential part of the outlined strategy for reaching this target in many countries (EREC, 2011). Governments worldwide have developed a number of different financial support systems, with the aim of making the technology a feasible alternative to traditional energy sources. These support measures have in many cases indeed succeeded, thereby greatly increasing global PV capacity. A study by the European Photovoltaic Industry Association (EPIA) shows that in 2013, over 138 GW of PV capacity had already been installed, with approximately 59 % coming from EU countries (EPIA, 2014). However, market penetration is not uniform across the EU: the same study shows a handful of countries account for most of the installed production capacity. Table 1 shows that Germany has by far the largest market in terms of total installed capacity in the EU, followed by Italy, Spain and France. Belgium is the sixth largest country in the EU with an installed PV capacity of 2.9 GW. When looking at the capacity installed per capita Germany, Italy and Belgium stand out from the pack, averaging more than 0.2 kW per inhabitant.

EPIA splits the European market into three segments: industrial, commercial and residential investors. The residential segment can be primarily distinguished from the commercial segment by the nature of the investor (private or public person), but also by the regime of retail electricity prices. In turn, the

industrial segment can be distinguished from the commercial by their respective electricity price contracts, with industrial investors often having negotiated nonstandard contracts due to the large volume of electricity they require. However, the segments also differ in terms of the average size and capacity of installations as well as the regulations and subsidies applicable.

This paper will focus on the residential PV segment. This segment is usually defined as consisting of all systems owned by residential households, generally rooftop-mounted and usually capped at a specific production capacity in terms of eligibility for the subsidy support scheme designed for residential investors. For example, in Germany, PV systems of up to 10 kWp are eligible for the most favorable subsidy rates, which are meant for residential household installations (Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, 2014). Since regulations and subsidy systems for every segment are very different in each country, the market share of each segment is not uniform across Europe. For example, in Belgium about 70 % of total PV capacity comes from residential installations, whilst in Germany residential installations account for less than 15 % of capacity (EPIA, 2014). Absolute numbers for the size of residential markets for all EU members are hard to establish, as each country's market is segmented differently due to different policies in terms of the maximum capacity of installations in a certain segment. In many countries no clear distinctions are made between segments, with some regulations being applicable to multiple segments, resulting in ambiguous numbers that cannot be used for a comparison between countries. The EU average residential market share in 2013 was estimated to be 22 % (EPIA, 2014).

This paper investigates the past and current levels of profitability of residential PV installations in the four largest EU markets - Germany, Italy, Spain and France - and Flanders (Belgium). Several papers have provided an overview of active support schemes in one or more EU countries and their results up to the point of publication. Both Dusonchet and Telaretti (2010) and Sarasa-Maestro et al. (2013) give an overview of the distinct support systems for photovoltaic development in most European Union countries. After this, a basic comparative economic analysis is carried out based on a simplified model using the internal rate of revenue as the key measure of performance. The results and conclusions are quite different for these papers. Some comparisons are rather superficial, leaving out relevant country-specific details and neglecting supportive subsidy schemes. In practice, these can have a large impact on the total investment profitability for the residential investors, making additional research valuable. Additionally, profitability within a certain country can also differ between geographic locations. Particularly in large countries, like the four major European markets (Germany, Italy, Spain and France) different solar irradiation zones might make an investment in a residential PV system more profitable in some regions than in others. Therefore, this paper includes multiple locations, all in different irradiation zones, for each of these major countries. The aim of this paper is to present a realistic scenario for potential residential investors that includes all relevant policy elements in each of the studied countries, and takes into account the different irradiation zones households may live in. The scenario is then thoroughly analysed in order to determine the economic attractiveness per location and how the policy elements in each country influence these results. Self-consumption, in particular, is not included or is at best treated superficially in many studies. In this paper self-consumption is not only treated as an essential driver of the achievable profitability of an investment, its significant potential for increasing revenue is further highlighted through a sensitivity analysis.

Next to this, most literature shows the attractiveness of an investment only at one date of recording. Campoccia et al. (2014) make a thorough analysis of residential PV profitability in a couple of EU markets. However, the study is limited to one specific date of record and uses dated investment cost estimates. Therefore, any comparison or judgment about policy efficiency is only valid for that specific moment in time. This is an important factor to take into account. Due to the rapidly decreasing cost of PV technology and ever-changing subsidy policies (Fraunhofer, 2015), profitability results obtained for one specific moment in time are not necessarily indicative for the effectiveness of governments' support policies in the longer run. Indeed, to achieve a high adoption level of PV technology in the residential sector, maintaining the economic attractiveness of the investment over a longer period of time can be important. A support policy that shows stable profitability at the moment of investment over a longer period of time, will positively influence investment decisions and increase the control governments have

over the amount of new capacity installed (Leepa and Unfried, 2013). This paper gives an indication of policy consistency and evolution over a wider timeframe by studying the investment profitability in the selected countries, not only at one recent time of recording, but over the past 5 years.

In the next section, a model is developed that accurately replicates the present and past design of support systems in each country. The third section presents the results by applying the model to a generic case. A sensitivity analysis checks the impact of a number of varying parameters. Also, an economic evaluation of investment profitability in previous years makes it possible to compare current and past support policies. The final section summarizes the most important findings.

2. Methodology

Policy makers have historically given the residential market segment a significant amount of attention when developing policies to support the adoption of PV systems (Avril et al, 2012). As a result, many different types of support schemes have been introduced across the EU. Battle et al. (2012) point out that the support methods for renewable energy sources for electricity (RES-E) can be categorized into two groups: *indirect* and *direct* support. Indirect methods include the funding of research and development for technology on the supply side and positive discriminatory regulations for RES-E technology. Another indirect support system that is becoming increasingly common in the EU is net metering or net billing. This system compensates residential producers on their electricity bill for electricity fed into the grid.

Direct support methods offer direct financial support for the demand-sided consumer. Both Battle et al. (2012) and Haas et al. (2011) distinguish between direct methods that are *quantity-based* and those that are *price-based*.

When using quantity-based support, the government sets a certain quota of renewable energy production and relies on the market mechanisms to establish a price. In the residential PV sector tradable green certificates (GCs) are the main quantity-based subsidy scheme. A green certificate is handed to a PV system owner after a predetermined amount of electricity has been produced. The green certificate price, and therefore the value of support for residential producers, is dependent on the size of the demand for certificates from the suppliers. Tradable green certificates have been the primary subsidy scheme for residential PV installations in the past decade for a few countries in Europe (Sarasa-Maestro et al., 2013) like Belgium, United Kingdom, Poland and Romania.

However, the primary subsidy schemes in the rest of the EU are mostly price-based. Governments offer a specified amount of support for RES-E technology which determines the market's demand and ultimately the amount of capacity installed. The most popular price-driven support scheme is the feed-in-tariff. Feed-in tariffs (FITs) remunerate producers for their production during a specified period. FITs guarantee a specific price for every unit of electricity produced or, depending on the particular legislation, for every unit fed into the electricity grid (this second option is more common in the EU). FITs have proved the most used support scheme in the EU for photovoltaics in the past decade. All the major photovoltaic markets within the European Union - Germany, Italy, France and Spain - are currently applying FITs for small residential PV installations or have used them in the recent past. Other price-based incentives include investment subsidy grants, tax credits and green loans that offer a reduced interest rate for investments in RES-E projects.

In most of the world's major markets the subsidy policy for photovoltaics in the last decade has consisted of either FITs or GCs combined with other supportive incentives such as grants, tax reductions or green loans. Worldwide more than 60 countries have put in place a subsidy system based on FITs, while 10 other countries implemented a certificate system (Del Río and Mir-Artigues, 2012). Table 2 summarizes all the different support measures discussed above. The support measures and specific remuneration conditions applicable in each country at the first of January since 2009 can be found in Table 3. Table 3 is not an exhaustive listing of all incentives available in each year. Instead, it represents the support schemes that are both possible and the most financially attractive under the generic case assumptions. For example, the subsidy on green loans available in Flanders up to 2012 is not included because the investment is completely self-financed with equity in the generic case. The self-consumption rate is 30 %, unless exporting all production into the grid is more profitable, in which case it is set at zero. It is

clear from Table 3 that over the past decade, FIT and GC reimbursement rates have dropped significantly in all countries employing them. This means that subsidy policies can usually not be regarded as being stable over a long period of time. Tariff degressions are very frequent. In most countries they are announced long beforehand to avoid investor uncertainty (Leepa and Unfried, 2013). Bazilian et al. (2013) indeed point out that to avoid excess profits for PV installation owners, policy makers have to keep up with the evolution of the PV market. They regularly re-evaluate subsidy policies and remuneration rates in order to keep them in line with the decreasing investment costs. It should be noted that many subsidies are not constant during a year but are updated monthly or quarterly. However, by recording the parameter values at the same date every year the evolution of support can be illustrated. The 1st of January is chosen as the date of record in each year. It should be noted that in Flanders and Spain retroactive adjustments were made to some subsidy rates. However, the purpose of this paper is to determine the investment attractiveness at the moment the investment decision is made, in other words: the perceived profitability at the moment of investment. Retroactive adjustments do not directly influence the investment decision as they cannot be predicted. As such, these adjustments should not directly influence adoption rate of new PV systems. Indirectly, repeated retroactive rate decreases can affect investor confidence, but this effect is beyond the scope of this paper.

In order to make a proper and relevant comparison of subsidy policies for photovoltaics between countries it is necessary to establish a common starting point for all the countries included. Therefore, the first part of this section presents a generic case of an investment in a residential PV installation on January 1st 2014 that will form the basis of the comparative research. The installation studied is rooftop-mounted with polycrystalline silicon panels (which are the most common ones (Leloux et al., 2012)). The investment will be financed entirely by equity, no loans are taken out to fund the purchase and installation cost of the PV modules. The further details of this generic case can be found in Table 4. The initial investment cost per kWp is uniform for all studied countries and based on the cost in a ‘mature’ PV market, i.e. the German market. This ‘mature’ market assumption reflects the ongoing convergence of system prices in the EU (Renewableenergyworld.com, 2011; EPIA, 2011). Furthermore, this assumption allows for the usage of the most recent investment cost estimates, directly from market surveys in Germany. Since prices for PV technology are decreasing rapidly, this method should deliver more accurate results than using more dated sources for all the studied countries. This paper does take into account the different VAT rates for PV systems in each country. The annual electricity price increase is also uniform as specific growth rates for the different countries are impossible to predict accurately and are assumed to balance each other out over the 25-year lifespan of the PV panels.

Further we assume that the residential PV installation produces the same amount of electricity in each location. However, as the electricity yield per unit of solar irradiation is different in every selected location, installed capacities will also differ. To determine the capacity of the installation in each location, the yearly irradiation values for each of the selected locations are requested in the European Commission Joint Research Centre PVGIS software tool. With this tool the energy produced per kWp (i.e. the yield) can immediately be calculated, taking into account both the specific solar irradiation of a location and the performance ratio (indicating at what rate solar irradiation is transformed into produced electricity). This ratio depends on the magnitude of system losses as well as on the orientation and slope of the installation. System losses are the result of the efficiency factor of the panels and the inverter and conduction losses in cabling. They are set at 14 %. As it is very rare for rooftop-mounted residential PV installations to have an optimal slope and orientation, we take into account a suboptimal slope of 45° and a south-eastern orientation. Together these inputs result in a performance ratio of approximately 76 %, which is consistent with assumptions often made in literature and with conducted surveys (EPIA, 2011; Leloux et al., 2012). For each country, three major cities are selected as studied locations. The first is located in the northern region of the country, the second is centrally located and the third is located in the south. In this way, the range of irradiation values in each country is adequately covered by having a location with low, middle and high solar irradiation. For Flanders only one location is selected as the differences between locations in this region are negligible. Table 5 shows the irradiation values, the yield for each selected city, the annual production and the required system capacity. The end-of-life value of recently installed photovoltaic

systems is hard to predict. It is unclear which method of disposal will be dominant in a few decades and what the associated costs of disposal will be. However, the impact of this unknown factor on the profitability of the residential owner is likely to be minimal. In 2014, the EU included solar waste in its Waste Electrical and Electronic Equipment (WEEE) Directive. The Directive dictates ‘extended producers responsibility’ for PV systems, i.e., producers are responsible for financing the taking back and disposing of PV modules. End-users will not have to pay any additional cost to dispose of their PV modules (solarwaste.eu, 2014). As each country is required to transform the WEEE Directive into national law, end-of-life value is assumed to be negligent for residential households and therefore can be omitted from the case study performed here.

To measure the performance of the presented case in each of the locations, we built an Excel model based on discounted costs and discounted revenues. Future cash flows are assumed to take place at the end of the year in which they are incurred or generated.

The total **costs** over an installation's lifetime are composed out of the three elements shown in Eq. (1). The first part represents the initial investment cost, obtained by adding the applicable VAT to the net investment cost (*NetC*) of the PV installation. The middle part of the equation is the cost for replacing the system's inverter. It is obtained by multiplying the installed capacity in kWp (*CAP*) by the replacement cost per kWp installed (*replaceC*). As replacement takes place halfway through the system's lifetime, its value is discounted in the 12th year. The third part represents the total present value of the annual maintenance and insurance costs. *m* is the percentage of the net investment cost spent on maintenance and insurance each year. *d* is the discount rate.

$$\begin{aligned} \text{Total costs} = & (\text{NetC} \times (1 + \text{VAT})) + \frac{(\text{CAP} \times \text{replaceC})}{(1 + d)^{12}} \\ & + \left[(m \times \text{NetC}) \times \frac{1 - (1 + d)^{-25}}{d} \right] \end{aligned} \quad (1)$$

The net investment cost (*NetC*) depends on the capacity installed as well as the VAT rate, as shown in Table 6. Since there are two VAT rates applicable in Flanders, they are evaluated separately. The VAT rate is 6% for installations placed on houses that are more than 5 years old. This is defined as ‘scenario Flanders a’. It is 21% for installations on houses that are not yet 5 years old, defined as ‘scenario Flanders b’. As stated in Table 4, the inverter replacement cost amounts to 200 €/kWp. Together, annual maintenance (0.5 %) and insurance costs (0.5 %) are 1 % of the *NetC*.

The first type of **revenue** from PV is gained through the *direct subsidy payments*, in the form of a feed-in-tariff or green certificates. These instruments are gradually losing their importance as the market matures. Italy and Spain have completely scrapped their subsidy tariffs for residential plants. In Flanders, green certificates are no longer available for new installations. In Germany and France a FIT for all electricity fed into the grid is still in force. In Italy, another type of direct subsidy, i.e., a tax deduction of 50%, is available. Half of the net investment cost can be recovered in the form of deductions from the household's tax bill in the first 10 years after the investment. Eq. (2) models the discounted value of these different types of direct PV subsidies.

$$\begin{aligned} \text{Direct subsidies} = & \sum_{i=1}^I \frac{\text{FIT} \times [(1 - s) \times ((\text{yield} \times \text{CAP})(1 - (i - 1)l))]}{(1 + d)^i} \\ & + \sum_{i=1}^I \frac{\text{GC} \times \frac{(\text{yield} \times \text{CAP})(1 - (i - 1)l)}{1000}}{(1 + d)^i} + \sum_{j=1}^J \frac{\frac{t \times \text{NetC}}{J}}{(1 + d)^j} \end{aligned} \quad (2)$$

The first two terms represent the discounted value of feed-in-tariffs and green certificates subsidies over the total period for which they are granted. *FIT* is the amount of money received per kWh fed into the grid and *GC* is the price at which PV users can sell their certificates, received for every 1000 kWh of production. *I* is the number of years these schemes provide pay-outs after investment. *Yield* is the amount of energy produced per kWp if the PV panels are in perfect condition. Yield values are found in the fourth column of Table 5. It should be noted that the $(\text{yield} \times \text{CAP})$ term is always 4500 kWh in the generic case. The self-consumption rate *s* needs to be included in the equation since only the part of

production fed into the grid and not self-consumed, i.e. $(I-s)$, is remunerated by most FITs. The annual degradation rate of the PV panels is represented by l . The third term depicts tax deductions, with J being the period they are active and t the percentage of the net investment cost that can be deducted. Table 3 shows that the applicable feed-tariff rate at the beginning of 2014 is 0.1368 €/kWh in Germany (Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, 2014) and 0.1454 €/kWh in France. In Italy, taking the example of Rome to illustrate the tax credit, investors can retrieve 2537.5 € of the 5075 € net investment in the generic case. This means that 253.75 € can be reclaimed annually for the first 10 years after the investment. To take full advantage of this incentive an income tax bill higher than the annual deduction is needed for each of the 10 years. It is assumed that this is always the case.

The second type of revenue from PV comes from *energy cost savings*. These are less straightforward to quantify than direct subsidies. One part of the savings on the electricity bill comes from the decrease in demand for energy from the grid. Since a share of the production from the PV installation is self-consumed, less energy is required from the grid. Of course, it is assumed that the household's electricity consumption level and pattern remains the same over the system's lifetime. The savings from self-consumption are represented by Eq. (3).

Self – consumption savings

$$= \sum_{n=1}^{25} \frac{[(CAP \times yield)(1 - (n-1)l)] \times s \times [P_1(1+g)^{n-1} + Z]}{(1+d)^n} \quad (3)$$

n is the year of operation with the total lifetime being equal to 25 years. P_1 is the retail household electricity price in the first year and g is the annual increase of the retail electricity price. Z represents possible self-consumption premiums. Currently these are not available in any of the countries studied, but they have been in the past and as such will be included when support in previous years is modelled. Table 7 gives an indication of the size of yearly self-consumption savings in the generic case by presenting the numbers for the first year. The electricity prices are retrieved from Eurostat (2013). As stated in Table 4, the self-consumption rate in the generic case is 30 %.

Besides self-consumption, the other part of savings on the electricity bill comes from *net metering schemes*, in so far as they are present in a particular country. Eq. (4) models the discounted savings possible from net metering. It consists of two different terms. The first represents the situation in year n where the amount of locally produced electricity that is fed into the grid ($Efed_n$), is smaller than the amount of electricity withdrawn from the grid, i.e., purchased from an electricity supplier ($Edrawn_n$). In this situation, savings on the electricity bill are realised by reimbursing the amount of electricity fed into the grid at the reimbursement rate r_n for that year. The second term represents the situation where the amount of energy fed in is actually larger than the amount withdrawn for that year. In this scenario, all the electricity purchased is reimbursed at rate r_n . In Italy, it is also possible to receive remuneration at rate h_n for the surplus of electricity fed into the grid as compared to withdrawals. Both r_n and h_n can be expressed as a percentage of the market electricity price P_n in year n . Eqs. (5) and (6) calculate respectively the electricity fed into the grid and the electricity withdrawn for year n . U represents the annual electricity consumption of the household.

Net metering savings

$$= \sum_{n=1}^{25} \frac{(Efed_n \times r_n)}{(1+d)^n} X + \sum_{n=1}^{25} \frac{(Edrawn_n \times r_n) + [(Efed_n - Edrawn_n) \times h_n]}{(1+d)^n} Y \quad (4)$$

X and Y are binary variables

$X = 1 \forall n$ for which $Edrawn_n > Efed_n$, $X = 0$ otherwise

$Y = 1 \forall n$ for which $Edrawn_n \leq Efed_n$, $Y = 0$ otherwise

$$Efed_n = [(CAP \times yield)(1 - (n-1)l)](1-s) \quad (5)$$

$$Edrawn_n = U - [(CAP \times yield)(1 - (n - 1)l)]s \quad (6)$$

To clarify the specific net metering schemes active in each country, the calculations for the first year of operation of the generic case installation ($n=1$) are demonstrated. Net metering is currently only possibly in Flanders and Italy. The generic case installation will generate 4500 kWh of electricity. Self-consumption is assumed to amount to 30 % of all energy generated, so 1350 kWh. The remaining 70 %, equal to 3150 kWh, is fed into the grid ($= Efed_1$). Since total household consumption over the year (U) is 4000 kWh, another 2650 kWh ($= Edrawn_1$) has to be drawn from the grid ($= 4000 - 1350$ kWh). The amount of energy fed into the grid is considerably larger than the amount withdrawn. In Flanders the reimbursement rate for electricity fed into the grid is equal to the electricity price ($r_n = P_n$). Since more electricity is exported than imported, the electricity bill at the end of the first year will be equal to zero. In Flanders, there is no remuneration for electricity fed in surplus of withdrawals, so $h_n = 0$. Hence, total net metering savings in Flanders are equal to the market value of the electricity drawn from the grid ($= 575 \text{ €} = 0.27 \text{ €/kWh} * 2650 \text{ kWh}$). Calculating the benefits from the Italian (Scambio sul Posto) net metering scheme is more complex. In Italy the electricity fed into the grid is not deducted from the bill at the full electricity retail price, as is the case in Flanders. The rate of reimbursement is less than the market price because charges and taxes, which make up a significant part of the retail electricity price, are excluded from the reimbursement rate. Hence, r_n is assumed to be 70 % of the market electricity price P_n (fotovoltaiconorditalia.it, 2013). With a market electricity price P_1 of 0.229 €/kWh (Eurostat, 2013), r_1 is equal to 0.16 €/kWh. As the amount of electricity fed into the grid is larger than the amount withdrawn, all of the purchased electricity can be compensated. This amounts to a reimbursement on the electricity bill of 424 € ($= 0.16 \text{ €/kWh} * 2650 \text{ kWh}$). As stated previously, an additional reimbursement is available for the surplus of electricity injected into the grid over the electricity drawn from it. In the first year of the presented case, this surplus amounts to 500 kWh ($= 3150 \text{ kWh} - 2650 \text{ kWh}$). The surplus is remunerated at a rate that represents only the net value of electricity, excluding not only taxes, but also network and other service costs. The raw price of electricity is assumed to be 50 % of the retail electricity price for households in Italy, i.e., h_n is equal to $0.5P_n$ (European Commission, 2014). The resulting reimbursement of the surplus amounts to € 57 ($= 0.5 * 0.229 \text{ €/kWh} * 500 \text{ kWh}$) in the first year. Summing up the two elements of the Scambio Sul Posto scheme, the total net metering compensation equals 481 € in the first year of operation. In Germany, Spain and France there is currently no legislation concerning net metering so no savings of this type are possible. Table 8 gives an overview of net metering savings in the first year.

As the aim of the model detailed above is to provide an estimation of the profitability of an investment in PV from the point of view of the average household, capital budgeting **evaluation criteria** are appropriate (Beliën et al., 2013). The first performance measure evaluated is the payback period (PBP). This measure indicates the number of years necessary for the investment to be recovered. From an economic point of view, it could seem rather inaccurate because it does not factor in the time value of money and it does not take into account the returns after the initial investment has been recovered. However, for the residential consumer, it is the most understandable and uncomplicated criterion available and many households rely primarily on a payback period calculation when considering an investment in PV. Since this paper aims to investigate the attractiveness of a PV investment from the perspective of the household investor, the PBP is an important evaluation criterion. The second criterion, the net present value (NPV), gives a more accurate picture. It calculates the total profitability of the investment over its operational lifetime by taking into account all ingoing and outgoing cash flows. Future cash flows are discounted to represent the time value of money. The third criterion is the internal rate of return (IRR). This is the percentage value for which the NPV of all cash flows resulting from the investment is zero. If the IRR is higher than the discount rate, then the investment is economically worthwhile. It is useful for ranking the profitability of different possible investments, or for the evaluation of an investment made in different countries, as is the case here.

3. Results and discussion

By applying the generic case assumptions to the developed model, the profitability of a PV investment in each location is obtained. The importance of each category of revenues for all countries is investigated. In the next part of this section, a sensitivity analysis is performed. The amount of electricity that is self-consumed, can affect the results obtained for the generic case. By varying this parameter, the total profitability of the PV installation is altered significantly in some countries, depending on their active support policies and the local electricity prices. Also, the effect of varying the discount rate, the electricity price growth rate and the panel degradation rate is checked. These are uncertain and uncontrollable parameters that could possibly turn out to have values that deviate from the assumptions in the generic case. In the last part, the evolution of the profitability of a PV installation over time is investigated by applying the support policies used in previous years to the model.

3.1. Results for the generic case

Table 9 shows the results for the generic case. Both the 6 % and 21 % VAT scenarios in Flanders offer a PBP of respectively 9 and 10 years for investors, figures which seem very reasonable and should be able to encourage households to invest in PV installations. The claim of the Flemish Energy Agency (VEA) - that under current market conditions green certificates are no longer necessary in order to obtain a return on investment of at least 5 % (VEA, 2013) - is confirmed by Table 9. Along the same lines, the NPV and IRR show that an investment in PV guarantees a high level of profitability. Germany and France perform worse than Flanders on all three evaluation criteria, having a longer PBP and a lower NPV and IRR in all locations. Nevertheless, German households can still be assured of a reasonable profit. In France, the attractiveness of the investment very much depends on the location. In the north (Paris region), the NPV is negative, while in the center and south of the country reasonable profitability can be assured. Italy is by far the best performer, showing a payback time of only 6 years in all three locations. The NPV is approximately double that of Flanders and the IRR of the investment ranges from 16.7 % in the north to 19.6 % in the south. PV system owners in Italy clearly profit from the simultaneous availability of a direct subsidy (tax credit) and a net metering regulation. The most remarkable result is the very poor performance of Spain. Despite having the location with the highest solar irradiation of all studied countries (Seville), the NPV is still negative there, while the IRR is far below the discount rate, which will discourage profit-seeking residential investors. In the center and north of Spain, investment is even less attractive.

In Figure 1 the discounted cumulative cash flows are represented. For clarity, only the centrally located city of each country is included in the figure (Brussels, Frankfurt, Rome, Madrid and Lyon). The other locations in a country have a similar graph pattern as the centrally located ones, but follow a slightly higher or lower trajectory because of a difference in investment cost. Initial investment costs are generally lowest in Spain, Italy and France, where the solar irradiation is highest and the smallest capacities are installed. The extensive level of support in Italy and the lack of any kind of support mechanism in Spain is immediately clear. The inverter replacement accounts for the drop in the cumulative cash flow in year 12. In both Germany and France, the rising trend diminishes after the 20th year because FIT payments end. Since Figure 1 shows discounted cash flows, the point in time in which the cumulative cash flow is more than zero actually shows the discounted PBP. This is several years longer for each country than the regular PBP in Table 9. In Spain (Madrid) the investment is never paid back according to the discounted PBP.

Figure 2 shows the composition of the total lifetime revenues of the PV installation in each country for the centrally located city. Since the total production is the same everywhere (4500 kWh), the total revenue of the PV system will be the same for each location within a country. In France the possible self-consumption savings are the lowest because of the low electricity price. Since German electricity prices are very high, the savings possible from self-consumption are the highest here. In the other countries, the self-consumption savings are almost the same because of similar electricity prices. Due to a lack of any supportive regulations for household PV systems in Spain, total revenue is significantly lower than in other countries. Net metering accounts for a large share of the total revenues in Flanders and Italy.

Because only 30 % of the electricity produced is self-consumed in the generic case, up to 70 % of the production can be remunerated using this mechanism. Indeed, because the electricity fed into the grid is larger than the amount withdrawn in most years, the exported electricity compensates fully (at the retail electricity price) all of the electricity drawn over the year. Only in the final years of the installation's lifetime does the amount of exported electricity becomes smaller than the amount withdrawn due to degradation of the panels. The Italian net metering savings are less because the exported electricity is only partially compensated at a rate below the retail price.

3.2. Sensitivity analysis

In the previous section, the results obtained were determined by a number of assumptions, based on a careful literature study and up-to-date information concerning the retail PV market. Because the goal is to provide well-balanced and critical results, the assumptions made are rather conservative. To this end, two additional analyses are carried out. In the first analysis, the effect of self-consumption on the total profitability of the investment is investigated. In the second analysis, the combined effect of a number of uncontrollable and uncertain parameters is studied with the help of a Monte Carlo simulation. Unless stated otherwise, all other parameters remain at the value assumed in the generic case. All the results in this section will be in terms of net present value.

There is a global trend towards more **self-consumption** in the PV sector. Self-consumption reduces the need for active subsidy support, in the form of FITs and net metering. At the same time, it also reduces administrative costs and the burden imposed on the electricity grid because less electricity is drawn from and fed into the grid. The self-consumption rate of generated electricity is fixed at 30 % in the generic case. However, it is possible for households to increase this share by changing their consumption patterns. Of course there are limits to this possibility. A certain amount of electricity will always be required in the evenings and during the night, for lighting and keeping appliances running. The percentage value of the self-consumption parameter is increased in increments of 10 %, starting from zero. Although high self-consumption rates of 70 % or more are unrealistic in most cases, it could be possible that a small capacity system is combined with a high level of consumption. High rates can also represent the use of PV storage technology. As the possibility for self-consumption is limited to the part of the day in which sufficient solar irradiation (daylight) is available, storage technology could greatly improve the amount of self-consumption possible. Battery systems are slowly finding their way onto the residential PV market. However, these storage systems are still costly and need subsidies to be profitable. A full study of the effect of storage systems on the total profitability of a residential PV system is beyond the scope of this paper. The results in Figure 3 indicate a positive effect on the NPV of an investment as the self-consumption rate of the household increases in most countries. It should be noted that self-consumption rates above 88.88% are not possible for the generic case, as indicated by the striped lines. That is because the household consumption level in the generic case is only 4000 kWh whereas the installation produces 4500 kWh.

Only the central locations in each country are included in the figure, as the other locations show only slightly different results. Spain and Germany show the greatest rise in profitability for every increase in the self-consumption parameter value. In Spain, the investment becomes profitable at approximately 40 % self-consumption. If 70 % or more is consumed on-site, the NPV is about the same as Flanders. Because of the high solar irradiation, an increased level of self-consumption can make the generic case investment profitable without any need for support. Although solar irradiation is much smaller than in Spain, German PV owners can also gain significantly higher profits by increasing their share of self-consumption. The combination of a high electricity price and a FIT that is much lower than the electricity price, encourages PV users to consume as much of their generated electricity as possible. The German government is one of the first countries in the world to begin subsidizing PV storage systems (PV-tech, 2013). This means higher self-consumption rates and the resulting higher lifetime profits could indeed be easily attainable in the near future in Germany. In France the incentive for self-consumption is limited because of the low electricity prices. At the moment, electricity prices are only slightly higher than the FIT rate, so the benefit from self-consuming rather than exporting to the grid is minimal. Flemish households do not have any incentive to consume their own produced electricity. As Figure 3 shows,

profits stay the same no matter how much production is consumed on-site. This is caused by the design of the Flemish net metering scheme in which each kWh of electricity produced can be fed into the grid, for a reimbursement that is equal to the retail electricity price. Hence, either produced electricity is self-consumed and a kWh less has to be purchased from the electricity supplier, or it is exported in which case it is reimbursed at the retail price thanks to the net metering scheme. In other words, there is no need for self-consumption as the Flemish' net metering scheme allows for the same amount of savings. The household electricity bill will amount to zero at the end of the year as long as the amount of electricity produced over that year is higher than the amount withdrawn. From the government's point of view, this policy is counterproductive in economic terms. Net metering results in a higher market electricity prices as electricity suppliers pass on the costs to consumers. Self-consumption can have the same savings impact for households as this net metering scheme, while decreasing the burden on the electricity grid (which lowers the need for grid capacity investments). However, the net metering scheme makes households indifferent as to whether they are self-consuming or not. Net metering is a useful tool to reward household PV owner for their PV production. Unfortunately, the full retail price paid out in the Flemish scheme, disincentives self-consumption and reduces its positive impacts. The Italian net metering scheme makes more sense from this perspective. By only partly compensating for electricity fed into the grid, self-consumption is still encouraged as it results in larger savings than the net metering reimbursement for purchased electricity. A partial reimbursement net metering scheme could also remove the need for a grid compensation fee, payable by all PV owners, which the Flemish electricity grid operators are demanding to be introduced. Indeed, currently Flemish PV owners pay no contribution for the use of grid, while they burden it twice as much as other consumers (by both feeding and drawing electricity from the grid). Grid operators claim that some sort of adjustment is needed. The demanded grid compensation fee was introduced in 2013, but was repealed shortly after because it was judged as unlawful. Now other methods, like a new tax, are being thought of to eliminate the imbalance (Izen, 2013). A partial reimbursement net metering scheme, which values all production fed into the grid at the price of raw electricity instead of the retail price, could present a more elegant solution. However, this does require the replacement of the mechanical electricity meters, currently present in most households in Flanders, by 'smart' digital meters. The mechanical meters simply count forward when electricity is drawn from the grid and backward when electricity is fed into the grid. Digital meters can actually count the amount of electricity injected into and drawn from the grid separately, making specific net metering reimbursement rates possible. PV storage technology currently has the most potential in Germany and Spain. In those countries a higher amount of self-consumption can greatly increase the profitability of a PV installation. Due to the partial net-metering mechanism in Italy and the small difference between the electricity price and the FIT rate in France, PV storage has less potential in those countries at the moment. In Flanders, it is currently rather useless because of the current net metering scheme.

Most of the assumptions made for the generic case are stable at the predetermined value, either because they are part of legislation, such as subsidy rates, or because they have been observed in real world situations (current electricity prices, system costs, panel yield). The household consumption level and the self-consumption rate are within the control of the PV system owner. However, there are three **uncontrollable parameters** that cannot be determined at a specific value with any certainty. The future growth of the household electricity price (g) can only be forecasted, and depends on numerous factors. The discount rate applicable for the investment (d) is dependent on the long-term inflation rate and the investment risk in the country in question. Both evolve over time as economic conditions change. The third unknown parameter is the PV panel degradation rate (l). Several longitudinal studies have been performed in the past that give an indication of how older PV systems perform. It is, however, impossible to measure the degradation rate of more recently manufactured PV panels over 25 years. The potential impact of these future uncertainties on the investment profitability are analysed with a Monte Carlo simulation (1000 iterations) in which the NPV for each country's central location is calculated with randomly generated values for the three uncertain parameters. The annual electricity price growth (g) is assumed to be normally distributed with a mean of 3 % and a standard deviation of 1.5 %.. This implies that it is 90 % likely to be 5 % or less, which is also the highest value of the forecasted scenarios in EPIA

(2011). The discount rate (d) is also normally distributed with a mean of 5 % and a standard deviation of 1 %. This represents a fluctuation of adjusted long-term government bond interest rates around a likely level of 3 %, while the risk premium of the investment remains constant at 2 %. The degradation rate (l) is lognormally distributed with a mean of 0.5 % and a standard deviation of 0.25 %. These values were based on data in Jordan and Kurtz (2013), which indeed show that the reported degradation rates of past studies are right-skewed. Table 10 summarizes the parameter distributions and values. Figure 4 shows the results for each country's central location in a Tukey box plot. The simulation indicates satisfactory results in Italy (Rome), with a NPV of about 5000 € in case of bad future conditions and up to 17000 € in the best scenarios. In Flanders (Brussels), there is also a lot of potential for additional profits as compared to the generic case for both scenarios (up to 15000 € for Flanders a and 14000 € for Flanders b). Only in the case where the 21 % VAT rate on the investment is applicable, a small negative NPV is possible, but this is very unlikely. These results indicate that risks are minimal in Flanders and Italy and uncertainty about profitability should not deter careful residential households. Even if all three uncertain parameters have very poor values from a profitability perspective, the NPV is extremely unlikely to be negative. In the best cases, the NPV more than doubles as compared to the generic case in these countries. This shows that there is a lot of potential for additional profits. Therefore, from an investor's point of view, an investment is always advisable in these countries. Germany (Frankfurt) shows a negative NPV for a small fraction of the Monte Carlo iterations, but the risks are fairly limited. Positive profits can be assured if not all parameter values have poor values. However, the upside potential in good scenarios is restricted as compared to Italy and Flanders with an upper limit of about 6000 €. Installations in France (Lyon) have a slightly negative NPV in 25 % of the scenarios. Hence, there is certainly some uncertainty about the future profitability of PV installations in France as a consequence of the unpredictability of the studied parameters. In Spain (Madrid), the NPV is negative for the generic case and for more than 75 % of the Monte Carlo iterations as well. In the best case, a small positive NPV is achievable, but the probability of very small. Investment in Spain is currently unlikely to be profitable, even if the three uncertain parameters should have favorable values.

3.3. Support history

We now analyse the evolution of PV support schemes over recent years by relying on Table 3. The data in Table 3 are fed into the model and the IRR is chosen since it is the most suitable performance measure to evaluate the profitability of a PV investment over the years (the NPV is not appropriate since the initial investment values differ over the years; the PBP is not appropriate because it favours years where the combination of support incentives is frontloaded). Figure 5 shows the IRR for each country's central location from 2009 until 2014. Except for 2009, Italy has the highest result every year. The high support levels make investment interesting but it could be argued that support was rather inefficient from the government's perspective. Because budget caps set quotas on the number of new PV systems eligible for support, not all potential investors could be reached. Only the ones that registered their installation the earliest could benefit from the high IRR, the others received no support. Lower rates could have attracted more investors at the same budget cost. Flanders' support is the highest in 2011. Around this time, Flemish policy makers started to realize subsidies were too high. PV investors were able to make windfall profits while the price of grey electricity for all other consumers rose as the cost of the subsidies trickled down to their electricity bill. Residential investments skyrocketed in that year, as households scrambled to install PV system before lower subsidy rates became active. Installed capacity more than doubled in 2011 (Jespers et al., 2013). The IRR falls to a more balanced level after the restructuring of the green certificate scheme. However, subsequent to the 2011 'boom', the market collapsed, with significantly less capacity added in the following years. The lack of stability in the subsidy policy discouraged a lot of potential investors and had an adverse effect on many businesses in the PV sector. These results show that the government should have adapted green certificate values faster, in order to provide a more stable investment attractiveness by reducing the overly high profits possible up to 2011, followed by a market stagnation afterwards. This confirms the conclusion made by Beliën et al. (2013) that PV in Flanders was over-subsidized during this period. Germany's support system has arguably been the most balanced over the period studied. Until 2012, the IRR is lower than in the other countries studied. However, it is

also clearly the most stable subsidy scheme with the IRR at a constant level between 6 and 8 %. This level offers a very reasonable level of profitability for potential investors while not increasing government's support costs more than necessary. Since the IRR is very constant over the years, households also feel less pressure to make an investment decision before a certain date, reducing the adverse effects of 'booms' and 'busts' in newly installed capacity. This stability plays a large role in the high adoption rate of residential PV in Germany during the studied time period, which consistently shows the most newly capacity installed each year out of all EU countries (except for 2011, in which Italy installed more) (EPIA, 2013). This shows that not only the projected profitability of a PV system is important for potential investors, but a stable and transparent subsidy policy that is easily available can also be a critical success factor for the wide scale adoption of PV systems. France's support shows a similar consistency, aside from an outlying result in 2010. However, a trend is visible in the IRR slowly decreasing ever since. Spain has attractive rates of return up to the moment FITs are abolished half-way through 2012. Yet, this result doesn't tell the entire story. Spain already encountered an uncontrolled 'boom' in PV deployment in 2008, because of a poorly set-up tariff scheme that handed out excessive subsidies to large-scale investors. After this early surge in deployment, government set up strict capacity quotas and introduced much lower tariffs, which significantly slowed down the residential market. Finally in 2012, the Spanish government, looking for ways to cut the spending budget, completely abolished all tariffs for PV. Clearly, this further reduced not only the financial attractiveness of investment, but also the confidence of potential investors. The Spanish example again shows the dangers of an uncontrolled 'boom' caused by an unstable IRR and the need for a balanced and thought-out subsidy policy. The increase in IRR from 2013 to 2014, however, indicates that residential PV systems could become profitable again in the years to come because of the combination of dropping system prices and rising household electricity costs.

4. Conclusions

In this paper a model is presented that measures the profitability of a residential household roof-top PV installation in the major European Union countries. Profits emerge from two different sources. Firstly, some countries offer direct subsidies in the form of feed-in-tariffs for electricity fed into the grid and tax credits. Secondly, a PV installation also generates savings on the household electricity bill in two ways. The amount of grid electricity needed can be reduced because part of the PV installation's production is self-consumed. In addition, the electricity withdrawn from the grid can be offset against the installation's excess production in countries employing a net metering support system. A realistic case for an investment in a PV installation is developed, using a series of assumptions that are representative for an average household in the EU. To take into account the impact of different levels of solar irradiation within countries, different locations are included for each country (except for the small region of Flanders). The results show that different locations within a country, which are eligible for the same support measures and face the same investment costs, can indeed have a significantly different investment profitability because of the difference in irradiation levels.

In Flanders, although all direct support measures have been abolished over recent years, residential households are guaranteed a solid profit margin on their investment. This is in line with the claim of the Flemish Energy Agency (VEA) which states that the recently abolished green certificates were no longer necessary in order to guarantee at least a 5 % return on the investment. The net-metering scheme currently in place offers adequate returns over the lifetime of the PV installation. Nevertheless, the Flemish policy can certainly be improved upon. The net metering scheme is set up such that self-consumption of produced electricity by households is not encouraged, making households indifferent as to whether they use the electricity themselves or feed it into the grid. Italy's support is the most profitable for residential investors. The combination of net metering and a very generous tax credit of 50 % leads to the highest level of profitability and the lowest payback period of all countries included in the study. However, it could be argued that an IRR of 16 - 18 % is much higher than should be necessary to attract investors, and wastes budget resources. Germany and France are the only two countries included in this paper that still use FITs. In Germany, the IRR ranges from 6.9 % in the north to 7.6 % in the south. This profit

performance should be adequate to attract investors across all irradiation zones in the country, under the assumptions made. Since the German FIT is much lower than the household electricity price, self-consumption is strongly encouraged. In France, irradiation levels vary significantly between the north and south. Hence, profitability is rather dependent on the location of the PV system, with an IRR of no more than 3.8 % in the northern region, as compared to 8.4 % in the south of the country. The difference between the electricity retail price and the FIT rate in France is minimal. Therefore, there is much less incentive for self-consumption than in Germany. Spain is the only country included that currently does not offer any kind of support measure to residential PV investors. Hence, a residential PV investment similar to the generic case is currently not economically interesting with a payback period that spans almost the entire installation's lifetime. Despite the high level of solar irradiation, the IRR is still only 3.3 % in the south of the country. However, these high solar irradiation levels in combination with the high electricity prices, result in a strong incentive for self-consumption. Therefore, smaller capacity installations, that enable owners to self-consume as much produced electricity as possible, are likely to be more appropriate for the Spanish residential market.

After the analysis of the present situation, the evolution of support over recent years in the different countries is compared. The support history indicates that the highest possible profitability level does not always equate to the best policy. A stable and consistent policy reduces the highs and lows in investor demand and leads to a more manageable steady growth of the market. Italy has offered the highest IRR in all years since 2009. Although the high IRR could attract a lot of interest, the subsidies only benefited the investors who were able to register their PV installation first, before the set quotas were filled up. Profitability for households was much higher in Flanders in the past. Up to 2012, the IRR was very close to the Italian level. The abolition of the green certificate system has since brought down the excessively high potential profitability to a more balanced level. Germany and France managed to keep the IRR fairly stable over the years. Germany in particular does well because of the continuously monitored FIT system, in which the tariff is reduced quarterly at a rate dependent on the number of new PV installations in the previous quarter. Spain stands in sharp contrast to this approach. It had an appealing IRR, until the FIT was abolished in 2012 because of the excessive support costs for the government. Now, profits are possible only under very favourable conditions.

When comparing the studied countries, the stability of the German support system should be encouraged, as this reduces government's support costs and investor uncertainty. At the same time it is recommendable to avoid the mistakes made by Spain and the unnecessarily high profits in Flanders up to 2012 and Italy.

References

- Avril, S., Mansilla, C. Busson, M. Lemaire, T., 2012. Photovoltaic energy policy: Financial estimation and performance comparison of the public support in five representative countries. *Energy Policy* 51, 244-258
- Battle, C., Pérez-Arriaga, I.J., Zambrano-Barrágan, P., 2012. Regulatory design for RES-E support mechanisms: Learning curves, market structure and burden-sharing. *Energy Policy* 41, 212-220.
- Bazilian, M., Onyeji, I., Liebreich, M., MacGill, I., Chase, J., Shah, J., Gielen, D., Arent, D., Landfear, D., Zhengrong, S., 2013. Re-considering the economics of photovoltaic power. *Renewable energy* 53, 329-338.
- Beliën, J., De Boeck, L., Colpaert, J., Cooman, G., 2013. The best time to invest in photovoltaic panels in Flanders. *Renewable Energy* 50, 348-358.
- Bhandari, R., Stadler, I., 2009. Grid parity analysis of solar photovoltaic systems in Germany using experience curves. *Solar Energy* 83, 1634-1644.
- Bundesnetzagentur, 2014. Photovoltaikanlagen: Datenmeldungen sowie EEG-Vergütungssätze, 2014. Retrieved April 1, 2014, from bundesnetzagentur.de: http://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/DatenMeldgn_EEG-VergSaetze/DatenMeldgn_EEG-VergSaetze_node.html.
- Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, 2014. Bestimmung der Vergütungssätze für Fotovoltaikanlagen nach § 32 EEG für die Kalendermonate Februar 2014, März 2014 und April 2014. Retrieved May 1, 2014, from http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/Datenmeldungen/EEGVerg_FebApril2014.xls?__blob=publicationFile&v=2.
- Del Río, P., Mir-Artigues, P., 2012. Support for solar PV deployment in Spain: Some policy lessons. *Renewable and Sustainable Energy Reviews* 16, 5557-5566.
- Dusonchet, L., Telaretti, E., 2010. Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European Union countries. *Energy Policy* 38, 3297-3308.
- ECB, 2014. Long-term interest rate statistics for EU Member States. Retrieved January 5, 2014, from European central bank: <http://www.ecb.europa.eu/stats/money/long/html/index.en.html>
- Eclareon, 2013. PV grid parity monitor - Residential sector 2nd issue.
- EREC, 2011. Mapping Renewable Energy Pathways towards 2020, EU roadmap
- EPIA, 2013. Global market outlook for photovoltaics 2013-2017.
- EPIA, 2014. Global market outlook for photovoltaics 2014-2018.
- EPIA, 2011. Solar Photovoltaics Competing in the Energy Sector – On the road to competitiveness
- EPRI, 2010. Addressing Solar Photovoltaic Operations and Maintenance Challenges, A Survey of Current Knowledge and Practices. 7.
- European Commission, 2007. The 2020 climate and energy package. Retrieved January 5, 2014, from http://ec.europa.eu/clima/policies/package/index_en.htm
- Eurostat, 2013. Electricity and natural gas price statistics. Retrieved January 5, 2014, from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_and_natural_gas_price_statistics
- Fotovoltaiconorditalia.it., 2013. Lo scambio sul posto fotovoltaico: guida completa. Retrieved February 2, 2014, from fotovoltaiconorditalia.it: <http://www.fotovoltaiconorditalia.it/idee/scambio-sul-posto-fotovoltaico-guida-completa>.
- Fraunhofer ISE, 2013. Photovoltaics report. Retrieved May 17, 2015, from <http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf>

- Fraunhofer ISE, 2015. Current and Future Cost of Photovoltaics, Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems. Retrieved May 15, 2015 from euractiv.com: http://www.euractiv.com/files/euractiv_agora_solar_pv_study.pdf
- Haas, R., Resch, G., Panzer, C., Busch, S., Ragwitz, M., Held, A., 2011. Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources - Lessons from EU countries. *Energy* 36, 2186-2139.
- Izen, 2013. Uitspraak klacht tegen netvergoeding: toelichting en gevolgen. Retrieved April 28, 2014, from [izen.eu](http://www.izen.eu/be/professioneel/nieuws_2/zonnepanelen/uitspraak-klacht-tegen-netvergoeding-toelichting-en-gevolgen/): http://www.izen.eu/be/professioneel/nieuws_2/zonnepanelen/uitspraak-klacht-tegen-netvergoeding-toelichting-en-gevolgen/.
- Jespers, K. K. Aernouts, Y., Dams, Y., 2013. Inventaris duurzame energie in Vlaanderen 2012 DEEL I: hernieuwbare energie. Mol: Vito NV.
- Jordan, D.C., Kurtz, S.R., 2013. Photovoltaic Degradation Rates—an Analytical Review. *Progress in Photovoltaics* 21, 12-29.
- Leepa, C., Unfried, M., 2013. Effects of a cut-off in feed-in tariffs on photovoltaic capacity: evidence from Germany. *Energy Policy* 56, 536-542.
- Leloux, J., Navarte, L., Trebosc, D., 2012. Review of the performance of residential PV systems in Belgium. *Renewable and Sustainable Energy Reviews* 16, 178-184.
- Solarwaste, 2014. Retrieved May 15, 2015 from [solarwaste.eu](http://www.solarwaste.eu/) <http://www.solarwaste.eu/>
- Nextville, 2014. Archivio incentivi. Retrieved April 1, 2014, from [Nextville.it](http://www.nextville.it/Archivio/97/Archivio_incentivi): http://www.nextville.it/Archivio/97/Archivio_incentivi.
- Renewableenergyworld; 2011. European Solar Module Prices Converge Retrieved May 15, 2015 from [Renewableenergyworld.com](http://www.renewableenergyworld.com): <http://webcache.googleusercontent.com/search?q=cache:GekXDQiVBOQJ:www.renewableenergyworld.com/rea/news/article/2011/10/european-solar-module-prices-converge+&cd=3&hl=en&ct=clnk&gl=be>
- Photovoltaik-guide, 2014. Retrieved January 28, 2014, from [Photovoltaik-guide.de](http://www.photovoltaik-guide.de/): <http://www.photovoltaik-guide.de/pv-preisindex>.
- Photovoltaïque.info, 2014. Tarif d'achat. Retrieved April 1, 2014, from [Photovoltaïque.info](http://www.photovoltaïque.info/-Tarif-d-achat-.html): <http://www.photovoltaïque.info/-Tarif-d-achat-.html>.
- Polverini, D., Field, M., Dunlop, E., Zaaiman, W., 2013. Polycrystalline silicon PV modules performance and degradation over 20 years. *Progress in Photovoltaics* 21, 1004-1015.
- PV Parity, 2012. Electricity prices scenarios until at least the year 2020 in selected EU countries. München.
- PVGIS, 2014. Performance of Grid-connected PV. Retrieved January 25, 2014, from <http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php>.
- PV-Tech, 2013. New German subsidy kickstarts solar storage market: IHS. Retrieved December 1, 2013, from http://www.pv-tech.org/news/new_german_subsidy_kickstarts_solar_storage_market_ihs.
- Sarasa-Maestro, C.J., Dufo-López, R., Bernal-Agustín, J.L., 2013. Photovoltaic remuneration policies in the European Union. *Energy Policy* 55, 317-328.
- SMA, 2010. The self-consumption bonus. Retrieved January 25, 2014, from [sma.de](http://www.sma.de/en/solutions/medium-power-solutions/knowledgebase/the-self-consumption-bonus.html): <http://www.sma.de/en/solutions/medium-power-solutions/knowledgebase/the-self-consumption-bonus.html>.
- Suelosolar, 2014. Tarifa Actual Energía Solar Fotovoltaica. Retrieved April 1, 2014, from [Suelosolar.es](http://www.suelosolar.es/tarifa.asp#otras): <http://www.suelosolar.es/tarifa.asp#otras>.
- VEA, 2013. <http://www.energiesparen.be/groenestroomcertificaten>. Retrieved December 27, 2013, from [Energiesparen.be](http://www.energiesparen.be/groenestroomcertificaten): <http://www.energiesparen.be/groenestroomcertificaten>.
- VEA, 2013. Rapport 2013/3 Deel 2: actualisatie OT/Bf.
- Wietze, L., Kruseman, G., 2008. Long-term price and environmental effects in a liberalised electricity market. *Energy Economics* 30, 230-248.
- VREG, 2013. Certificatensysteem voor nieuwe zonnepanelen 2013. Retrieved December 27, 2013, from [vreg.be](http://www.vreg.be/certificatensysteem-voor-nieuwe-zonnepanelen-vanaf-2013): <http://www.vreg.be/certificatensysteem-voor-nieuwe-zonnepanelen-vanaf-2013>.

World Energy Council, 2013. Average electricity consumption per electrified household. Retrieved November 1, 2014, from <http://www.wec-indicators.enerdata.eu/household-electricity-use.html>.

Country	Total PV capacity (MW)	kW/Inhabitant
Germany	35715	0.436
Italy	17928	0.294
Spain	5340	0.116
France	4673	0.071
Belgium	2983	0.268
Rest of Europe	14849	Not available (NA)

Table 1: Cumulative total PV capacity in 2013 (EPIA, 2014)

Indirect methods	R&D subsidies	
	Net metering	
	RES-E obligation for new housing	
Direct Methods	Quantity-driven	Green certificates (GCs)
		Tendering schemes
	Price-driven	Feed-in-tariff (FIT)
		Capital grants
		Fiscal incentives
		Green loans

Table 2: RES-E support schemes

		2009	2010	2011	2012	2013	2014
Flanders	GC: (€/1000 kWh)	450	350	330	250	21	NA
	<i>Period of eligibility</i>	20 yrs. ^a	20 yrs.	20 yrs.	20 yrs.	20 yrs.	
	Net metering ^a	MEP	MEP	MEP	MEP	MEP	MEP
	Tax credit (on gross investment)	40 %	40%	40%	NA	NA	NA
Germany	FIT (€/kWh)	0.4301	0.3914	0.2874	0.2443	0.1702	0.1368
	Self-consumption premium (€/kWh)	0.2501	0.2276	0.1236	0.0805	NA	NA
	<i>Period of eligibility</i>	20 yrs.	20 yrs.	20 yrs.	20 yrs.	20 yrs.	20 yrs.
Italy	FIT ^a (€/kWh)	0.412 ^b	0.403 ^b	0.377 ^b	0.247 ^b	0.196	NA
	Self-consumption premium (€/kWh)	NA	NA	NA	NA	0.114	NA
	<i>Period of eligibility</i>	20 yrs.	20 yrs.	20 yrs.	20 yrs.	20 yrs.	NA
	Net metering ^a	PR	PR	PR	PR	NA	PR
	Tax credit (on net investment)	NA	NA	NA	NA	NA	50%
Spain	FIT (€/Kwh)	0.34	0.34	0.3135	0.2738	NA	NA
	<i>Period of eligibility</i>	25 yrs.	25 yrs.	25 yrs.	25 yrs.	NA	NA
France	FIT (€/kWh)	0.328	0.42	0.3035	0.2249	0.1817	0.1454
	<i>Period of eligibility</i>	20 yrs.	20 yrs.	20 yrs.	20 yrs.	20 yrs.	20 yrs.
	Tax credit (on gross investment)	50 %	50%	22%	11%	11%	NA

^a yrs stands for 'years', MEP stands for 'at market electricity prices'; PR stands for 'partial reimbursement'.

^b In Italy, up to 2012 the FIT is available for all electricity produced rather than for the share of electricity fed into the grid, which is the case in all other countries offering FITs.

Table 3: RES-E support schemes for a residential PV installation in Flanders (Belgium), Germany, Italy, Spain and France on the first of January since 2009 (Sources: Photovoltaik-guide (2014), VREG (2013), Bundesnetagentur (2014), Nextville (2014), Suelosolar (2014), Photovoltaïque.info (2014))

Parameter	Value	Reference(s)
Life expectancy panels	25 years	Beliën et al. (2013)
Annual electricity production	4500 kWh	Leloux et al. (2012), Beliën et al. (2013)
Total net cost per kWp	1500 € (no loan)	Photovoltaïk-guide (2014)
Inverter replacement period	12 years	Fraunhofer ISE (2014)
Inverter replacement cost	200 €/kWp	Fraunhofer ISE(2014)
Yearly degradation rate of PV panels	0.5 %	Jordan and Kurtz (2013), Polverini et al. (2013)
Annual maintenance cost	0.5 % (of net investment cost)	EPRI (2010)
Annual insurance cost	0.5 % (of net investment cost)	Requested quotations from specialized PV insurers
Self-consumption rate	30% or 1350 kWh	SMA (2010)
Total annual household consumption	4000 kWh	World Energy Council (2013)
Yearly electricity price increase rate	3%	EPIA (2011); PV Parity (2012); Wietze and Kruseman (2008); Bhandari and Stadler (2009)
Discount rate	5%	ECB (2014); Eclareon (2013)

Table 4: The assumptions for the generic case of an investment in a residential PV installation

Country	City	Irradiation (kWh/m ² per year)	Yield (kWh/kWp per year)	Annual production (kWh)	Installation capacity (kWp)
Flanders	Brussels	1180	899	4500	5
Germany	Berlin	1180	899	4500	5
	Frankfurt	1210	925	4500	4.865
	Munich	1240	952	4500	4.727
Italy	Milan	1560	1180	4500	3.814
	Rome	1780	1330	4500	3.383
	Palermo	1890	1410	4500	3.191
Spain	Bilbao	1390	1050	4500	4.286
	Madrid	1850	1400	4500	3.214
	Seville	2030	1490	4500	3.020
France	Paris	1270	957	4500	4.702
	Lyon	1450	1110	4500	4.054
	Marseille	1800	1360	4500	3.309

Table 5: Average annual solar irradiation and energy production (PVGIS, 2014), annual production and installation capacities

Country	City	Net initial investment cost (€)	VAT rate	Gross initial investment cost (€)
Flanders a	Brussels	7500	6 %	7950
Flanders b	Brussels	7500	21 %	9075
Germany	Berlin	7500	19 %	8925
	Frankfurt	7298	19 %	8685
	Munich	7091	19 %	8438
Italy	Milan	5721	10 %	6293
	Rome	5075	10 %	5583
	Palermo	4787	10 %	5265
Spain	Bilbao	6429	21 %	7779
	Madrid	4821	21 %	5833
	Seville	4530	21 %	5481
France	Paris	7053	20 %	8464
	Lyon	6081	20 %	7297
	Marseille	4964	20 %	5957

Table 6: Initial investment cost of residential PV installations for the generic case on the first of January 2014

Country	Self-consumption (kWh)	Electricity price P_1 (€/kWh)	Savings (€)
Flanders	1350	0.217	292
Germany	1350	0.292	394.2
Italy	1350	0.229	309.2
Spain	1350	0.223	301
France	1350	0.147	198.5

Table 7: Self-consumption savings in the first year of operation of residential PV installations for the generic case on the first of January 2014

Country	Electricity fed into grid (kWh)	Electricity withdrawn from grid (kWh)	Electricity price P_l (€/kWh)	Reimbursement rate r_n (€/kWh)	Surplus reimbursement rate h_n (€/kWh)	Net metering savings (€)
Flanders	3150	2650	0.217	0.27	0	575
Germany	3150	2650	0.292	0	0	0
Italy	3150	2650	0.229	0.16	0.1145	481
Spain	3150	2650	0.223	0	0	0
France	3150	2650	0.147	0	0	0

Table 8: Net metering savings in the first year of operation of residential PV installations for the generic case on the first of January 2014

Country	City	PBP (years)	NPV (€)	IRR (%)
Flanders a (6 % VAT)	Brussels	9	6993.27	11.5
Flanders b (21 % VAT)	Brussels	10	5868.27	9.9
Germany	Berlin	13	1728.88	6.9
	Frankfurt	13	2013.43	7.2
	Munich	11	2303.64	7.6
Italy	Milan	6	9143.12	16.7
	Rome	6	9743.79	18.6
	Palermo	6	10 010.94	19.6
Spain	Bilbao	25	-3733.55	0.0
	Madrid	20	-1441.85	2.6
	Seville	19	-1027.12	3.3
France	Paris	16	-920.09	3.8
	Lyon	14	455.47	5.7
	Marseille	10	2036.27	8.4

Table 9: The results for the payback period, net present value and internal rate of return of the generic case

Parameter	Distribution	Mean	Standard deviation
Electricity price growth (g)	Normal	3 %	1.5 %
Discount rate (d)	Normal	5%	1 %
Degradation rate (l)	Lognormal	0.5%	0.25%

Table 10: The parameter assumptions used in the Monte Carlo simulation.

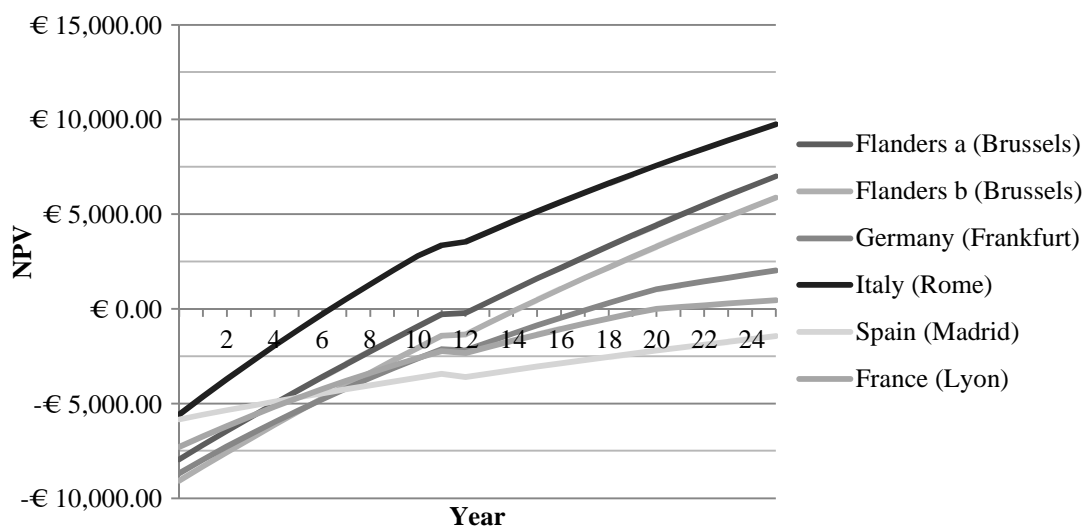


Figure 1: The cumulative cash flows over the operational lifetime for the generic case

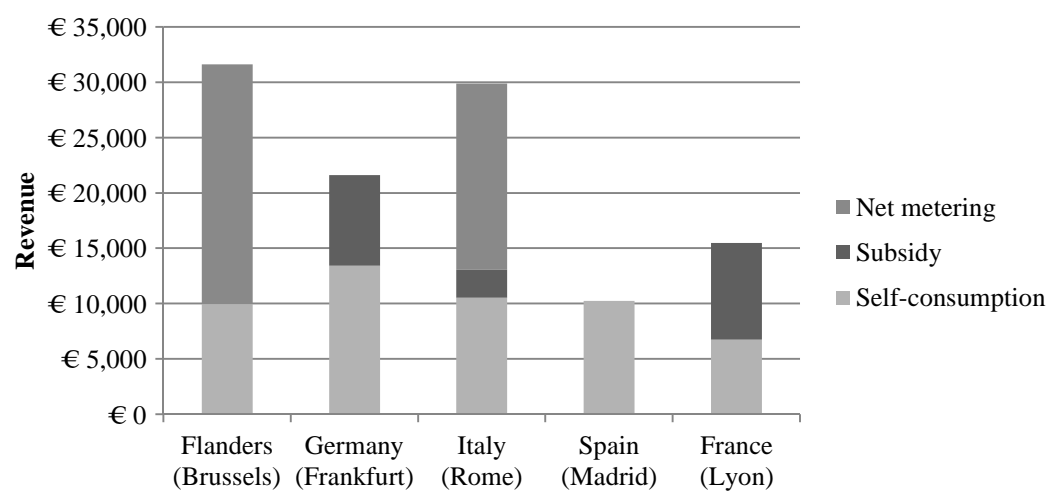


Figure 2: The revenue composition for the generic case

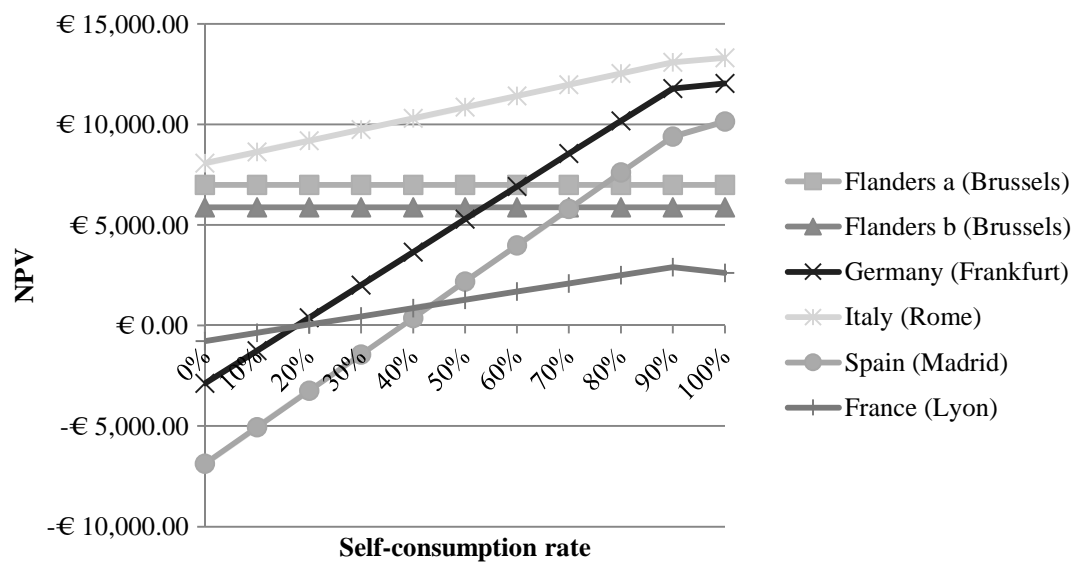


Figure 3: The net present value for different self-consumption rates

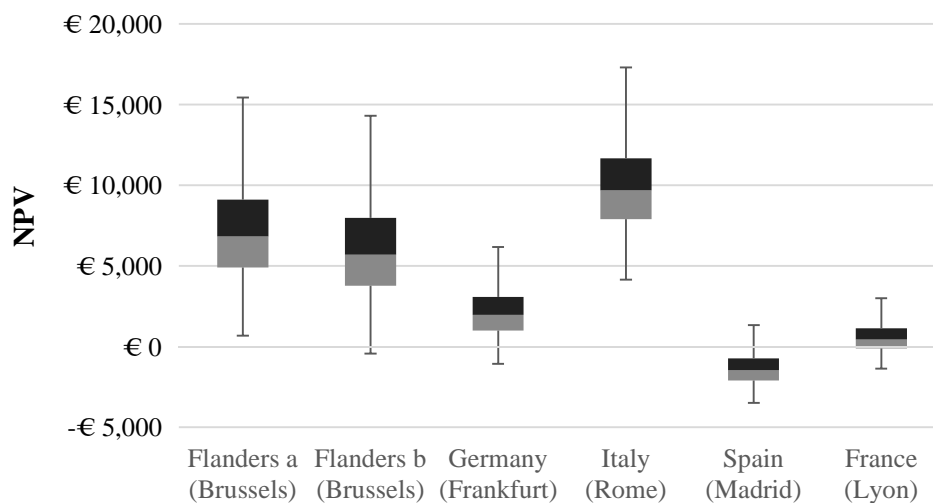


Figure 4: Box plot of the Monte Carlo simulation results for the NPV using the electricity price growth, the discount rate and the panel degradation rate as variable parameters

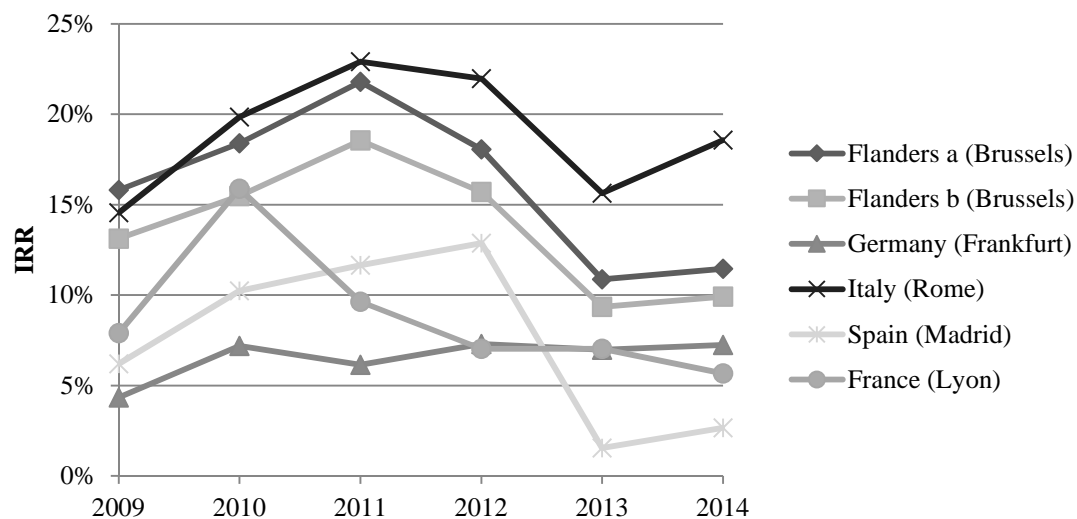


Figure 5: Evolution of the internal rate of return since 2009