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Research article

Do smart grid innovations affect real estate market values?

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Abstract: To date photovoltaic energy systems have been widely installed on homes in Europe and all over the world. In Europe and in Italy investments in domestic photovoltaic power plants (PV) were boosted by generous feed-in tariffs that made these investments extremely attractive for small private investors, such as homeowners. It is commonly agreed that the greater the building energy efficiency, the greater the property market value. It is of paramount importance to determine the value that PV systems may add to home sale transactions. The aim of the paper is to investigate whether Smart Grids (SGs) innovation can increase market values due to higher production and consumption flexibility. SGs give de facto producers and consumers, the opportunity to be active in the energy market and strategically decide their optimal production/consumption pattern. In this paper, we provide a model based on the real option theory to determine the value of this flexibility and the related market value increase. We model the homeowner decision to invest in a solar home with a PV plant and connect to an SG by comparison to the decision to invest in a solar home not connected to an SG. We determine the property potential market value increase due to the opportunity to perform active energy management given by smart grids and we compare this value increase to the PV plant value per se. To capture the value of managerial flexibility we implement a real option approach. Results of simulations, performed according to zonal prices' trend and volatility in the North and South of Italy, show that in the North and in the South, being connected to an SG increases by about 5-10% the PV investment's value and this quota increases as energy savings and flexibility increase. The greater the flexibility, the greater the property market value.

Keywords: Real estate market values; Smart grids; Investments under uncertainty; Real options; Photovoltaics

1. Introduction

Buildings energy efficiency is generally regarded in terms of energy consumption, energy costs and GHG emissions reduction in line with Europe 2020 targets. To date, in order to increase energy efficiency, deep retrofitting have been set in place [1]. At the same time, solar photovoltaic energy systems have been widely installed on homes in Europe and all over the world. In Europe and in Italy investments in domestic photovoltaic power plants (PV) were boosted by generous feed-in tariffs that made these investments extremely attractive for small private investors, such as homeowners [2,3]. It is commonly agreed that the greater the building energy efficiency, the greater the property market value. It is of paramount importance to determine the value that PV systems may add to home sale transactions [4]. The real estate hedonics literature explores how different housing attributes are capitalized into home prices. Solar installation can be regarded as a quality improvement in the home and solar homes can be considered as one of the better-known 'green product' sold in the market [5]. Although the residential solar home market is continuously growing, there is little direct evidence on the market capitalization effect. Recent contributions in the literature provide some capitalization estimates of the sales value of homes with PV systems installed relative to comparable homes without solar panels. These contributions document evidence of a solar home price premium in the US real estate market [4–8] and find that this premium is larger in environmentalist communities. They found that solar panels adds from 3% to 4% to the sale price of a home and the premium is on average equal to 4 $/W for an average-sized 3.6-kW PV system. Specifically according to [4] average market premiums across the sample of 22,822 homes analyzed are about 4 $/W or $15,000 for an average-sized 3.6-kW PV system.

Although PV systems are widespread, their installation was not able to foster consumers to change their energy consumption patterns and increase efficient energy management. Therefore overall cost-savings by PV-generation systems resulted in a marginal impact on buildings energy efficiency increase and real estate market values.

The aim of the paper is to investigate whether smart grids innovation can increase market values due to higher production and consumption flexibility. A smart grid (SG) gives de facto producers and consumers, the opportunity to be active in the energy market and strategically decide their optimal production/consumption pattern.

In this paper, we provide a model based on the real option theory to determine the value of this flexibility and the related market value increase. We model the homeowner decision to invest in a PV plant and connect to an SG by comparison to the decision to invest in a PV plant not connected to an SG. We determine the property potential market value increase due to the opportunity to perform active energy management given by SGs and we compare this value increase to the PV plant value per se. To capture the value of managerial flexibility we implement a real option approach. The greater the flexibility, the greater the property market value.

The remainder of the paper is organized as follows. In Section 2, we provide the basic model and we derive the value of flexibility of being connected to an SG. In Section 3, we calibrate the model and provides numerical simulations to test the model theoretical results with respect to the Italian electricity market and discuss results. Section 4 concludes.

2. Materials and method

2.1. Model

According to hedonic price modelling, property prices depends on their inherent attributes. These attributes usually include structural attributes (e.g., dwelling age and floor area, number of rooms and bedrooms), socio-economic characteristics of the surrounding neighbourhood (e.g., unemployed rate, racial diversity and occupations of the inhabitants) and locational attributes (e.g., proximity to services and pleasant landscapes).

At the simplest, a hedonic equation is a regression of expenditure values on housing characteristics, where the independent variables represent the individual characteristics of the property, and the regression coefficients may be transferred into estimates of the implicit prices of these characteristics:

$$V = \sum_{i=1}^{n} C_i \, p_i \qquad 1$$

where C*i* is the i-th characteristisc or attribute and p_i is its implicit marginal price.

Once a PV plant is installed, the value of the attribute C_{PV} should capture the value of energy savings (in KWh) generated during the PV plant production life. Nonetheless, usually PV plants' size rather depends on peak demand/consumption energy quotas than on average daily average consumption quotas. In other words, the plant size is set to satisfy the peak end-user demand when solar radiation is maximum. This in turn allows homeowners to save energy costs by solar energy production and to trade in the market energy quotas that are not prosumed.

When the PV plant is connected to an SG, the value of the attribute C_{PV+SG} captures the value of energy savings due to solar energy production plus the value of flexibility to switch between the two following regimes: a) the homeowner can self-consume the energy produced by the PV plant and satisfy the rest of its demand by buying energy from the national grid at a fixed contractual price; and b) the homeowner can buy energy from the national grid at a fixed contractual price to satisfy its demand and sell totally the energy produced in the local market at its market (spot) price.

Consequently, C_{PV} and C_{PV+SG} can be defined as follows:

$$C_{PV} = \max_{T_{PV}} E\left[e^{-rT_{PV}} \left(NPV_{PV}(T_{PV}) \right)\right] \qquad 2$$

$$C_{PV+SG} = \max_{T_{PV+SG}} E\left[e^{-rT_{PV+SG}} \left(NPV_{PV+SG}(T_{PV+SG}) \right)\right] \qquad 3$$

where r is the risk adjusted rate of return, NPV_{PV} and NPV_{PV+SG} are the investment net present values once the PV system is installed and is not connected to an SG in the former case, and the PV plan is connected to an SG in the latter case respectively, and T_{PV} and T_{PV+SG} are the relative investment timings.

Then, indicating by V_{PV} the property value where a PV is installed and by V_{PV+SG} the property value where a PV plant is installed and connected to an SG, by (1) we obtain:

$$V_{PV} = \sum_{i=1}^{n-1} C_i p_i + C_{PV} p_{PV} \qquad 4$$

$$V_{PV+SG} = \sum_{i=1}^{n-1} C_i p_i + C_{PV+SG} p_{PV+SG} \qquad 5$$

where the last terms represent the increase in the property value attributable to the *PV-th* attribute and the *PV + SG-th* attribute respectively.

In order to determine the effect of SGs on solar homes sale price, we base our analysis on the contribution by [9] and we introduce the following assumptions.

i) The homeowner's energy demand per unit of time is normalized to 1 (i.e., 1 MWh). Energy demand can be represented as follows:

$$1 = \xi\alpha_1 + \alpha_2 \qquad 6$$

where $\alpha_1 > 0$ is the PV production per unit of time, $\xi \in [0,1]$ is the production quota used for prosumption and $0 < \alpha_2 \leq 1$ is the energy quota bought from the national grid. Storage is not possible, i.e. no batteries are included in the PV plant, and energy must be used as long as it is produced.

ii) The homeowner receives information on the selling price at the beginning of each time interval *t* and, based on this information, he makes the decision on the quota of the produced energy to be prosumed and on the quota to be sold in the local market.

iii) The homeowner cannot buy energy from the local market and can only contribute to the balancing of the electric system when demand is greater than supply by selling a quota of energy produced by the PV plant.

By the above assumptions, net present values of PV plant not connected and connected to an SG respectively are:

$$NPV_{PV} = \frac{\xi\alpha_1 c}{r} + \frac{(1-\xi)\alpha_1 v(t)}{r-\gamma} - I(\alpha_1) \qquad 7$$

$$NPV_{PV+SG} = \begin{cases} \dfrac{\xi\alpha_1 c}{r} + \dfrac{(1-\xi)\alpha_1 v(t)}{r-\gamma} - \hat{A}v(t)^{\beta_1} - I(\alpha_1) & if\ v(t) < c \\ \dfrac{\alpha_1 v(t)}{r\ \ \gamma} - \hat{B}v(t)^{\beta_2} - I(\alpha_1) & if\ v(t) > c \end{cases} \qquad 8$$

where $\hat{A} = \xi\alpha_1 c \frac{1}{(r-\gamma)c^{\beta_1}} \frac{r-\gamma\beta_1}{r(\beta_2-\beta_1)}$, $\hat{B} = \xi\alpha_1 c \frac{1}{(r-\gamma)c^{\beta_2}} \frac{r-\gamma\beta_2}{r(\beta_2-\beta_1)}$, c is the fixed buying price of energy, $v(t)$ is the stochastic selling price of energy, β_1 and β_2 are the negative and the positive roots of the characteristic equation $\Phi(\beta) = 0.5\sigma^2\beta(\beta-1) + \gamma\beta-r$ respectively. In other words $\hat{A}v(t)^{\beta_1}$ is the option value to switch from prosumption to energy selling in the local market when $v(t)$ increases whereas $\hat{B}\,v(t)^{\beta_2}$ is the option value to switch back to prosumption when $v(t)$ decreases.

It can be demonstrated that the selling price of energy is driven by a following Geometric Brownian Motion [9,10]:

$$dv(t) = \gamma v(t)dt + \sigma v(t)dz(t) \quad with\ v(0) = v_0 \qquad 9$$

where *dz(t)* is the increment of a Wiener process, σ is the istanataneous volatility and γ is the drift term lower than the market discount rate $r \geq \gamma$.

The value of flexibility of being connected to an SG is therefore given by:

$$V_{PV+SG} - V_{PV} = (C_{PV+SG})p_{PV+SG} - (C_{PV})p_{PV}. \qquad 10$$

2.2. Model calibration

In order to test the model theoretical results we performed numerical simulations and used to calculate (9) parameter estimates provided by [9–14] with respect to the Italian electricity market, whereas we used to calculate (10), marginal prices (i.e., premiums) provided by [4,5] with respect to the US real estate market[1]. In what follows:

1) *c* is the fixed buying price of energy as homeowners are connected to the national grid via a flat contract where the price is fixed over the contract length. It is representative of the average price paid by household consumers. The average basic energy price paid by household consumers over the period 2014–2018 can be set to *c* = 160 Euro/MWh net of taxes and levies [15];

2) *v(t)* is the stochastic selling price of energy and it coincides with the price paid by the local Transmission System Operator (TSO) to procure the resources needed to manage, operate an control the power system. The Italian electric system is divided into different zones [9–11,15], therefore we use as a proxy for v(t) Italian zonal prices recorded over the period from 2010 through 2018[2]. We verified that they are distributed as a Geometric Brownian Motion by testing for lognormality and the presence of unit root. The estimated parameters, for the geographical areas North and South [9,11] are reported in Table 1 (see Table 1):

Table 1. Estimated values for γ and σ.

Geographical Areas	γ	σ
North	0.5439%	41.88%
South	0.5526%	45.69%

As starting value v_0 in each zone we took the yearly average selling prices recorded in the time interval January2016–December 2018 [9,17] as summarized in Table 2 (see Table 2):

[1] As a caveat for our simulations, we outline that, to our knowledge, the only data available in the literature on implicit marginal prices refer to the US real estate market. We are conscious that such estimates should refer to the local market. Our estimate on Italian premiums is therefore a proxy to be further investigated in future research.

[2] The Italian electric system is divided into different zones, among which physical energy exchanges are limited due to system security needs. These zones are grouped into: a) geographical zones; b) national virtual zones; c) foreign virtual zones; and d) market zones. Geographical zones represent a geographical portion of the national grid and are respectively classified into northern area, northern-central area, southern area, southern-central area, Sicily and Sardinia. Differences in zonal prices are determined by differences in transmission capacity, consumers' behavior [16] and different distributed production patterns.

Table 2. Average zonal prices over the period January 2016 - December 2018.

Average zonal prices (€/MWh)		
January 2016-	North	South
December 2018	55.42	49.82

3) T (i.e., the plant's useful life) is equal to 20 years and 25 years;

4) r (i.e., the risk adjusted rate of return) is equal to 4% and it is determined according to the Capital Asset Pricing Model $r = r_f + \beta \cdot MRP$, where r_f is the risk-free interest rate, MRP is the market risk premium and β measures the systematic risk. According to [18,19], the Italian market risk premium is 5%. The risk-free interest rate is assumed as the average of interest rates on Italian Treasury Bonds (BTPs) with a maturity of 20 and 25 years [20] and the systematic risk of the photovoltaic sector ranges between 0.5 and 0.6 [9–11];

5) $\overline{\alpha}$ (i.e., the energy quota that can be prosumed by the homeowner during the photovoltaic day) is equal to 30% and 50%. The smaller value represents the actual average percentage of daily energy usage [21], whereas the greater value is meant to consider the effect of being connected to a smart grid in terms of energy management;

6) I (i.e., the PV plant costs) are determined according to the Levelized Cost of Electricity, namely LCOE [21–24]. LCOE is equal to 110 Euro/MWh and 180 Euro/MWh respectively[3].

3. Results and Discussion

We implemented our analysis for two geographical zones in Italy: North and South. We considered a residential 3.6-kWp PV plant, which is the average nominal power of residential PV plants in Italy[4]. We performed simulations for two different scenarios: a) the homeowner decides to invest in a home with the opportunity to install a 3.6-kWp PV system connected to an SG; b) the homeowner decides to invest in a home with the opportunity to install a 3.6-kWp PV system not connected to an SG. We consider both a 3.6-kWp PV plant located in the North of Italy, which produces about 4,680 kWh/year, and a 3.6-kWp PV plant located in the South of Italy, which produces about 5,760 kWh/year.

In order to determine the premium for solar homes connected to an SG we should calculate the marginal price of the C_{PV+SG} characteristic. This is not possible at present since SGs are not implemented yet in Italy. We can estimate the premium's lower bound by assuming that p_{PV+SG} is

[3] These value are consistent with the results of the analysis on LCOE 2018 by Lazard (https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/), according to which LCOE for residential solar PV (rooftop) plants ranges from 160$ to 267$.

This range is consistent with 2017 LCOE values by the International Renewable Energy Agency https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf), which considers an average LCOE for solar PV including residential, industrial, community etc.

[4] This installed power can satisfy the average demand of a household of four people (http://www.fotovoltaiconorditalia.it/idee/impianto-fotovoltaico-3-kwdimensioni-rendimenti). It is worth noting that on average, in Northern Italy, a 1-KWp plant produces about 1100–1500 KWh/year, whereas in the South, due to more favorable weather conditions, the average is 1500–1800 KWh/year (www.fotovoltaicoenergia.com; http://re.jrc.ec.europa.eu/pvgis/).

equal to p_{PV} multiplied by the percentage increase in the investment value due to the connection to an SG. In accordance with [4–5] we assume that the marginal price of the C_{PV} characteristics, p_{PV} is equal to 3.6%, that is solar houses add 3.6% to the sale price of a home.

Tables 3 and 4 (see Tables 3 and 4) display the PV investment's values when the system is connected to an SG, the increase in the investment value due to the connection to an SG and the relative premiums in the North and the South of Italy respectively.

Table 3. Investment value of PV plants connected to an SG, investment value increase and relative premiums in the North of Italy for different LCOE, T and $\bar{\alpha}$.

North					
	T	$\bar{\alpha}$	C_{PV+SG}	C_{PV+SG}/C_{PV}	P_{PV+SG}
LCOE = 110	20	0.3	10,577.22	1.05	3.77%
	25	0.3	10,687.75	1.05	3.78%
	20	0.5	15,649.12	1.09	3.93%
	25	0.5	16,058.13	1.09	3.94%
LCOE = 180	20	0.3	9,654.65	1.05	3.80%
	25	0.3	9,341.81	1.06	3.80%
	20	0.5	15,025.02	1.10	3.96%
	25	0.5	14,712.19	1.10	3.97%

Table 4. Investment value of PV plants connected to an SG, investment value increase and relative premiums in the South of Italy for different LCOE, T and $\bar{\alpha}$.

South					
	T	$\bar{\alpha}$	$\mathbf{C_{PV+SG}}$	$\mathbf{C_{PV+SG}/C_{PV}}$	$\mathbf{P_{PV+SG}}$
LCOE=110	20	0.3	13,393.17	1.05	3.77%
	25	0.3	12,881.38	1.05	3.77%
	20	0.5	20,331.49	1.09	3.92%
	25	0.5	19,819.71	1.09	3.93%
LCOE=180	20	0.3	11,848.54	1.05	3.79%
	25	0.3	11,535.78	1.05	3.79%
	20	0.5	18,786.86	1.10	3.95%
	25	0.5	18,474.11	1.10	3.95%

The remarkable result is that in the North and in the South being connected to an SG increases by about 5–10% the PV investment's value and this quota increases (as expected) as energy savings and flexibility increase. Improvements in household energy management i.e., increasing $\bar{\alpha}$, induce homeowners to invest in bigger plants, whereas an increase in the plant useful life T reduces the optimal plant size. As in [9], the optimal invest strategy does not differ in the North and South: energy markets in Italy are sufficiently stable and correlated to show common performances. In the South, the plant size is larger and the investment value is greater, due to more favorable weather conditions. Both in the North and in the South, it is always optimal to wait to invest. Most of the plant's value is captured by the flexibility embedded in the SG. The increase in the property value due to flexibility and SGs is small both in the North and in the South. Consequently, price premiums of solar homes connected to an SG (p_{PV+SG}) are greater than those of solar homes not connected to an SG (p_{PV}). Price premiums increase on average by 5–10% due to the connection to an SG. Nonetheless, in the North and in the South the property value increase is due to the flexibility of waiting to invest rather than to the flexibility of being connected to an SG.

4. Conclusion

We modeled the homeowner decision to invest in a PV plant and connect to an SG by comparison to the decision to invest in a solar home not connected to an SG. We determined the property potential market value increase due to the opportunity to perform active energy management given by SGs, and we compared this value increase to the PV plant value per se. Results of simulations performed according to zonal prices' trend and volatility in the North and South of Italy show that in the North and in the South being connected to an SG increases by about 5-10% the PV investment's value and this quota increases as energy savings and flexibility increase. The increase in the property value due to flexibility is small both in the North and in the South. Nonetheless, premiums of solar homes connected to an SG (p_{PV+SG}) are greater than those of solar homes not connected to an SG (p_{PV}): price premiums increase on average by 5–10% due to the connection to an SG.

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Conflict of Interest

All authors declare no conflicts of interest in this paper.

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