Vimpari, Jussi; Junnila, Seppo

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Evaluating decentralized energy investments: Spatial value of on-site PV electricity

Jussi Vimpari*, Seppo Junnila

Aalto University, School of Engineering, Department of Built Environment, P.O. Box 15800, 00076 Aalto, Finland

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ABSTRACT

Today solar power is still dominantly presented to be expensive source of electricity. However, the profitability of solar and other electricity generation technologies is typically evaluated with the Levelized Cost of Electricity (LCOE) approach. This paper questions the traditional investment evaluation logics of power production (LCOE) in the interesting case of rooftop PVs and based on customer value generation logics presents a new approach for evaluating the profitability of rooftop PV investments. The approach recognizes the value that PVs produce to real estate owners and utilize basic real estate investment models to evaluate the profitability of PVs. The results imply that, if PVs are considered as a part of the underlying property, rooftop PV systems are already today profitable in many European cities and can provide substantial returns on investment for property owners. More interestingly, the results imply that rooftop PV investments are most profitable in the dense urban cores instead of more remote (industrial) locations, and thus the current trend of urbanization seems to further strengthen the profitability of rooftop solar power. This paper points out that spatial locations drive the economic analysis of real estate, and thus it is likely that it will drive the economic analysis of decentralized on-site energy investments as well.

1. Introduction

The cost of on-site solar photovoltaic (PV) energy production has been continuously claimed to be more expensive than conventional off-site large-scale energy production. This cost comparison between PV and different electricity generation technologies is most often calculated using the Levelized Cost of Electricity (LCOE) [1–5], as identified by Branker, Prathak and Pearce [6], and also the latest widely cited studies seem to follow the path [7,8]. LCOE measures the net present value of the full life-cycle costs of electricity over the generated electricity in a given system.

In this paper, we claim that the LCOE approach is based on an outdated transformation concept of production, and its application to on-site energy production. The transformation concept has dominated production for the most part of the latest century [9]. The model is based on Taylor’s [10] famous principles of scientific management, where production is seen as a transformation of production factors into products and gives its most fascinating outcome when considering mass production. The application of the same model to PV considers the transformation of photonic energy to power and evaluates the investment based on this transformation task. A more current value generation concept of production, often credited to Drucker [11], argues that the value of a product can only be determined in reference to a customer and the goal of production is satisfying customer needs. When this model of production is used as the basis of PV investment, the investment model should be capable of evaluating the value of electricity production to the customer.

We claim that the understanding of “value-to-customer” in production is mostly missing from PV studies, and thus they end stating that the cost of PV production on-site is higher than conventional (off-site large-scale) production [6–8]. More specifically, previous studies have not understood the connection between rooftop PV electricity production and its value to the customer, i.e. the property owner. The purpose of this paper is to question the traditional investment evaluation logics of power production, and based on customer value generation logics of production, present a new approach for evaluating the rooftop PV investments. This review presents how PV creates more value to the customer (property owner) through value creation mechanism of real estate economics. The paper collects literature related to the technical and economic performance of solar PV systems and presents a rationale why it is sensible to value rooftop solar PV investments with property valuation logics rather than traditional energy investment analysis (LCOE).

The methodology of the paper is applied to 25 European capital
The long-term technical performance of PV modules has received an increased interest from the academic community. Jordan and Kurtz [13] conducted a very extensive review of literature assessing the degradation rates of modules. They concluded from nearly 2000 degradation rates observed in previous literature that modules have median degradation rates of 0.5% per year. These rates result in a reasonable module performance after 25 years. Wohlgemuth, Cunningham, Nguyen and Miller [14] measured 5 modules that had been in outdoor use for over 10 years and the average degradation was 0.5% per year. Dunlop and Halton [15] measured the performance of 40 silicon PV modules that had been in outdoor use for 20–22 years. They concluded that most of the tested modules had very high performance ratios even after 20 years (the majority of modules exceeding performance of 92%), and that the actual lifecycle of these products is “significantly more than 20 years”. Skoczek, Sample and Dunlop [16] continued on the same topic by analysing 204 modules from 20 different producers. The concluded that if a performance ratio of 80% is needed, the measurements points out that the useful lifecycle of modules is not limited to 20 years.

Interestingly, Sharma and Chandel [17] conducted a thorough review about the technical and degradation performance of solar PV modules in actual outdoor operation. Similarly to Jordan and Kurtz they found that modules experience continuous degradation due to aging and this degradation varies through different climate zones. They concluded that as manufacturers develop different kinds of applications for different climate zones, the quality tests of module degradation become more difficult in the future.

Branker et al. [6] evaluated PV module lifecycles for calculating the LCOE. From a large amount of literature, the concluded that a “30 year lifetime or more is becoming more expected” for PV module lifecycle. Recently, Vartiainen, Masson and Breyer [18] have suggested that 50 years is an appropriate estimation for the technical life-cycle based on their finding that many PV systems installed 40 years in Germany are still operating with a measured annual degradation between 0.3%–0.5%. Furthermore, Fraunhofer ISE have measured degradation levels in Germany since 1990, and found in their latest study of 17 PV systems an average degradation rate of 0.1% [19]. Based on the research on this topic, the consensus seems to be that crystalline silicon PV modules have high reliability and low long-term degradation rates. Therefore, the assumption of at least 25 years for module lifecycle seems to be justifiable.

The technical performance of PV often culminates in the uncertainty of inverter lifecycle, as the other parts of the system have no moving parts and require little maintenance. It seems that inverter lifecycle is not as widely studied as module lifecycle. Nevertheless, many studies calculating solar performance are using inverter lifecycles ranging from 10 to 15 years [6,7,20–22]. In practice, during the first 10 years inverter replacement is often guaranteed by warranties, and after that the replacement can be covered by extra warranties from the manufacturers. Inverter replacement costs are often included in the operating expenses of a PV system in economic analysis.

The lifecycle of a building is often considered to be 50 years. Duffy and Henney [23] pointed out that a building can be divided into three main parts: skin (façade and roof), services (HVAC and electricity) and structures which have to be replaced over a 50 year period. A recent study by Huuhka and Lahdensivu [24] has recorded that the actual life cycle of a building is around 50 years (44–64 years) until demolition. However, actual building components have substantially shorter life spans and have to be replaced during the 50-year period. Estimates of 15–25 years for HVAC and main electricity units or 20–40 years for façades and roofs are often used [25]. If the economic obsolescence of the building’s technical systems is included in the equation the actual life cycles may be substantially shorter [26].

2.2. Investment economics

As the technical lifecycle of rooftop PV systems is comparable to
the lifecycles of building components, the rooftop PV system should be appraised together with the property similarly to the other technical building components that are part of the property. If this connection is made, the value of the system depends on the cash flow it generates for the property owner as stated by the International Valuation Standards [12]. This has important implications because it changes the risk-return profile of the investment. LCOE studies [6,7] have pointed out the difficulty in defining the correct discount rate for PV investments. In the current approach, the market already defines the correct discount rate based on the spatial location of the property.

Commercial property investments are appraised with the discounted cash flow (DCF) method. In the method, the net operating income (rental earnings deducted by operating expenses) of a property is projected into the future and then discounted back to the present with an appropriate yield. The yield is the return required by the investor and it represents the risk inherent in a specific property, specifically from the vacancy perspective. For example, properties in city centres and global metropolises are typically valued higher than properties in rural areas. If rooftop PV is appraised with the same yields as the underlying properties, a significant part of the PV’s value is created through the spatial location. Below we strengthen this claim by assessing the economic risk of PV investments from the energy supply and demand perspectives.

The demand risk is actually already included in the property yield, as it considers the risk that the building is unoccupied. Therefore, the property yield already accounts for the risk that the electricity generated by the PV system is not consumed on-site. The supply risk, i.e. the quantity and price of the generated solar electricity, is evaluated by assessing solar insolation volatility and market risks regarding electricity prices.

Drury et al. [27] found the annual solar variability to be very low in 19 US locations. The average standard deviation was only 2% p.a. for a 20-year period based on 45 years of simulation. Fraunhofer ISE [28] have analysed 60 years of historical insolation data in Germany and have found that the average standard deviation has ranged around 2–3% p.a. These findings allow for a detailed analysis of solar insolation variations. For example, Thevenard and Pelland [29] found that standard deviation for solar insolation ranged between 2.5% and 5.0% p.a. in Canada.

The market risks consist mainly of future electricity rates and possible changes in regulation. Retail electricity rates are expected to increase in the long-term, especially due to taxes and transfer prices, and historically the increase has been higher than the average consumer price index [30] to which property rental agreements are commonly tied. The largest source of risk can be estimated to be the regulatory risk as governments may start to impose different taxes on on-site electricity production as well. However, as many governments are taking a more proactive political stance towards climate change, the realization of these risks might be in line with overall regulation changes towards properties themselves, as they are a significant source of emissions themselves.

Finally, if rooftop PV is considered as an integral part of the cash flow generating system of the property and appraised with the same methods as the underlying property, we can calculate the value of the systems for the customer (property owner) in different locations. Additionally, we can roughly approximate the adoption years for different locations based on the learning curve approximations of future PV instalment costs [13].

3. Methods and data

Many organisations compile statistics of property yields for different markets around the globe. The most widely cited organisations are large international real estate consultancy companies that collect property data for individual cities around the world. In this study, the property yields are derived from CBRE, which updates their outlook for EMEA region yields quarterly. This information can be used to determine the required return for rooftop PV systems for different types of properties in Europe. This paper analyses office, retail and industrial properties.

Fraunhofer ISE [31] reported that the investment cost in Germany for a 10–100 kWp system was approximately 1300 €/kWp in Q1/2015. Recently, Vartiainen et al. [13] estimated that system instalment prices will decrease for the next decades. Based on these findings, we approximate that the average instal price in Q4/2015 is 1200 €/kWp in most European countries. In practice, the investment costs have some variation between European countries but for the purposes of this paper, we assume the same investment cost for all markets.

The return of a rooftop PV system (PV Yield) is calculated by dividing the value of generated electricity by the system investment costs. The following simple formula is used:

\[
PV \text{ Yield} = \frac{(SP(1-D)+P-I^*E)}{I}
\]

where S = solar irradiance (kWh/kWp), D = degradation (0,5%), P = electricity price (€/kWh), I = investment cost (€/kWp), E = operating expenses (1,5%). The value of the generated electricity is affected by solar irradiance in the specific location as well as country-specific electricity prices. The solar irradiance data are drawn from the EU Joint Research Center [32,33] and the average electricity prices are drawn from Eurostat [23], using Q4/2015 prices for industrial customers (without taxes). Table 1 presents the core input data and results for the investment calculation for 25 European capital cities. The property yields for the three property types are shown from CBRE [34].

4. Results

The results in Table 1 implicate that PV yields are higher than the respective property yields in many of the locations. The industrial properties seem to have a bit later adoption years than office and retail properties, due to the higher property yields. The adoption year is the year when the PV yield is higher than the property yield. The future adoption years are based on the predicted cost reduction of PV calculated by Vartiainen et al. [13] and on an estimate of 3,0% p.a. increase of electricity prices. The property yields are assumed to remain the same, on average, as historically long-term average property yields have not increased; rather the opposite [35]. It should be noted that the calculus is based on the average industrial electricity price, which is most likely lower than the price paid by most commercial properties in practice. Eurostat tracks only residential and industrial electricity prices, not commercial prices. The residential yields are much higher than industrial prices and thus cannot be used for this analysis. Additionally, residential properties are appraised differently than commercial properties.

The results in Table 1 are based on the prime yields of capital cities in 25 European countries, i.e. with the lowest yields of the respective countries. As we move to other locations within the country, the yields increase, which can reduce the profitability and postpone the adoption year. Tables 2 and 3 present the spatial analysis for office yields in 37 locations in the UK and Finland and the relevant property value increases. The property value increases because the produced electricity decreases the operating expenses of the property. This is explained with the following direct capitalization property appraising formula:

\[
Property \text{ value} = \frac{\text{Rental income} - \text{Operating expenses}}{\text{Property yield}}
\]

The property appraising logic indicates that if the PV yield is higher than the respective property yield, the property value increase is higher than the investment cost for the PV system. This creates extra value for the property owner due to the electricity generated by the PV system.

Based on the spatial analysis, PV investments seem to be already profitable in all of the estimated locations in the UK. In Finland, which has higher property yields and risks, as well as lower electricity prices,
PV investments were profitable in less than half of the studied locations and with adoption years around 2020 in the rest of the locations. The tables also explain how the current solar incentives in both markets influence the profitability and property value increases.

In the UK, rooftop PV systems receive a Feed-in-Tariff (FiT) for the generated electricity. In Q4/2015, the middle-rate FiT was 8,29 £sd/kWh for systems over 150 kWp [36] (a conversion factor of 1 GBP to 1,3 EUR is used for the calculus). This increases the PV yields, as it is calculated on top of the on-site electricity. The last two columns in Table 2 present the property value increase (€/kWp) for the different locations, with and without incentives. The results show how location affects the value of the PV system. The property appraisal logics imply that PV investments are most profitable in the dense urban core instead of more remote locations. Additionally, the results challenge the need of FiTs in the UK as the property value increase is higher than the investment costs even in the most remote locations, such as the North East. With incentives, the property value increase compared to the investment costs has a multiplying factor ranging from 2.0 (North East) to 4.2 (West End) for the different locations. This is extra value created for the property owner.

| City       | Industrial Electricity price (c/kW h) | Solar Irradiance (kW h/kWp) | PV Yield (%) | Office Prime Yield (%) | Adoption Year | Retail Prime Yield (%) | Adoption Year | Industrial Prime Yield (%) | Adoption Year |
|------------|--------------------------------------|-----------------------------|--------------|------------------------|--------------|------------------------|--------------|-----------------------------|--------------|
| Amsterdam  | 7.21                                 | 900                         | 3.9%         | 4.5%                   | 2017         | 3.4%                   | now          | 5.5%                        | 2019         |
| Athens     | 10.37                                | 1425                        | 10.8%        | 9.9%                   | now          | 6.5%                   | now          | 10.0%                       | now          |
| Belgrade   | 5.91                                 | 1275                        | 4.7%         | 9.0%                   | now          | 6.5%                   | now          | 7.8%                        | now          |
| Berlin     | 8.09                                 | 900                         | 4.5%         | 4.0%                   | now          | 3.9%                   | now          | 5.2%                        | now          |
| Bratislava | 10.81                                | 1050                        | 7.9%         | 6.9%                   | 2017         | 3.5%                   | now          | 6.3%                        | 2019         |
| Brussels   | 8.98                                 | 825                         | 4.6%         | 5.3%                   | 2017         | 7.3%                   | 2019         | 8.8%                        | 2021         |
| Bucharest  | 7.07                                 | 1200                        | 5.5%         | 7.5%                   | 2018         | 7.0%                   | 2018         | 8.5%                        | 2020         |
| Budapest   | 7.78                                 | 1125                        | 5.8%         | 7.2%                   | now          | 3.5%                   | now          | 6.3%                        | 2018         |
| Copenaghen| 8.94                                 | 900                         | 5.2%         | 4.3%                   | now          | 3.3%                   | now          | 5.8%                        | now          |
| Dublin     | 12.94                                | 825                         | 7.4%         | 4.7%                   | 2018         | 4.3%                   | 2018         | 6.3%                        | 2023         |
| Helsinki   | 6.37                                 | 900                         | 3.3%         | 4.3%                   | now          | 5.0%                   | now          | 7.0%                        | now          |
| Lisbon     | 9.89                                 | 1500                        | 10.8%        | 5.5%                   | now          | 4.0%                   | now          | 4.5%                        | now          |
| London City| 14.35                                | 900                         | 9.2%         | 4.0%                   | now          | 3.5%                   | now          | 6.5%                        | now          |
| Madrid     | 11.16                                | 1500                        | 12.4%        | 4.3%                   | now          | 3.5%                   | now          | 6.5%                        | now          |
| Oslo       | 6.12                                 | 825                         | 2.7%         | 4.2%                   | 2020         | 4.0%                   | 2020         | 5.5%                        | 2023         |
| Paris      | 7.55                                 | 975                         | 4.6%         | 3.3%                   | now          | 3.0%                   | now          | 6.0%                        | 2018         |
| Prague     | 7.61                                 | 900                         | 4.2%         | 5.8%                   | 2019         | 5.5%                   | 2018         | 6.5%                        | 2021         |
| Riga       | 8.18                                 | 900                         | 4.6%         | 7.3%                   | now          | 3.5%                   | now          | 6.5%                        | now          |
| Rome       | 9.43                                 | 1275                        | 8.5%         | 4.0%                   | now          | 3.5%                   | now          | 6.5%                        | now          |
| Stockholm  | 6.17                                 | 900                         | 3.1%         | 4.0%                   | 2018         | 4.0%                   | 2018         | 5.8%                        | 2022         |
| Tallinn    | 7.55                                 | 900                         | 4.1%         | 6.7%                   | now          | 3.8%                   | now          | 6.3%                        | 2019         |
| Vienna     | 7.31                                 | 975                         | 4.4%         | 4.2%                   | 2019         | 6.5%                   | 2018         | 8.5%                        | 2021         |
| Vilnius    | 9.10                                 | 900                         | 5.3%         | 7.0%                   | 2018         | 5.5%                   | 2017         | 6.4%                        | 2019         |
| Warsaw     | 8.33                                 | 900                         | 4.7%         | 5.8%                   | 2019         | 8.0%                   | 2019         | 9.3%                        | 2021         |

| City       | Office Property Prime Yield (%)     | PV Yield (%) without incentives | PV Yield (%) with incentives | Property value increase without incentives (€/kWp) | Property value increase with incentives (€/kWp) |
|------------|-------------------------------------|---------------------------------|-------------------------------|---------------------------------------------------|-----------------------------------------------|
| London (West End) | 4.2%                             | 9.6%                            | 17.7%                         | 2759                                              | 5068                                         |
| London (City)     | 4.2%                             | 9.6%                            | 17.7%                         | 2766                                              | 5080                                         |
| London (Mid Town)  | 4.9%                             | 9.6%                            | 17.7%                         | 2359                                              | 4332                                         |
| London (Docklands) | 4.8%                             | 9.6%                            | 17.7%                         | 2388                                              | 4386                                         |
| London (Southbank) | 4.7%                             | 9.6%                            | 17.7%                         | 2438                                              | 4479                                         |
| M25 North         | 7.1%                             | 9.6%                            | 17.7%                         | 1636                                              | 3005                                         |
| M25 South         | 6.3%                             | 9.6%                            | 17.7%                         | 1831                                              | 3363                                         |
| Thames Valley     | 5.9%                             | 9.6%                            | 17.7%                         | 1972                                              | 3621                                         |
| Key Provincial Cities | 5.5%                        | 9.6%                            | 17.7%                         | 2086                                              | 3831                                         |
| Out of Town       | 6.5%                             | 9.6%                            | 17.7%                         | 1783                                              | 3274                                         |
| Central London    | 4.3%                             | 9.6%                            | 17.7%                         | 2714                                              | 4985                                         |
| Suburban London   | 5.9%                             | 9.6%                            | 17.7%                         | 1958                                              | 3597                                         |
| South East        | 6.4%                             | 9.6%                            | 17.7%                         | 1805                                              | 3315                                         |
| Eastern           | 6.7%                             | 9.6%                            | 17.7%                         | 1716                                              | 3152                                         |
| South West        | 6.6%                             | 9.6%                            | 17.7%                         | 1758                                              | 3229                                         |
| East Midlands      | 6.8%                             | 9.6%                            | 17.7%                         | 1691                                              | 3106                                         |
| West Midlands      | 6.7%                             | 9.6%                            | 17.7%                         | 1716                                              | 3152                                         |
| Wales             | 7.5%                             | 8.7%                            | 16.1%                         | 1390                                              | 2569                                         |
| North West        | 7.3%                             | 8.7%                            | 16.1%                         | 1424                                              | 2632                                         |
| Yorkshire & Humberside | 7.3%                        | 8.7%                            | 16.1%                         | 1420                                              | 2625                                         |
| North East        | 8.1%                             | 8.7%                            | 16.1%                         | 1288                                              | 2382                                         |
| Scotland          | 6.9%                             | 8.7%                            | 16.1%                         | 1511                                              | 2793                                         |
These results are compared to Finland, which has similar average solar irradiance as the UK but much lower electricity prices and a different incentive system. Table 3 presents the same data as the previous table for 15 locations in Finland. Additionally, the adoption year with and without incentives is calculated (in UK, adoption year for all the locations is now).

In Finland, rooftop PV investments (only non-residential properties) receive a 30% compensation for the total investments costs. Additionally, all rooftop PV systems are exempted from electricity taxes, which increase the value of generated electricity. In the calculus, the electricity tax (2,253 c/kWh) for commercial buildings is included. The Finnish incentive system does not impact the size of the property value increase, because it only affects the investment costs rather than the value of generated electricity. The results suggest that incentives are still needed in countries with very low electricity prices, such as Finland, to make PV investments profitable. The results also present the differences between the two different incentive systems; the Finnish incentive system (compensation on direct investment) does not create extra property value but the UK system (a Feed-in-Tariff) does.

The results of this study are discussed in comparison to the LCOE. However, calculating LCOE for the exact cities would require choosing the correct discount rate when comparing the solar PV investment as a stand-alone investment to the property integrated investment. The used discount rate in the past LCOE studies have had large variation, which complicates the comparison. For example, Branker et al. [6] used 0%, 4.5% and 10% for different scenarios, Hérnandez-Moro and Martínez-Duart [7] used 10% and Reichelstein and Yorston [8] used 8%. Vartiainen et al. [18] recently calculated LCOEs for different cities in Europe and concluded that by 2030 PV LCOE will be competitive against retail electricity prices in most of the European countries, depending on the chosen discount rate. If the approach of this paper is taken, rooftop PV will be profitable by most European cities by 2021. This is the so-called “customer value” that can be captured by the property valuation logic. Thus, the results indicate that on-site solar PV will be adopted faster than the LCOE would imply.

The customer value can be explained through two dimensions. In purely quantitative terms, the results here explain why solar PV is already profitable when compared to the underlying property returns, i.e. for the property owner the yield exceeds the property value and thus it is profitable enough for positive investment decision. Additionally, out of the scope of this study, the results could be explored more subjectively as the rooftop PV can have additional value for different stakeholders. For example, many property owners have started to emphasize the role of environmental performance of buildings. A popular measure for this during the past decades has been green certificates, such as LEED, BREEAM and ENERGY STAR. A growing amount of research [38,39] has indicated that the certificates, per se, can increase occupancy rates and property values, even though they may not actually affect the energy performance of the building. It may be possible that solar PV is similarly seen as a “positive market signal” for green performance of the property. Other subjective values may arise from increasing energy self-sufficiency, promoting environmental, governance and social issues, etc.

5. Conclusions

There is an on-going debate in Europe whether to adopt small-scale renewable energy production in buildings. On one hand buildings consume 40% of energy [40], but on the other small-scale energy production is considered to be too expensive. For example, Defaix, van Sark, Worrel and de Wisser [41] have estimated that the technical potential of Building Integrated (rooftop and façade) PV in EU-27 is 951 GWp, which could deliver up to 840 TW h of electricity (equivalent of 22% of the expected 2030 annual electricity consumption). Earlier, it has not been possible (on a large scale) for the property industry to produce its own energy. However, the landscape seems to be changing fast with low and nearly zero energy buildings, affordable solar, smart grids, and energy storages, which all have a huge influence on profitability of energy sector. Thus, it is utmost important that the energy sector understands how the real estate industry evaluates investments. We have already seen several occasion where the energy industry evaluates solar investments unprofitable, where on the contrary the real estate industry sees investment as profitable.

This paper has tried to demonstrate that rooftop PV systems are actually already profitable in a large proportion of buildings, as long as the value-to-customer is understood properly in the investment evaluations and PV is considered a part of the underlying property. More interestingly, the results imply that rooftop PV is most profitable in the dense urban core, due to the spatial variable specific in real estate economics. Previous PV studies seem to have missed the spatial value and its implications for the customer.

It is important that stakeholders both in the property and energy industry are familiar with the approach of this paper. The property industry will likely accelerate investments into rooftop PVs and other small-scale renewable energy as the economic equation becomes clearer to them. More importantly, it seems that the energy industry is not familiar with the value creation mechanisms of their customers in the property industry. The paper provides an important insight to traditional energy companies as they try to make sense of the energy revolution and try to position themselves into the new market order. There has been a lot of discussion regarding the role of small-scale energy production in the built environment. For that discussion the paper offers a more concrete economic perspective. Finally, the results of this paper have suggested that the incentives for solar PV might not
be needed anymore in markets where rooftop solar PV profits exceed the profits of properties. The incentives could be changed towards a solid regulation for encouraging long-term renewable decentralized energy production, similarly as the property sector have enjoyed a rather solid regulation for encouraging long-term investments into land. Applying this kind of regulation compared to direct incentives would likely receive better acceptance from the public as well.

References

[1] International Energy Agency (IEA). Solar Photovoltaic Energy. IEA Technology Roadmaps, 1–48; 2010.
[2] Price S, Margolis R. Solar technologies market report. Energy Effic Renew Energy US Dep Energy 2010;1:131.
[3] Yang C. Reconsidering solar grid parity. Energy Policy 2010;38:3270–3.
[4] Singh PP, Singh S. Realistic generation cost of solar photovoltaic electricity. Renew Energy 2010;35:561–9.
[5] Denholm P, Margolis RM, Ong S, Roberts B. Break-even cost for residential photovoltaics in the United States: key drivers and sensitivities. Natl Renew Energy Lab (NREL) Tech Rep 2009.1–33.
[6] Braneker K, Pathak MJM, Pearce JM. A review of solar photovoltaic leverized cost of electricity. Renew Sustain Energy Rev 2011;15:4470–82.
[7] Hernández-Moro J, Martinez-Duart JM. Analytical model for solar PV and CSP electricity costs: present LCOE values and their future evolution. Renew Sustain Energy Rev 2013;20:119–32.
[8] Reichelestein S, Yorston M. The prospects for cost competitive solar PV power. Energy Policy 2013;55:117–27.
[9] Koskela L. An exploration towards a production theory and its application to construction. VTT Publ 2000;408.
[10] Taylor FW. The principles of scientific management. (Harpers & Brothers; 1911.
[11] Drucker P. ‘The New Realities’ (Harper and Row; 1989.
[12] International Valuation Standards Council (IVSC). International valuation standards. (IVSC, 2011).
[13] Jordan DC, Kurtz SR. Photovoltaic degradation rates—an analytical review. Prog Photovolt: Res Appl 2013;21:12–29.
[14] Wohlgemuth JH, Cunningham DW, Nguyen AM, Miller J. Long term reliability of PV modules. In Proceedings of the 20th European Photovoltaic Solar Energy Conference; 2005.
[15] Dunlop ED, Halton D. The performance of crystalline silicon photovoltaic solar modules after 22 years of continuous outdoor exposure. Prog Photovolt: Res Appl 2006;14:53–64.
[16] Skoczek A, Sample T, Dunlop ED. The results of performance measurements of field-aged crystalline silicon photovoltaic modules. Prog Photovolt: Res Appl 2009;17:227–40.
[17] Sharma V, Chandel SS. Performance and degradation analysis for long term reliability of solar photovoltaic systems. Renew Sustain Energy Rev 2013;27:753–67.
[18] Vartiaimen E, Masson G, Breyer CPV. LCOE in Europe. In: Proceedings of the 31st European Photovoltaic Solar Energy Conference; 2015.
[19] Kiefer K, Dinsberger D, Müller B, Heydenreich W, Kroger-Vodde A. A degradation analysis of PV power plants. In: Proceedings of the 25th European Photovoltaic Solar Energy Conference; 2010.
[20] U.S. Department of Energy (USDE). Sunshot. SunShot Vision Study. (USDE, 2012).
[21] Zweibel K. Should solar photovoltaics be deployed sooner because of long operating life at low, predictable cost?. Energy Policy 2010;38:7519–30.
[22] Pasca S, Sivaraman D, Koeleman GA. Parameters affecting the life cycle performance of PV technologies and systems. Energy Policy 2007;35:5316–26.
[23] Duffy F, Henney A. The changing city. London, UK: Bulstrode Press; 1989.
[24] Huhuka S, Lahdensivu J. Statistical and geographical study on demolished buildings. Build Res Inf 2016;44:1–24.
[25] Junnila S. The environmental impact of an office building throughout its life cycle. Hels Univ Technol Constr Econ Manag Res Rep 2004:2.
[26] Barras R, Clark P. Obsolescence and performance in the Central London office market. J Prop Valuat Invest 1996;14:63–78.
[27] Druzy E, Jenkins T, Jordan D, Margolis R. Photovoltaic investment risk and uncertainty for residential customers. IEEE J Photovolt 2014;4:278–84.
[28] Müller B, Wild M, Driesse A, Behrens K. Rethinking solar resource assessments in the context of global dimming and brightening. Sol Energy 2014;99:272–82.
[29] Thevenard D, Polland S. Estimating the uncertainty in long-term photovoltaic yield predictions. Sol Energy 2013;91:432–45.
[30] Eurostat. Electricity prices for industrial consumers. Eurostat Energy price statistics; 2015 S1, (2015).
[31] Fraunhofer Institute for Solar Energy Systems (ISE). Photovoltaics Report, November, 1–43 (2015).
[32] Sürçi M, Huld TA, Dunlop ED, Ossenbrink HA. Potential of solar electricity generation in the European Union member states and candidate countries. Sol Energy 2007;81:1295–305.
[33] Huld T, Müller R, Gambarrella A. A new solar radiation database for estimating PV performance in Europe and Africa. Sol Energy 2012;86:1803–15.
[34] CBRE. EMEA Rents and Yields Marketview Q4/2015. CBRE Research Gateway; 2015.
[35] IPF. Implications for Property Yields of Rising Bond Yields. IPF Research Programme 2011–2015 Short Paper19, 1–29; 2014.
[36] OFGEM. Feed-in Tariff (FIT) Payment Rate Table for Photovoltaic Eligible Installations (1 October 2015 – 31 December 2015). OFGEM Tariff Tables; 2015.
[37] Catella. Property Market Trends Autumn 2015 Finland. Catella Research; 2015.
[38] Fuerst F, McAllister P. Green noise or green value? Measuring the effects of environmental certification on office values. Real Estate Econ 2011;39:45–69.
[39] Eichholtz P, Kok N, Quigley JM. Doing well by doing good? Green office buildings. Am Econ Rev 2010;100:2492–509.
[40] European Commission. Directive 2010/31/EU of the European Parliament and of the Council.
[41] Defaux PR, van Sark WGHJM, Worrel E, de Visser E. Technical potential for photovoltaics on buildings in the EU-27. Sol Energy 2012;86:2644–53.