INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
M. Castaneda et al., Vol.9, No.2, June, 2019

Solar Power Business in the UK: A Bright or Cloudy Future ahead?

Monica Castaneda*, Sebastian Zapata*‡, Jorge A. Herrera**, Andrés J. Aristizábal*, Isaac Dyner*

*Departamento de Ingeniería, Universidad Jorge Tadeo Lozano, Bogotá Colombia

**Departamento de Ingeniería, Universidad Jorge Tadeo Lozano, Bogotá Colombia, Instituto Técnico Metropolitano, Medellín Colombia

(mcastanr@unal.edu.co, szapatar@unal.edu.co, jorgea.herrerac@utadeo.edu.co andresj.aristizabalc@utadeo.edu.co, idyner@unal.edu.co)

‡ Corresponding Author; Sebastian Zapata, Carrera 4 #22-61, Bogotá, Colombia, Tel: +571 2427030 ext. 1707
szapatar@unal.edu.co,

Received: 29.03.2019 Accepted:07.05.2019

Abstract- The paradigm shift towards a decentralised power industry seems unavoidable as distributed generation (DG) grows as a future trend. The monopolies characteristic of the utilities sector, and the low incentive to innovate that result from this, will cause these industries to struggle for a market share in a more competitive future environment. Solar power business may emerge as an opportunity for electricity utilities increase earnings, though their burgeoning depends on favourable framework conditions, such as subsidies. The objective of this paper is to study the long-term effects of the deployment from distributed solar on solar companies' generation and electricity utilities. The findings indicate that distributed generation may reduce the domestic energy consumption; however, the development of solar PV (photovoltaic) is limited under the British electricity market's conditions. In addition, the most beneficial option to solar company is a PPA (Power Purchase Agreement) model. Specifically, a PPA business model that promotes solar PV systems plus a battery storage is the most successful business in terms of savings for PV adopters, but the benefit to solar companies is reduced.

Keywords Solar PV, Feed-in Tariff, System Dynamics, Solar power business.

1. Introduction

Solar PV is often view as the most promising technology among renewable technologies. As it has experienced a dramatic cost reduction during the last years, falling about 73% between 2010 and 2017 [1]. This trend is expected to continue in the future, indeed, the average Levelised Cost of Electricity (LCOE) of solar PV could fall by as much as 59% by 2025, while onshore and offshore wind is expected to drop by 26% and 35%, respectively [2]. A driver in cost reduction of solar PV is the substantial increase of solar PV's global installed capacity, where between 2010 and 2017, the annual installed capacity for solar PV grew from 40GW to 402GW [3]. Currently, solar PV plays an important role in the electricity sector of several countries. In 2017, China (131 GW), USA (51 GW), Japan (49 GW) and Germany (42 MW) [4].

On the one hand, the larger the penetration of PV in a country's energy matrix, the more successful this market/technology could be considered. On the other hand, the priority for electricity utility companies is to increase returns, which is achieved through increased consumption of energy. Solar PV could have a negative effect on utilities due to it causing a net reduction in energy sales. As more consumers become PV adopters and higher grid tariffs are charged to remaining non-PV adopters, the rate of PV adoption increases, causing electricity sales to fall as a result [5]. Yet, electricity generation from solar sources can also provide opportunities to electricity companies [6], [7]. Such is the case of some companies in Germany like EON, RWE and NRG, which are exploring new arenas in solar business models [8]; similarly, some U.S utilities have invested in community solar project such as Sacramento Municipal Utility and Tucson Electric Power. Utilities can assume different positions to face the challenges posed by the increase in solar PV deployment, choosing a defensive or proactive strategy [9], [10].

With a defensive strategy, different measures to ensure full cost recovery would be encouraged for utilities to maintain the status quo. A defensive measure could be to change the tariff design to reflect the costs imposed by each network user; e.g., to add a fixed charge or demand charge to the volumetric rate. Likewise, utilities could advocate for reducing the compensation received by PV adopters for power generation on the basis of fairness and avoiding free-riding behaviours [11]. While an important question about the value of solar energy arises, a similar argument is used to increase the PV cost using connection charges. Although these measures are antithetical to renewable energy efforts in their arrest of solar PV development, they have been already implemented in a number of countries.

Instead of opposing solar PV adoption, a proactive strategy offers a long-term solution to the problem. It requires a move towards new business models, exploiting current capabilities and developing new ones. Here, the crux is to evolve quickly enough to adapt to environmental change. Richter argues that utilities in industrialised countries may be reluctant to innovate with new business models because of conflict with existing business models and risk aversion. Richter shows that business models for solar PV are the keystone to manage the transformation of the power industry toward renewable energy sources [12].

Utilities could therefore rethink their strategies to find a way to create and deliver value and to convert the solar PV threat into an opportunity [13], [14]. A systemic approach of the dynamics of PV business models could help utilities to make decisions about their future. Existing literature provides useful information about: (i) the effect of distributed solar generation on power industry, defined as small-scale electricity generation, not centrally planned and located near to the point of consumption (e.g., [15]–[20]) and (ii) Photovoltaic new business models for utilities (e.g., [21], [22]).

Nevertheless, there is still an important gap in the literature relating to a systemic approach for analysing the dynamics of PV business models as a means to offset revenue erosion of utilities caused by PV deployment. This study aims to fill this gap.

This research seeks to address following questions: How will penetration of distributed solar PV affect revenue of electricity utilities? Can the solar company be financially sustainable? What is the most suitable solar business model? If utility revenue is harmed due to the rise of, distributed solar PV, then: How can utilities be compensated by the solar company business? Under a scenario of subsidy cuts, then: What are the long-term effects of subsidy cuts on solar business models? How to improve the economic return of solar companies under subsidy cuts?

An in-depth quantitive case study has been considered to address/solve these issues. Specifically, a system dynamics (SD) model was built to represent the residential PV adoption in the British electricity market, their effects on utilities and solar companies. The British electricity market is an interesting case study because, first, it is a pioneer country in liberalization and market reform for decarbonization. i.e., this country has implemented important policies to encourage solar PV growth [23] ; second, recent cuts of one of these policies − feed-in tariffs for solar PV − have added uncertainty to the future paths of solar PV in this country motivating even more this research.

2. Literature Review

The impact of high penetrations of distributed PV systems has motivated publications in recent years; this section discusses the articles dedicated to study the impact of PV adoption on traditional utility business model. Further, in a later subsection, a literature review of business models based on distributed solar generation is also shown.

2.1. The impact of PV adoption on traditional utility business model

Researchers have investigated the financial impact of solar PV systems' expansion on different stakeholders in the short-term [16], [24], [25]. Eid et al. [16] indicate that Net Metering along with a volumetric charge produce an income-reduction to utilities and cross-subsidies, this effect is enlarged with a larger period for which surplus of electricity production is valid. Satchwell et al. [25] found that distributed solar generation may reduce the revenue of utilities, however the electricity tariffs would increase moderately even at the highest levels of PV penetration. Oliva et al. [24] conclude that utilities' revenue may be reduced depending on the level of PV exported.

Though the preceding review indicates that several authors have studied the utility death spiral issue by considering the feedback loops associated with PV adoption, only a few authors such as Grace [26], Laws at al., [27] , Castaneda et al., [28] have explicitly used System Dynamics (SD) methodology.

2.2. New utility business based on distributed

A broad spectrum of literature review of business models based on distributed solar generation is shown.

There is no consensus on the classification of business models for solar PV but three main business models were found by Huijben & Verbong [10]: Customer Owned; Community Solar and Third Party Ownership (TPO).

In the Customer owned PV business model the customers have enough money to purchase the PV systems themselves. The Community solar consists of multiple customers who purchase a portion of the generation of PV systems, and receive a compensation on their electricity bill. The Third-party ownership (TPO) business models are also known as solar service companies, and includes the leasing and PPA (Power Purchase Agreement) models [10].

In the leasing and PPA business models a long-term contracts (20-25 years) is signed between the third party (solar company) and customer, the third party owns install and operates the PV systems while the customer has access to solar energy and pays monthly instalments to the third party [29]. In the leasing business model, a fixed monthly payment is made to the solar company by customers; while in the PPA business model, customer makes a payment to the solar company per each kWh produced. The PPA payment is usually lower than electricity rate and grows to an escalation rate [21].

Most articles about solar business models are focus on making an overview of business models through a literature review or qualitative analysis [10], [21], [29]–[31] A different study is conducted by Rai & Sigrin who study the PV diffusion process considering a PPA vs a Leasing through a financial model for the residential PV market in Texas [32].

To date, no study has been developed about the long-term effect of solar companies on the deployment of distributed solar generation and electricity utilities. This objective is aimed through a system dynamics model that provides a systemic perspective of the electricity industry, the case study is the British electricity sector, which is an interesting case since the development of distributed solar generation is subject to high uncertainty due to the recent subsidy cuts.

3. Model Description

PV diffusion is addressed by two key drivers: the energy from the grid vs the energy from PV systems. When more PV adoption is produced, distribution companies may spread their fixed costs on the remaining energy consumption, this means to increase charges to compensate energy reduction by self- generation. As consequence, PV systems become more attractive and PV adoption increases even more. This feedback is illustrated in Fig. 1 (For more details see [5]).

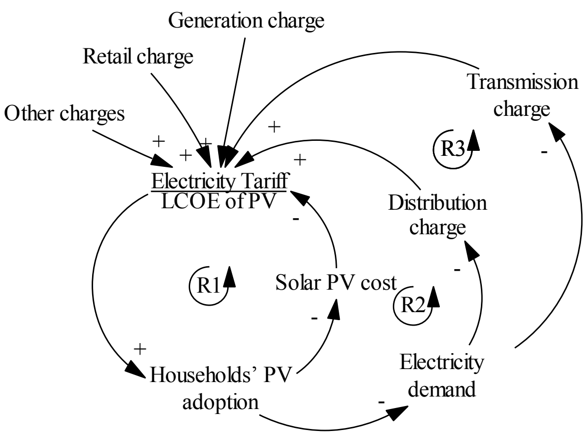

Fig. 1. Death spiral of utilities. Source: Authors.

The electricity tariff EC paid by consumers (Eq. (1)) incorporates the following components: generation charge G (also called electricity price in Fig. 1), transmission charge T, distribution charge D, retail charge R, and other charges that incentivise renewable energies and security of supply.

$$EC = G + T + D + R + Other \quad (1)$$

Next, the economic benefits of adopting a solar PV system through a PPA or leasing contract are described. It was assumed that customers seek the services of a solar company to acquire a solar PV system; this company may offer a PPA or leasing contract. It was also assumed that the solar company receives the government incentives such as a feed-in Tariff and export tariff.

For a PPA contract, the cost of adopting a solar PV system depends on the contract fee or Power Purchase Agreement PPA fee (y), which in turns depends on the levelised cost of electricity from solar PV (c) minus the solar PV incentives such as the feed-in tariff (v) and the income from the energy exported to grid (x.w). The latter depends on the energy exported (w) and the portion of energy exported to the grid (x), which is assumed to be 50%, and this term is multiplied by the profit margin 1+m (See Eq. 2).

$$y = (c - v - x \cdot w) \cdot (1 + m) \quad (2)$$

For a leasing contract, it was assumed that the leasing fee (z) is equivalent to the PPA fee (y) multiplied by the annual average monthly generation of a solar PV system ($\bar{g}$) (See Eq. 3).

$$z = y \cdot \bar{g} \quad (3)$$

The ratio of willingness to adopt, s_i, is depicted using a Logit Model [33], [34] that compares the net cost of adopting a solar PV system, CPV, against the cost of consuming energy from the grid, ET, where λ is a positive parameter that indicates the willingness to choose the PV technology (See Eq. 4). CPV is a function of the PPA payment or leasing fee, and the energy savings by self-consumption. In contrast, ET depends on the energy needs and the electricity tariff.

$$s_i = \frac{CPV^{-\lambda}}{ET^{-\lambda} + CPV^{-\lambda}} \quad (4)$$

Regarding the Bass model, this considers how information is disseminated through potential households that become PV-adopters. Eq. (5) establishes the equation developed by Bass [35] where the adoption rate, n(t), depends on the potential number of adopters, m, the cumulative number of adopters at time t, N(t), and coefficients of innovation and imitation, which correspond to p and q, respectively [35]:

$$n(t) = \frac{dN(t)}{dt} = p[m - N(t)] + \frac{q}{m} N(t)[m - N(t)] \quad (5)$$

Fig. 2 shows an overview of the model structure comprising of the main components of the model. The model proposed here integrates the dynamic and structural complexities of the electricity industry, including the key drivers of supply-demand interactions and their effect on investment decisions. Potential PV adopters grow due to difference between electricity tariff and cost of solar. Household PV adopters generate their own electricity, as a result buying less electricity from the grid, increasing solar PV adoption, therefore electricity tariff increases.

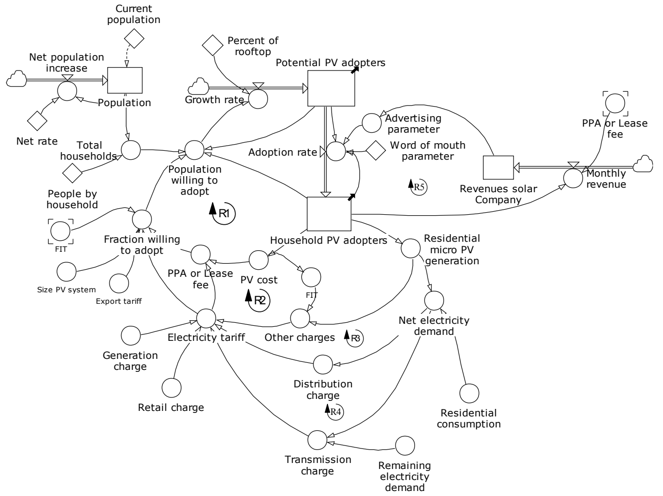

Fig. 2. Stock and flow diagram to simulate the effect of solar PV development on utilities and solar companies. Source: Authors.

Based on the proposed model structure, a formal simulation model was built in the Powersim software to test the dynamic hypothesis presented in Fig. 1. A simulation time horizon of 10 years (2016-2026) was considered enough to observe the mid- to long-term effects of the penetration of renewables.

3.1. Data

The inputs used for the model includes the cost associated to solar PV generation, average energy consumption, electricity tariffs, cost of battery, and current solar PV installed capacity in the British electricity market. Table 1 summarize the input used for the described model along with the main sources of information.

Table 1. Main inputs

Variable	Value	Source
Capex solar PV<4kW	1688£/kW	[36]
Opex solar PV<4KW	32.7 £/kW/year	[36]
Sun hours per month	{1.11, 1.75, 2.9, 3.8, 3.9, 4.06, 4.02, 3.52, 3.12, 2.16, 1.43, 1.01}	[37]
Lifetime	35 years	[36]
Hurdle rate	7%	[36]
Average electricity consumption	341kWh/month	[36]
Electricity tariff	14p/kWh	[38]
Number of households	27 million	[39]
Feed-in tariff	4.3p/kWh	[39]
Export tariff	4.9p/kWh	[39]
Solar PV deployment	10799MW	[40]

A p is the abbreviation of pence, i.e., 1 pence is equivalent to 0.01 pounds

The hurdle rate is the rate of return that a private fund guarantees to deliver to its investors, here it is used as a discount rate.

3.2. British electricity market.

In the late 1980s, Great Britain pioneered the liberalisation of electricity markets in the industrialised world. The most important changes included the creation of a wholesale electricity market – based on an electricity pool and long-term contracts– and the separation of activities along the supply chain in order to promote a competitive generation industry [38].

During the past few years, the political trend in the British electricity markets has not only been directed at inducing a competitive electricity industry; in 2011, British government proposed the Electricity Market Reform (EMR) seeking to reach environmental targets and delivering secure, sustainable and affordable electricity [39]. In this way, British electricity market is not only pioneer in liberalization but also in market reform for decarbonisation [23].

In 2016, the incentives to PV market were Renewable Obligation (RO) and Feed-in tariff scheme. The Feed-in tariff scheme available to small power generators was in place from 1st April 2010, PV systems lower than 50kW are only eligible for Feed-in tariff scheme [40]. Through a contract period of 25 years, the owners of solar panel benefit from Feed-in tariff scheme in three different ways, which are explained next [41], [42]: (i) PV producers gain a generation tariff per kWh produced also known as FIT during a period of 20 to 25 years − a PV system for a domestic household may produce 4448 kWh-year which are paid at a FIT rate of 14.90 p/kWh. Thus a household would receive £663; (ii) the electricity exported into the grid is paid at export tariff per kWh, which is an additional payment to the FIT, it is assumed that 50% of the solar energy production is exported into the grid – continuing the example above, the 50% of the PV energy produced is 2224kWh which is paid at the export tariff of 4.64p/kWh, thus the household would receive £103 by the exported energy; (iii) the electricity generated can be used to compensate the consumption reducing the energy bills, as 50% of the energy is exported and the reaming is used to satisfy domestic energy needs the energy bill savings are equivalent to multiply 2224kWh per the electricity of 15p/kWh resulting in £334. Add it all up the total savings amount to £1100 (see Table 2). However, if a household signs a contract with a solar company, the latter would receive the FIT, export tariff and monthly instalments (more than £766).

Table 2. Feed- in tariff scheme in the British electricity market

Benefits from feed-in tariff scheme	
Generation tariff	4480 kWh *14.9 p/kWh=£663
Export tariff	2224 kWh *4.64 p/kWh=£103

Energy bill savings	2224 kWh *15 p/kWh=£334
Total savings	£1100

The incentives provided for solar PV have contributed to a significant development of solar PV systems in the British electricity market (See Fig. 3). Recent changes in regulations have prompted uncertainty with respect to the development of solar business models because of tariff reductions of 64% (See Table 3). Therefore, many questions arise about the future and the power transition as grid parity of solar PV is near.

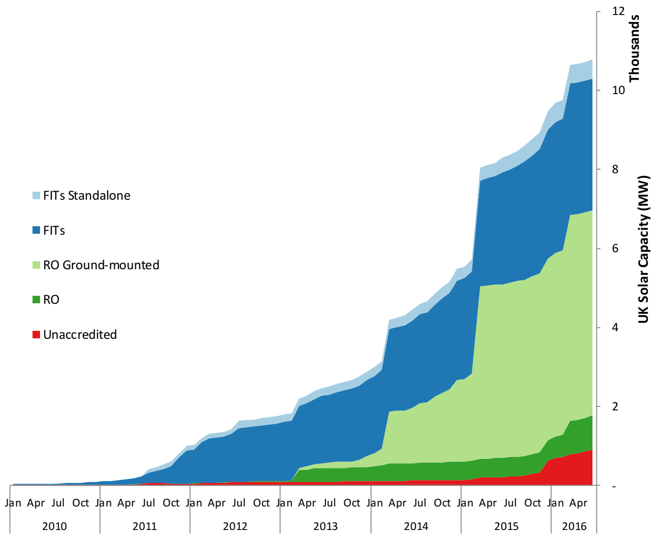

Fig. 3. Cumulative installation of FIT projects in GB, categorised by incentives. Source: [40].

Table 3. FIT tariff rates. Source: own elaboration with data from Ofgem. Source [36]

Tariffs (p/kWh)	Tariff January 2016 (<4kW)	Tariff February to March 2016 (<10kW)	Reduction January to February 2016 (%)
Higher rate	12.03	4.39	64%
Middle rate	10.83	3.95	64%
Lower rate	5.73	0.87	85%

The solar resource is a key variable for reaching the grid parity in Great Britain, where the seasonal component is significant as seen Fig. 4.

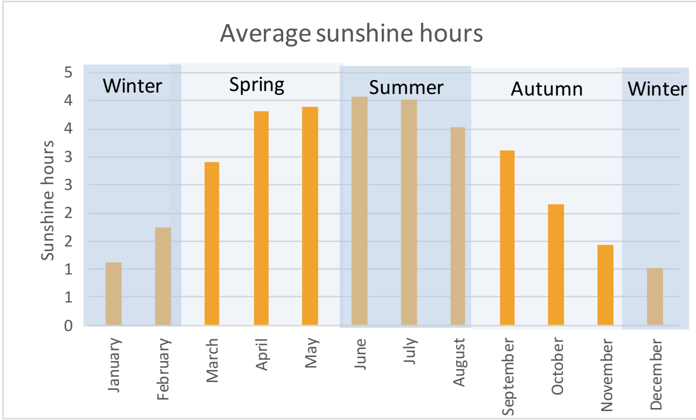

Fig. 4. Solar resource in Great Britain. Source: own elaboration with data from [44]

Regarding to the distribution charging methodology, low voltage customer including domestic customers pay two charges: (i) a fixed or standing charge to recover the forward looking cost of low voltage networks and (ii) the volumetric charge to recover the costs of higher voltage networks.

4. Results

Scenario-based modelling is helpful when the future is highly uncertain, as has been previously discussed in the context of the problem faced in this paper [45]. To analyse the effect of investments in distributed solar energy on the power market following scenarios are posed:

i) Business as usual (BAU) scenario
ii) Zero subsidy scenario

A BAU scenario includes the current state of incentives in the British electricity market along as the current distribution charging methodology. BAU scenario is used to answer research questions from subsection 4.1 to 4.3. Under a zero subsidy scenario the subsidies for solar PV are reduced to zero. Zero subsidy scenario is used to answer research questions from subsections 4.4 and 4.5. Results are mainly focused on two different business models (PPA and leasing) and their impact on the PV development and energy consumption at the residential level.

4.1. How will penetration of distributed solar PV affect revenue of electricity utilities?

Both business models lead to the same adoption of PV systems by households about 7 million households by the end of 2026, PV systems are adopted by 40% of the residential sector, this produces a reduction in the domestic energy consumption. Consequently, the energy consumption from the residential sector is reduced in the same ratio (11%) for both business models by the end of 2026 (See Fig. 5 and 6, respectively). Under these scenarios, utilities recover completely their costs, because the impact of the reduction in domestic energy consumption is spread on the remaining customers.

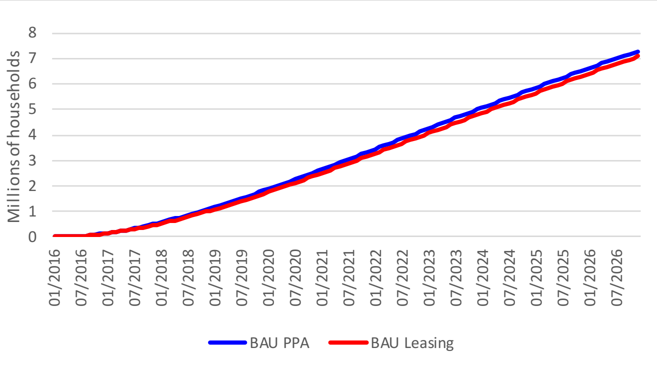

Fig. 5. Household adopters under a PPA business model vs a leasing business model

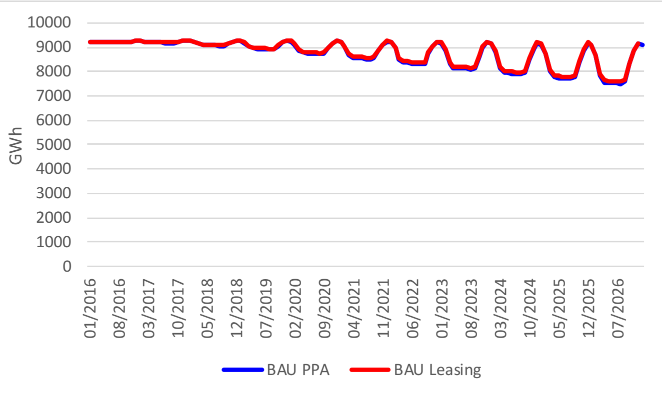

Fig. 6. Domestic energy consumption under a PPA business model vs a leasing business model

It is necessary to recognise under what conditions a death spiral of utilities is possible for the current British electricity market (Given that the electricity tariff has a transportation component –distribution charge–, which is mainly volumetric, i.e., it can be calculated as the fixed cost divided by the electricity demand [14]. With more PV systems in place, electricity demand falls, which forces utilities to raise distribution charges in order to compensate for energy usage reduction and to help recover costs; the rise in electricity tariff accelerates PV adoption and further charge increases, inducing to a death spiral of utilities [28].). In previous studies [5], it was identified a net metering scheme and oversized PV systems, i.e., An oversized PV array, is a PV system dimensioned to supply more than 100% of the household energy consumption. as keys for a death spiral of utilities. As net metering scheme is not possible for the British electricity market, because a feed-in tariff is in place. Oversized PV systems were tested; results suggest that costs of self-generation are increased significantly making the solar PV penetration lower than under a scenario of non-oversized PV systems (See Fig. 7). Therefore, current feed-in tariff payment is not enough to cover solar PV cost of oversized PV systems. Finally, though distributed solar generation leads to revenue erosion of utilities, an extreme scenario of death spiral for utilities in the British electricity market is unlikely, at least under the current conditions of the British electricity market.

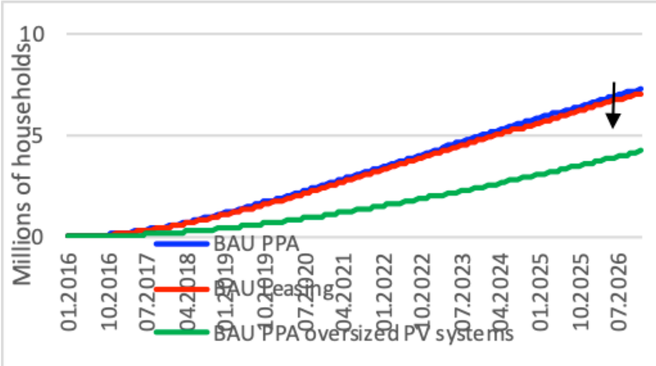

Fig. 7. Household adopters BAU vs oversized PV systems

4.2. *Can the solar company be financially sustainable? What is the most suitable solar business model?*

Results show that PPA business model is a more stable business in terms of revenues (see Fig. 8). This is because PPA is paid for each kWh of solar energy produced (declining from 13.12p/kWh to 10.67p/kWh between 2016 to 2026). While leasing is paid as a fixed monthly instalment according to a forecast of solar energy production (declining from 3763p/month to 3010p/month between 2016 to 2026). This situation makes the leasing business model vulnerable to recover their costs, since the leasing fee is a monthly fixed charge, during some periods the solar company will face losses while in some others earnings (See Fig. 9). To avoid this, leasing fee should exceed PPA fee instead of being financially equivalent to this.

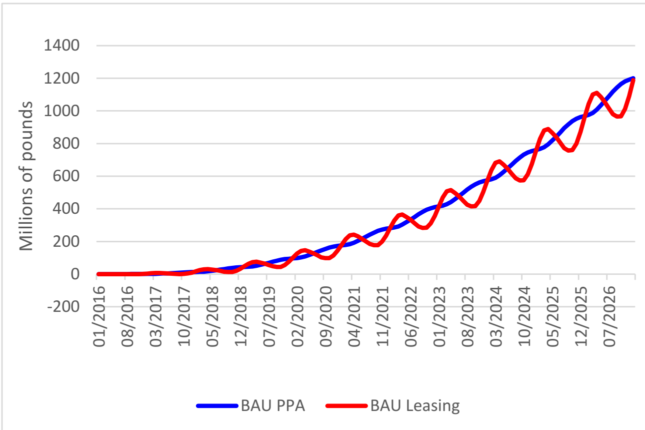

Fig. 8. Cumulative revenue from solar company under a PPA and a leasing business model

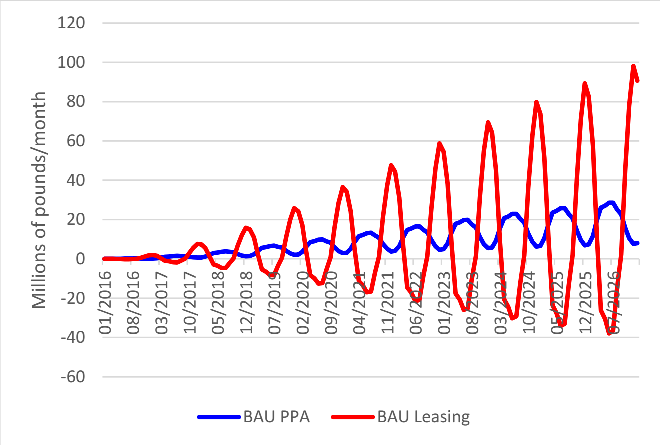

Fig. 9. Monthly revenue from solar company under a PPA and a leasing business model

4.3. *Can the electricity utility be compensated by the solar company business?*

Utilities may be hampered by the transition toward renewables, however the energy transition towards brings also opportunities for new incomes. For instance, the reduction in the domestic energy consumption is equivalent to a 20% of the distribution income, while the earnings for the development of a solar PV business model are equivalent to an 11%. These earnings depend on subsidies. Recently, subsidies for solar PV systems were reduced, which is adverse for the business development of solar companies, following results corroborate it under the extreme scenario of zero subsidies.

4.4. *What are the long-term effects of subsidy cuts on solar business models?*

When feed-in tariff and export tariff fall to zero, by the end of the simulation period the PV systems penetration rate (PV system penetration rate is equivalent to the total PV adopters divided by the total households, the later includes the PV adopters plus the non-PV adopters) is 20%, domestic energy consumption remains almost constant for both business models (PPA and leasing) (See Fig. 10 and 11).

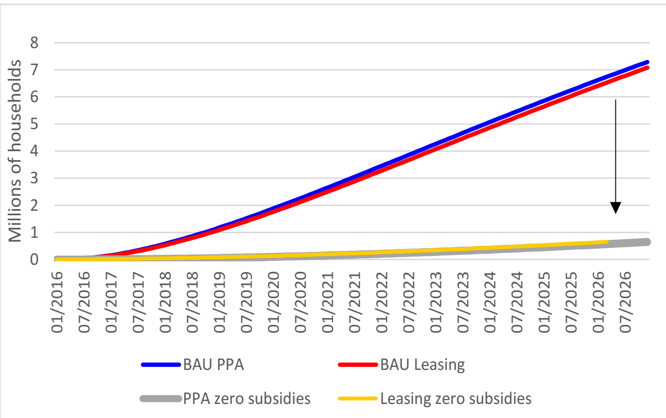

Fig. 10 Household adopters BAU vs zero subsidies

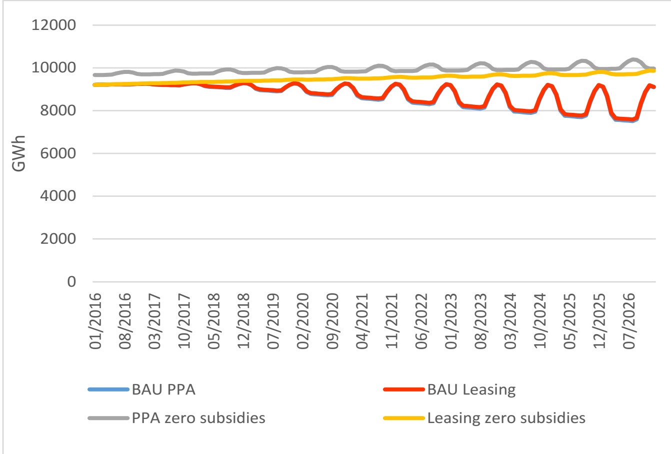

Fig. 11. Domestic energy consumption BAU vs zero subsidies

The effect of a cut in subsidies is negative for solar companies. Cumulative revenue from solar company is also reduced considerable, along with the monthly revenue. As solar PV adoption is lower, also the oscillations of leasing business model are lower (See Fig 12 and 13).

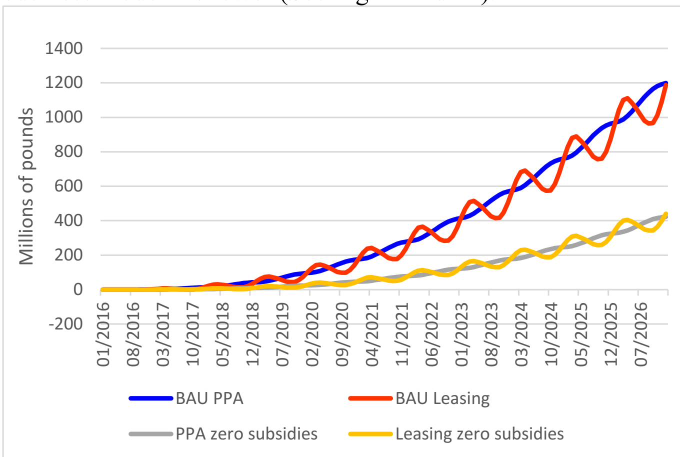

Fig. 12. Cumulative revenue from solar company under a PPA and a leasing business model

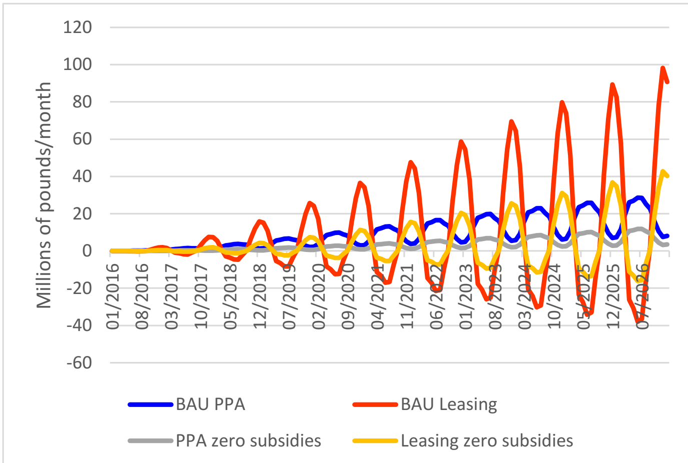

Fig. 13. Monthly revenue from solar company under a PPA and a leasing business model

4.5. *In a scenario of subsidy cuts, what energy services could be provided by the solar company to customers?*

When subsidies are zero, self-consumption will need to increase in the long-term to provide profitability to solar company. Therefore, under a zero subsidy world, the solar company must establish strategies to take advantage of the solar energy resource; this means that the solar energy produced during the sunshine hours must be used in a 100%. An alternative to reach this is to install solar PV systems plus a battery.

Findings suggest that under a zero subsidy scenario to offer a battery plus a solar PV system increases the benefits of the PV customers, therefore the solar PV adoption when batteries are promoted is greater than when they are not. However, the effects are only notice when the time framework is increase to 20 years (from 2016 to 2036) (See Fig. 14).

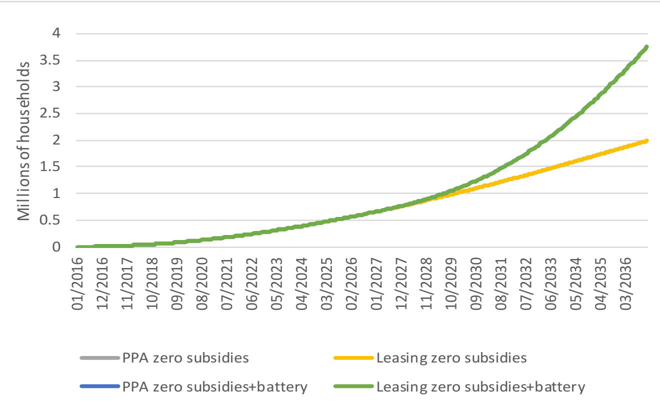

Fig. 14. Household adopters zero subsidies vs zero subsidies plus battery

In terms of benefits to the company, to add a battery to solar PV system portfolio reduces the revenue of the solar company, given that a cost is added (See Fig. 15). The increase in solar PV adopters for adding a battery does not compensate the increase in the cost of solar PV systems assumed by the solar company.

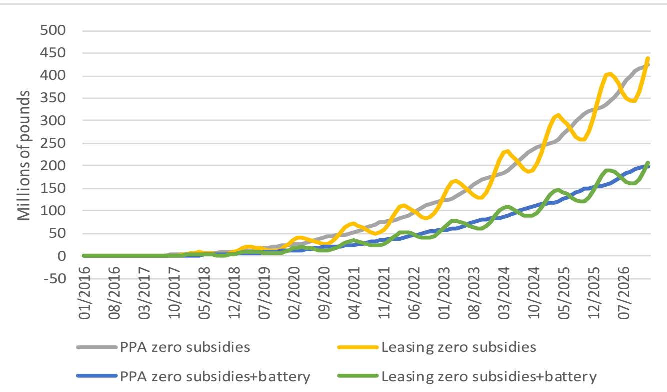

Fig. 15. Cumulative revenue from solar company under zero subsidies vs zero subsidies plus battery

5. Conclusion

This article provides a holistic view of the development of distributed solar generation on traditional business models and new business models. A scenario of the death spiral is not possible under current conditions in the British electricity market. A meaningful portion of the population may adopt solar PV systems, though this may reduce the long-term income for distribution companies, it is offset with increases of tariffs.

Under current conditions, a PPA business model seems a stable and therefore a safe option to sell solar PV systems. This in comparison to the leasing business model. The penetration of distributed solar PV produces a reduction of utility income of 20% while the earnings of solar companies are equivalent to an 11% of utility income. Even though solar companies may represent an opportunity to receive new incomes, this does not fully offset the needs of the utility sector. Additionally, the deployment of distributed energy resources must be seen as a whole, for instance the development of electric vehicles may increase the energy demand from the grid. Therefore, a traditional utility not necessarily will be harmed because of the power transformation.

Without subsidies, the solar PV industry will not reach high levels of development. A battery may improve the benefits for PV customers, but utilities will experience a reduction in incomes since batteries entails higher costs. However, this may change if future cost reduction of batteries is high enough.

Finally, under subsidy cuts, other strategies to maximize self-consumption may be exploring. Future research may be focused on following strategies: (i) to change energy consumption patterns to the hours of high availability of solar energy, (ii) to install a lower size array for the PV systems.

Acknowledgements

Universidad de Bogota Jorge Tadeo Lozano under grant 830-15-17 supported this research. We are grateful with our friends, which give us a lot of advice and support.

References

[1] IRENA, “Global Renewable Generation Continues its Strong Growth, New IRENA Capacity Data Shows,” 2018. .

[2] M. Taylor, P. Ralon, and A. Ilas, “The power to change: solar and wind cost reduction potential to 2025,” 2016.

[3] REN21, *Renewables 2018 global status report*. Athens, 2018.

[4] G. Masson, I. Kaizuka, and M. Brunisholz, “2018 Snapshot of global photovoltaic markets,” 2018.

[5] M. Castaneda, C. J. Franco, and I. Dyner, “Evaluating the effect of technology transformation

on the electricity utility industry," *Renew. Sustain. Energy Rev.*, vol. 80, no. 65, pp. 341–351, Dec. 2017.

[6] E. Funkhouser, G. Blackburn, C. Magee, and V. Rai, "Business model innovations for deploying distributed generation : The emerging landscape of community solar in the U.S.," *Energy Res. Soc. Sci.*, vol. 10, pp. 90–101, 2015.

[7] M. E. Wainstein and A. G. Bumpus, "Business models as drivers of the low carbon power system transition: A multi-level perspective," *J. Clean. Prod.*, vol. 126, pp. 572–585, 2016.

[8] G. Kungl, "Energy Research & Social Science Stewards or sticklers for change ? Incumbent energy providers and the politics of the German energy transition," *Energy Res. Soc. Sci.*, vol. 8, pp. 13–23, 2015.

[9] T. Stenzel and A. Frenzel, "Regulating technological change-The strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets," *Energy Policy*, vol. 36, no. 7, pp. 2645–2657, 2008.

[10] J. C. C. M. Huijben and G. P. J. Verbong, "Breakthrough without subsidies? PV business model experiments in the Netherlands," *Energy Policy*, vol. 56, no. January 2012, pp. 362–370, 2013.

[11] N. R. Darghouth, G. Barbose, and R. Wiser, "The impact of rate design and net metering on the bill savings from distributed PV for residential customers in California," *Energy Policy*, vol. 39, pp. 5243–5253, 2011.

[12] M. Richter, "Utilities' business models for renewable energy: A review," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 2483–2493, Jun. 2012.

[13] L. Okkonen and N. Suhonen, "Business models of heat entrepreneurship in Finland," *Energy Policy*, vol. 38, no. 7, pp. 3443–3452, 2010.

[14] O. Winarmo, A. Yogi, and S. Mujiyanto, "Policies and strategies for renewable energy development in Indonesia," in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 2016, pp. 270–272.

[15] N. R. Darghouth, R. H. Wiser, G. Barbose, and A. D. Mills, "Net metering and market feedback loops : Exploring the impact of retail rate design on distributed PV deployment," vol. 162, pp. 713–722, 2016.

[16] C. Eid, J. Reneses, P. Frías, and R. Hakvoort, "The economic effect of electricity net-metering with solar PV : Consequences for network cost recovery , cross subsidies and policy objectives," *Energy Policy*, vol. 75, pp. 244–254, 2014.

[17] A. Sarin, R. Gupta, and V. V Jituri, "Solar Residential Rooftop Systems (SRRS) in South Delhi : A Strategic Study with Focus on Potential Consumers ' Awareness," *Int. J. Renew. Energy Res.*, vol. 8, no. 2, pp. 954–63, 2018.

[18] P. Nammalvar, S. Ramkumar, and R. Umadevi, "Cost Effective Solitary Stage Single Phase Inverter for Solar PV Integration in to Grid," *Int. J. Renew. Energy Res.*, vol. 8, no. 3, pp. 1309–1317, 2018.

[19] M. Yesilbudak and A. Colak, "Integration Challenges and Solutions for Renewable Energy Sources, Electric Vehicles and Demand-Side Initiatives in Smart Grids," *2018 7th Int. Conf. Renew. Energy Res. Appl.*, vol. 5, pp. 1407–1412.

[20] Y. Utsugi, S. Obara, and Y. Ito, "Planning of the Optimal Distribution of Renewable Energy in Hokkaido, Japan," *4th Int. Conf. Renew. Energy Res. Appl.*, pp. 22–25, 2015.

[21] S. Tongsopit, S. Moungchareon, A. Aksornkij, and T. Potisat, "Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand," *Energy Policy*, vol. 95, pp. 447–457, 2016.

[22] D. Motyka, M. Kajanová, and P. Bracin, "The Impact of Embedded Generation on Distribution Grid Operation," *2018 7th Int. Conf. Renew. Energy Res. Appl.*, vol. 5, pp. 3–7, 2018.

[23] M. Keay, J. Rhys, and D. Robinson, "Chapter 2 – Electricity Market Reform in Britain: Central Planning Versus Free Markets," in *Evolution of Global Electricity Markets New Paradigms, New Challenges, New Approaches*, 2013, pp. 31–57.

[24] S. Oliva H, "Assessing the growth of residential PV exports with energy efficiency and the opportunity for local generation network credits," *Renew. Energy*, vol. 121, pp. 451–459, 2018.

[25] A. Satchwell, P. Cappers, L. Schwartz, and E. M. Fadrhonc, "A Framework for Organizing Current and Future Electric Utility Regulatory and Business Models," 2015.

[26] W. Grace, "Exploring the Death Spiral : A system dynamics model of the electricity network in Western Australia," 2015.

[27] N. D. Laws, B. P. Epps, S. O. Peterson, M. S. Laser, and G. K. Wanjiru, "On the utility death spiral and the impact of utility rate structures on the adoption of residential solar photovoltaics and energy storage," *Appl. Energy*, 2016.

[28] M. Castaneda, C. J. Franco, and I. Dyner, "Evaluating the effect of technology transformation on the electricity utility industry," *Renew. Sustain. Energy Rev.*, vol. 80, no. 65, pp. 341–351, 2017.

[29] H. Overholm, "Spreading the rooftop revolution: What policies enable solar-as-a-service?," *Energy Policy*, vol. 84, pp. 69–79, 2015.

[30] Q. Zhang and S. Su, "Determinants of urban expansion and their relative importance: A

comparative analysis of 30 major metropolitans in China," *Habitat Int.*, vol. 58, pp. 89–107, Nov. 2016.

[31] E. H. Enrique and J. D. Walsh, "Analysis of Touch Potentials in Solar Farms," in *3rd International Conference on Renewable Energy Research and Applications (ICRERA)*, 2014, pp. 916–921.

[32] V. Rai and B. Sigrin, "Diffusion of environmentally-friendly energy technologies: Buy versus lease differences in residential PV markets," *Environ. Res. Lett.*, vol. 8, no. 1, 2013.

[33] Bierlaire, "Discrete Choice Models," in *Operations Research and Decision Aid Methodologies in Traffic and Transportation Management*, Berlin: Springer, Berlin, Heidelberg, 1998, pp. 203–227.

[34] K. U. Rao and V. V. N. Kishore, "A review of technology diffusion models with special reference to renewable energy technologies," vol. 14, pp. 1070–1078, 2010.

[35] F. Bass, "A new product growth for model consumer durables," *Manage. Sci.*, vol. 15, no. 5, pp. 215–227, 1969.

[36] Ofgem, "FIT tariff rates," 2016. .

[37] E. & I. S. Department for Business, "National Statistics Solar Photovoltaics Deployment," 2017. .

[38] D. Newbery, "Missing money and missing markets: Reliability, capacity auctions and interconnectors," *Energy Policy*, pp. 1–10, 2015.

[39] D. M. Newbery, "Contracting for Wind Generation," *Econ. Energy Environ. Policy*, vol. 1, no. 2, pp. 19–36, 2012.

[40] L. Dusonchet and E. Telaretti, "Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in eastern European Union countries," *Energy Policy*, vol. 38, no. 7, pp. 4011–4020, 2010.

[41] F. Muhammad-sukki *et al.*, "Revised feed-in tariff for solar photovoltaic in the United Kingdom : A cloudy future ahead ?," *Energy Policy*, vol. 52, no. 2013, pp. 832–838, 2013.

[42] R. Cherrington, V. Goodship, A. Long, and K. Kirwan, "The feed-in tariff in the UK : A case study focus on domestic photovoltaic systems," vol. 50, pp. 2–7, 2013.

[43] Department for Business Energy & Industrial Strategy, "DUKES chapter 5: statistics on electricity from generation through to sales," London, 2017.

[44] European Commission, "Study on tariff design for distribution systems," 2015.

[45] I. Dyner and E. R. Larsen, "From planning to strategy in the electricity industry," *Energy Policy*, vol. 29, no. 13, pp. 1145–1154, Nov. 2001.