Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 145 (2016) 1448 – 1455

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Batteries as a service: a new look at electricity peak demand management for houses in the UK

Davis, M.J.M.[a,b]*, Hiralal, P.[c]

[a] *Pontificia Universidad Catolica de Ecuador (PUCE), Facultad de Arquitectura, Diseño y Artes (FADA), , Av. 12 de Octubre 1076 y Roca, Quito, Ecuador*

[b] *Evolution Engineering, Design and Energy Systems Ltd. 5 Silver Terrace, Exeter EX4 4JE, UK*

[c] *Department of Engineering, University of Cambridge, Trumpington Street Cambridge CB2 1PZ, Cambridge, UK*

Abstract

Tesla recently introduced its Powerwall line of batteries, aimed at a sector of housing with solar electricity installed. This paper considers the economics behind mass introduction of batteries in the housing sector in the UK from the perspective of peak demand management. Utilities use differential tariffs (such as the Economy 7 tariff on Southern Electric in the UK) to encourage more homogeneous loads. Given current costs of battery systems, this work considers the rates of return that may be possible by buying electricity from the grid in times of low demand, and reselling at peak demand from the perspective of an average UK household. We consider the regulatory framework that would have to be in place to make this feasible and look at the effect a mass uptake of battery technology would have on peak demand management in the UK scenario. Overall however, it is found to not be economically feasible at current prices without heavy government subsidies.

Peer-review under responsibility of the organizing committee of ICSDEC 2016

Keywords: Batteries; Electricity peak demand; Tariffs; low demand; UK.

* Corresponding author. Tel.: +441392581579 / +593981869424.
E-mail address: davismaks@evolutionecoengine.com

Peer-review under responsibility of the organizing committee of ICSDEC 2016
doi:10.1016/j.proeng.2016.04.182

1. Introduction

Energy storage has been recognised to play a fundamental role in making a more efficient use of our energy resources. From storing excess renewable energy for times of no production to managing peak consumption demands, the ability to store energy is fundamental for matching demand and supply, and hence reducing the requirement for excess production. In recent years, several battery technologies have appeared as contenders for grid scale storage, perhaps the most publicised example being Tesla's attempt. The UK government recently put out its Green Deal [1], an initiative aimed at incentivizing economically sound energy efficiency investments for homeowners, in which the work and installations are done at zero up-front cost and repaid as a function of savings in the energy bill, ensuring only economically viable improvements are made. In this context, this work looks at the economic viability of home based battery energy storage systems for a typical UK household. In this case excess electricity is bought to charge the battery in times of low demand when electricity is cheap, and then peak demands (when electricity is expensive) are drawn from the battery instead of from the national grid. In the current context, the only variable pricing system available in the UK is Southern Electric's Economy 7 tariff, which is taken as an example from which to justify the economic viability of these devices.

2. Methodology

The benefits of the storage system can be quantified from two different viewpoints. On one side, maximising the economic returns locally. In this case, the battery is fully charged at night time (low cost) and fully discharged during peak time (high cost), and the battery sizing is an optimization between reducing overall system cost per kWh and maximising its usage and lifetime. On the other hand, a global viewpoint may be taken. In this case, the battery pool performs collectively for matching demand and supply. This second option may have larger benefits overall, but requires more complex pricing models in order for the final user to benefit.

In order to study peak demand management, it is first necessary to understand the typical consumption profile of a British home. Palmer et al [2] looked at 24 houses and profiled their electrical power consumptions throughout the day. Using their consumption data as a basis, it is possible to: a) see how much electricity would need to be stored in order to mitigate peak household electricity demands, b) determine the size and type of battery that would be needed to do so.

The demand profile studied was for houses with no electric heating. Additionally, all the households and residence types and sizes were included. Finally, all of the days of the year were used. The 24-hour consumption profile for a typical UK house is shown in Figure 1.

Now, with the consumption profile established, there are several ways a battery may be employed to treat the variations. On a first approach, the battery is used to maintain household demand flat. This is achieved by dividing the profile in two in such a manner that the area of the peaks (above the division line) is equal to the area of the troughs (below the division line). As such the kWh that would need to be stored in periods of low demand (the total trough areas), in order to satisfy the kWh that would be needed in the times of peak demand (the total peak areas), could be calculated. It is noted in practice the peak area would have to be about 95% of the trough area to compensate for charging inefficiencies in the battery. This was then coupled with a battery with the capacity to meet this storage demand. The result of this is to flatten the household electricity demand,

A second approach was to displace *all* of the daytime electricity demand to the nighttime period. This approach maximizes the economic returns than can be obtained from day/night price differentials, and allows to determine the economic viability of the technology in the current market with no subsidies and pricing changes. Although this approach does not serve to flatten the household consumption, it will contribute to normalizing the overall grid consumption. Firstly, the uptake of batteries in UK households will not be instantaneous; therefore overcompensation is actually helpful. Secondly, a good part of the consumption from the national grid is not from housing but from other sectors such as business. In practice there is always excess power at night times. The process would more likely be gradual, and as such it makes more sense to offer stronger incentives to early up-takers who install a battery. These early clients would benefit from greater savings for their electricity bills. Further down the line, once a critical mass of household batteries is reached, adjustments could be made more in line with flattening the electricity demand from households outlined above. This would be similar to the approach taken in subsidizing solar power in the UK. From 2008 to 2014 the average price of PV modules fell by 80%, principally as a result of economies of scale [3]. This was in comparison to installed capacity in the UK increasing from 24 MW in 2008 to 1000 MW by the last quarter of 2011 [4]. Controversial as the setting up and stopping of subsidies may be, they may be necessary for to make the technology a viable investment until economies of scale can bring cost down.

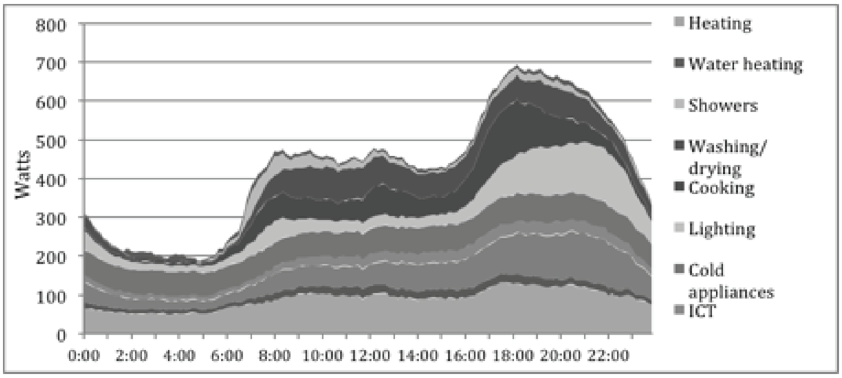

Fig. 1. 24 hours household electricity profile studied [2].

3. Results

3.1. Charge-Discharge Scenarios

The charge discharge profiles of the two scenarios described above are shown in figure 2. The division of the graph where the peaks (above the division line) are equal to the area of the troughs (below the division line) can be seen in Figure 2(a), where the total area of peaks or troughs was found to be 1.48 kWh. The model in which all of the daytime demand is displaced to cheaper nighttime rates is shown in Figure 2(b), where a total of 5.87 kWh can be displaced. In this case the time period between 7am and 7pm was taken, which corresponds to Southern Electric's Economy 7 tariff for households without electric heating [5].

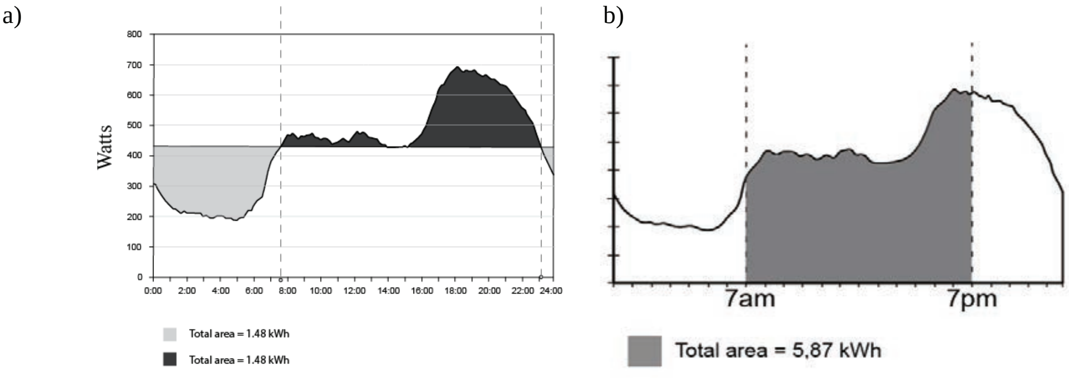

Fig. 2 (a) peaks = troughs division of 24-hour profile; (b) displacement of *all* daytime demand to nighttime

3.2. Energy (kWh) Displacement

In order to understand the economics of a system, it is fundamental to understand the price differential and the amount of energy that may be displaced on a typical household. Clearly, the second scenario, where all daytime consumption is supplied by batteries, allows for the biggest energy displacement, the amount saved is simply 5.87 kWh per day as shown in Figure 2 (b).

In the case of the first scenario where peaks equal troughs, the next step is to quantify exactly how much savings would be made under the Economy 7 tariff. In order to do this the areas need to be considered with respect to the times of the price changes. According to Southern Electric, for houses with gas or oil-fired heating electricity used from 7pm to 7am Monday to Friday is supplied at a cheaper tariff [5]. These times are shown on the electricity demand graph in Figure 3a. In terms of the savings to be made, there is an overlap in A) where despite being in a trough area (low demand) the price changes to a more expensive tariff. In practical terms this implies that excess expensive electricity would be purchased to charge the battery, to then be used to offset expensive electricity being purchased in a corresponding section of peak usage. As such, the replacement of expensive electricity with expensive electricity can be said to be nothing lost-nothing gained. The same is true in section C), where despite being in a period of peak demand the Economy 7 tariff charges a cheaper rate. Therefore in this period cheap electricity that would have already been bought in a trough period offsets cheap electricity in a peak period. Once again, nothing lost-nothing gained. Area B) is the one of most interest in this case, as it represents peak demands in a period of expensive electricity tariffs. This means that electricity that would be expensive to purchase is offset by electricity from the battery bought in trough periods where it is cheaper. By quantifying the kWh of area B), it is possible to estimate the savings that would be made. This is shown in Figure 3, where a total of 0.77 kWh of expensive electricity is replaced by electricity bought in cheaper periods to charge the battery.

It would be better to have the price change more in line with the switch from trough to peak. For houses with electric heating Southern electric offers cheap electricity between 11:30 pm and 06:30 am [5]. Electric heating changes the electricity demand over a 24 hour period greatly. However, if the cheaper electricity were offered for houses without electric heating in the 11:30 pm to 06:30 am period, this would give an improved total of 1.43 kWh of expensive electricity is replaced by electricity bought in cheaper periods (Figure 3.b). In an ideal scenario, the full 1.48 kWh savings would be made as in Figure 2.

a) b)

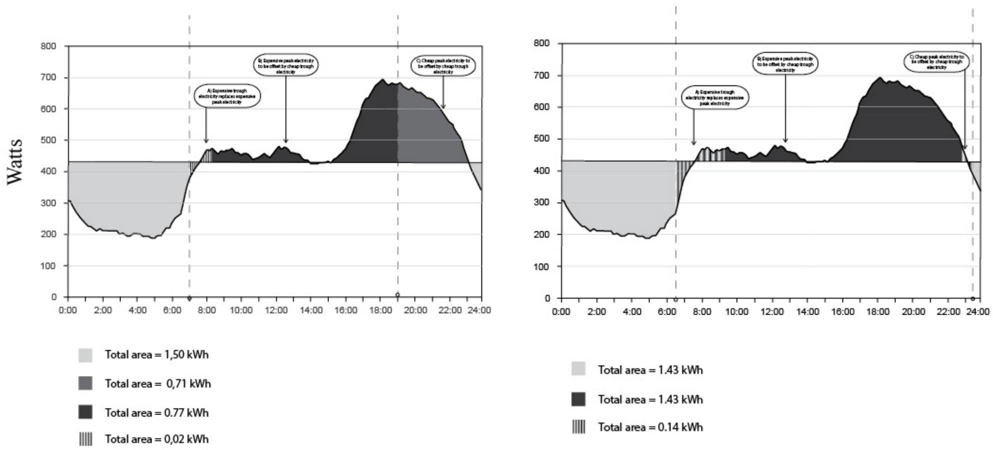

Fig. 3. A closer look at costs (a) Economy 7 from 7pm to am, and (b) Economy 7 from 11:30 pm to 06:30 am

Therefore, assuming an 80% depth of discharge for a battery, peak flattening would require around a 1.9 kWh system, whilst a 7.3 kWh system would be required to completely supply peak time demand from the household.

4. Discussion

4.1. The savings to be made

Southern electric sets its price per kWh at 7.54p per kWh during nighttime and 16.07 per kWh during the day Monday to Friday [5]. Let it be assumed that there are 260 weekdays for the 52 weeks of a year. For the first scenario where peaks equal troughs, this would give the annual savings of:

a) 17.08 GBP for 7pm to 7am tariff.
b) 13.71 GBP for 11:30pm to 06:30 am tariff.
c) 32.82 GBP for the ideal situation where the tariff is in line with the peak-to-trough change.

For the second scenario, where all of the daytime demand would be displaced to the nighttime period, the annual savings become:

d) 130.18 GBP.

This therefore sets the maximum costs of any battery system to be economically viable at the current market with no energy pricing modifications.

4.2. Choosing a battery and the costs involved

Three battery types are considered here: Lithium-Ion, Lead-Acid and the Aquion Energy Aqueous Hybrid Ion (AHI) technology. These were chosen due to the fact of the first two being readily available, with Tesla's recent introduction of its products into the market having sparked particular interest. The third was chosen due to it also being available on the market, in addition to it having excellent environmental credentials and being the only Cradle to Cradle registered product [6].

In terms of costs, a full economic analysis is out of the scope of this study. However, an appreciation can be made for the investments involved through carrying out some initial calculations. A Lithium-Ion battery configuration for solar installations costs per kWh vary between 600 USD (413 GBP) [7] and 700 EUR (526 GBP) [8]. In the case of a Tesla Powerwall, a 7 kWh battery is advertised at 3000 USD [9], giving a cost per kWh of only 428.6 USD (295 GBP). In terms of Lead-Acid batteries, battery configurations for solar installations cost per kWh capacity are between 120 USD (82.6 GBP) [7] and 150 EUR (112.9 GBP) [8]. This would need to be doubled however, in order to take into account that they are limited to up to 50% discharge for each cycle [7]. Finally, the AHI battery costs 1094 GBP for a stack that gives approximately 2 kWh per cycle [10]. Additionally, the cost of the inverter and installation need to be taken into account. As an example, Solar City offers an all-round service for the Tesla's PowerWall battery and installation for small-scale household systems that comes to 714 USD/kWh (498 GBP/kWh) [11]. For this paper a fixed cost for the inverter and installation is taken from SolarCity as 7140 USD (cost of package), minus 3500 USD (cost of 10 kWh PowerWall SolarCity installs), given a total of 3640 USD (2545 GBP).

Another factor that needs to be taken into account for payback periods is the battery lifetime, which is usually given in terms of charge/discharge cycles. A Lead-Acid battery has the shortest lifespan of up to 1000 cycles if in a moderate climate [7] (2.7 years daily use). Tesla offers a warranty for it's PowerWall of up to 10 years [9], which equates to 3650 daily charge/discharge cycles. Regarding the AHI battery, it is said to have a life of 3000 full charge/discharge cycles [6], which would equate to 8.2 years of daily usage.

4.3. Net Present Values

For this paper a simple Net Present Value (NPV) calculation has been carried out, using the savings to be made in section 4.1. A 10% discount rate was used, which was in accordance to the DECC's Electricity Generation Cost calculations [12]. The battery lifetime was taken for the number of years a return is made. For Lithium-Ion, Telsa's 10 year warranty was adopted. Scenario 4 was considered first, as it would be the most favourable scenario. This gave the initial input variables of:

- Discount rate: 10%.
- kWh displaced (for battery sizing): 5.87 kWh.
- Inverter and installation costs: 2545 GBP.
- Return per year: 130.18 GBP.

The results are shown in Table 1.

Table 1. NPV results.

Battery type	Battery Initial Costs (GBP)	Total Initial Costs (GBP, including inverter & installation)	Battery lifetime (years)	NPV (GBP)
Lead-Acid	5511.93	8056.93	2.7	-6,973.59
Lithium-Ion	2755.965	5300.965	10	-4,091.88
Tesla PowerWall (7 kWh)	2099	4644	10	-3,494.64
AHI	3282	5827	8.2	-4,710.08

Overall, it is evident that the NPV would not be of interest for individual homeowners. By running the calculation in reverse, it is possible to reach the point the homeowner would break even if a 130.18 return were made per year. In order to have a NPV of approximately zero, a limit to the initial investment would be 800 GBP, where anything over this would not provide a positive return. It is suggested in this paper that a value of 500 GBP as initial investment for the homeowner could be adopted.

4.4. Not a private enterprise, but a service to be paid for

It is clear to see that it would not be of interest for homeowners to have a battery installation. To this extent, it is argued that the initiative should be government or utility company led. In essence, the homeowners are providing a service to the national grid that negates the need to run expensive power plants held in reserve to meet peak demands only. The national grid reported to have spent 27.95 million GBP to utilise 233 GWh of Short Term Operating Reserve (STOR) power plants from April 2014 to March 2015 [13]. This is equivalent to 120 GBP per MWh, or 12p per kWh. There is also debate that the need for STOR plants has led to a recent boom in polluting diesel micro-plants [14]. 12p per kWh is also similar to the Feed-In Tariff rate for residential solar photovoltaic systems [15]. As such, it is argued to not be unreasonable to pay homeowners with a battery system installed for every kWh of peak electricity demand displaced, *in addition to* the savings the homeowner would make from the Economy 7 tariff.

4.5. Need to subsidize until the price drops

Unfortunately, in the end even if the national grid paid an extra 12p per kWh displaced, it would not be profitable for the homeowner to install a battery. The break-even point, where the NPV would be approximately zero, would be increased from 800 to 990 GBP. Neither would the NPV for the national grid be positive if it were to install batteries enough to flatten the domestic peak demand. This begs the question: "How much would the government be willing to pay?". The benefits in mass battery household battery installations are clear terms of: energy security of supply, CO_2 emission reductions and mitigating the need to construct new power plants to replace decommissioned ones, as well as being able to rely more heavily on fluctuating renewable sources. However, it is the work of further research to quantify these benefits in monetary terms. As it stands, maybe the national grid could be convinced to pay 12p per kWh produced. Perchance the homeowner might be willing to invest 600 GBP (thus earning a NPV of 356 GBP over 10 years). This would then still leave a 4044 GBP gap per household to be filled.

5. Conclusions

This paper put forward that a battery is added to households to displace the daytime peaks of domestic electricity demand. It was suggested that excess electricity is bought to charge the battery in times of low demand when electricity is cheap, and then peak demands (when electricity is expensive) are drawn from the battery instead of from the national grid. For this to be possible a differential tariff system is necessary, and the Economy 7 tariff of Southern Electric was used as a point of departure.

Overall, at present it would not be an attractive investment for homeowners, even if they were to displace all of their daytime demand to cheaper night time periods. The break-even point could be raised from 800 GBP to 990 GBP if the national grid were to pay 12p for every kWh displaced. This would be equivalent to the costs of running STOR plants to meet peak demands. However, a gap of over 4000 GBP would still need to be filled in order to cover the battery, inverter and installation costs. It is suggested that further research into government subsidies could be of interest however, given the benefits to be gained in terms of: energy security of supply, CO_2 emission reductions and mitigating the need to construct new power plants to replace decommissioned ones, as well as being able to rely more heavily on fluctuating renewable sources. Over time, through subsidizing battery costs the prices would drop due to economies of scale, similar to that observed with solar photovoltaics. Furthermore, for larger scale batteries, the costs per kWh may be reduced and start to become more attractive.

6. Recommendations for further research

It is recommended in the future that the role of government subsidies and economies of scale be studied in greater depth. It would also be of interest to try to carry out a prototype installation in practice.

Acknowledgements

The research project would not have been possible without the dedication, support and patience from a team of undergraduate students from the Department of Architecture, Arts and Design from the Pontificia Universidad Católica of Ecuador. In particular, thanks are extended to: Giselle Aguirre, Johanna Cuito, Zaoky Guanoluisa, Jimena Román, Dario Silva, Ana Carolina Mesias and Paola López.

References

[1] United Kingdom Government, Department of Energy & Climate Change. Electricity Market Reform: Capacity Market 2015. UK: Department of Energy & Climate Change; 2015. Available from: www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/electricity-market- reform [Accessed 07 January 2016].

[2] Palmer J, Terry N, Kane T. Early Findings: Demand side management. UK: Cambridge Architectural Research, Loughborough University, Element Energy; 2013. Available from: http://www.eclipseresearch.co.uk/download/energy/Early%20Findings%20revised%20200613.pdf [Accessed 30 November 2015].

[3] Ferroukhi, R. et al. RETHinking Energy. IRENA. 2014. Avilable at: http://www.irena.org/rethinking/Rethinking_FullReport_web.pdf [Accesssed 16 January 2016].

[4] Department of Energy and Climate Change. Solar Photovoltaics Deployment, United Kingdom, December 2015. Available from: https://www.gov.uk/government/statistics/solar-photovoltaics-deployment [Accessed 06 January 2016].

[5] SSE Southern Electric [www.southern-electric.co.uk], Gas and Electricity, Different Meters Types, United Kingdom, [date unknown]. Available from: https://www.southern-electric.co.uk/GasAndElectricity/YourMeter/DifferentMeterTypes/ [Accesssed 06 January 2016].

[6] Aquion Energy. The Advantages of Aqueous Hybrid Ion Batteries over Lead Acid Batteries. United States: Aquion Energy; 2014. Available from: https://cdn2.hubspot.net/hubfs/147472/01_Product_Documentation/Aquion_Energy_S20-P08F_Product_Specification_Sheet.pdf [Accessed 06 January 2015]-

[7] Albright G, Edie J, & Al-Hallaj. A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications, AllCell Technologies LLC, Alternative Energy eMagazine Industry ,United States, 2012. Available from: http://www.batterypoweronline.com/main/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf [Accessed 06 January 2015].

[8] Powertech Systems. Lithium-ion vs Lead-Acid cost analysis, 2015. Available from: http://www.powertechsystems.eu/home/tech-corner/lithium-ion-vs-lead-acid-cost-analysis/ [Accessed 06 January 2016]

[9] Tesla. Tesla-Powerwall, United States, Tesla Motors, 2015. Available from: https://www.teslamotors.com/powerwall [Accessed 06 January 2015]

[10] Wind & Sun Powering the future, Aquion Energy Batteries, United Kingdom,[date unknown]. Available from: http://www.windandsun.co.uk/products/Batteries/Aquion-Energy-Batteries#10918 [Accessed 06 January 2016].

[11] Randell, T.. SolarCity Taking Orders for Tesla Batteries Starting at $5000. Bloomberg Business. 2015 May 01. http://www.bloomberg.com/news/articles/2015-05-01/solarcity-taking-orders-for-tesla-batteries-starting-at-5-000 [Accessed 06 January 2016].

[12] United Kingdom Government, Department of Energy & Climate Change, Electricity Generation Costs 2013, United Kingdom, 2013. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223940/DECC_Electricity_Generation_Costs_for_publication_-_24_07_13.pdf [Accessed 07 January 2016].

[13] the National Grid. STOR Annual Market Report Data 2014-15. National Grid. Available from: http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=44494 [Accessed 06 January 2016].

[14] Macalister, T. UK energy bill subsidies driving boom in pollutting diesel farms. The Guardian Energy. 2015 May 06. Available from: http://www.theguardian.com/environment/2015/may/06/uk-energy-bill-subsidies-driving-boom-in-polluting-diesel-farms [Accessed 12 January 2016].

[15] Ofgem. Feed-in Tariff (FIT) Payment Rate Table for Photovoltaic Eligible Installations (1 January 2016 – 31 March 2016). Ofgem e-serve. 2015 Oct 30. Available from: https://www.ofgem.gov.uk/sites/default/files/docs/2015/10/fit_payment_rate_table_for_publication_1_january_2016_pv_tariffs.pdf [Accessed 12 January 2016].