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THE IMPACT OF DISRUPTIVE TECHNOLOGY ON THE PERFORMANCE OF ELECTRICITY COMPANIES IN INDONESIA, STRATEGIC MANAGEMENT PERSPECTIVE

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Abstract

The power utility industry is in the midst of transition driven by three global movements; de-carbonisation, de-centralisation and digitalisation. The 4.0 revolution direct the electricity environment is becoming more complex than ever before, with rapidly evolving disruptive technologies. This study is to assess empirically how such disruptive technology affect power utility industry. The three most disruptive technologies have been investigated; solar PV, battery energy storage and smart grid. Based on 336 engineers' reviews from 118 business unit of Indonesia Electricity State Company, it is found that not all disruptive technology does negatively affect the firm performance. The customer pulls and digitalisation as the antecedents of the disruptive technology have been assessed. Instead of their negative impact, the firms can utilise certain disruptive innovation to be beneficial for their competitive advantages if they know a way to deal with it.

Keywords: Disruptive technology; digitalisation; power utility industry; customer pull; solar PV; battery storage; smart grid

INTRODUCTION

Technology continues to evolve and reshape business model, pushing companies to find an inno- vative way to deal with its unpredictable and fast changing. The negative impact of it is disruptive technologies, continue to pose challenges for industries worldwide, and firms are constantly learn- ing how to adapt in order to survive. The key driver of the disruption is rapid technological advances providing product or service with better performance and competitive price. Nowadays the Fourth Industrial era build on the digital uprising and combines multiple technologies leads to unprece- dented paradigm shifts in the economy, business, industry, social, community, and for individuals.

The 4.0 revolution drive the electricity environment is becoming more complex than ever before, with rapidly evolving technologies, emerging innovative business models and shifting regulatory landscapes. Practically, the disruption to the grid occurs by three impacts: significantly decreasing cost with continuous technical enhancements, empowering customers by enabling such innovative business models, and increasing utilisation rate of the electricity system across its supply chain (World Economic Forum 2017, MIT Energy Initiative (MITEI) 2016). However, following the

Christen- sen’s disruptive innovation theory, the most affected factor is lowering cost by providing better per- formance (Christensen 2000).

Thus, along with the depletion of fossil energy and climate change awareness, the economic advantage of renewable energy will be masked (Swenson 2016). Referring to a report in 2017 issued by the International Energy Agency (IEA), the wind and solar power costs fell dramatically due to soaring capacity factors. This brings renewable energy penetration close to a 20% to 30% share in some markets. Following PV module price drops of more than 80% in the past 5 years, global PV deployment has increased from a base of 3.7 Giga watts in 2004 to more than 150 GW in early 2014.

This renewable global shift has affected the power utility at some regions in term of ‘negative price’. When electricity prices in Germany have reached as low as negative 320 euro per mega- watt-hour and frequently remain below zero for hours at a time, the share prices of three Germany’s key players have collapsed by 45 percent to 66 percent over the five years. In US, The Electric Reliability Council of Texas faced negative prices in nearly 18 percent of generating hours in 2011. At the same year, some California Independent System Operator units faced negative prices for nearly 6 percent (MIT Energy Initiative (MITEI) 2016).

For all stakeholders the trend is clear: renewable energy is no longer a niche resource in many global power systems, but rather one of the largest sources of new generating capacity (MIT Energy Initiative (MITEI) 2016; International Energy Agency 2019). A steady shift towards renewable energy products has exacerbated the disruption of utility business models (Li, Porter, and Suominen 2018; Rachinger et al. 2019). Unfortunately, the disruptive technology for the grid system is not just renewable energy especially Solar and Wind energy but also other different technologies such as smart sensors, artificial intelligence, robotic, battery energy storage, and smart grid.

Utilities should find new ways to adapt to the ongoing changes if they wish to remain survive. Even though extinction of the utility is still too far but the time has finally come for utilities to trans- form themselves for dealing with the unprecedented disruption. Therefore, one of the first thing to do is defining what types of technology is really disrupt their business, and which have the most impact on their firm performance both financially and non-financially.

LITERATURE REVIEW

The adoption of new technologies on power sector such as smart metres, energy storage, electric vehicles, and advanced automation, have forced the utility to experience a rapid change of their business model. Implementation of Smart meter with AMI (Advanced Metering Infrastructure) system, for example, has created two ways communications putting utilities and customers on an equally commercial relationship. It changed the way of utility to gather data, collect the bill, count the consumption, and deliver information of their customer. Even though emerging technol- ogy is not always to be disruptive innovation, yet if they are able to create new markets then it pushes the incumbent firm to 'red ocean' situation (Christensen and Bower 1996). Along with other rivalry forces, the disruptive technology is able to bring down the status quo in existing market (Christensen and Bower 1996; Christensen 2000), and even displace the incumbent (Christen- sen and Bower 1996). A recent study shows that disruptive technology has a significant negative effect on the utility firm's competitive advantage (Marica 2014).

Disruptive technology

The disruptive technology can be traced back to the origin Schumpeter's 'destructive innovation' theory, although it has been popularised lately by (Christensen and Bower 1996). The concepts have been widely adopted in academic dialogue and applied to the corporate strategy practices (Christensen 2000). At power utility industry, the advancement of disruptive technologies for both demand and supply side have pushed utilities to shift from an old to a new system which is not only more reliable, but also sustainable and affordable (Marica 2014; Afrianda 2024). The concept of a large centralised fossil-based energy is shifting to a decentralised system integrating by renewable energy sources combining with other emerging technologies such as dynamic forecasting, data ana- lytic and smart sensors. By empowering customer to well use energy based on the preferences of price and eco-friendly, the new business model authorise the grid to be more secure, reliable and efficient (Bhatti and Danilovic 2018).

Nowadays the power utility industry is in the midst of transition, driven by three global issues; de- carbonisation, decentralisation and digitalisation (World Economic Forum 2017; Di Silvestre et al. 2018). Those make a certain landscape to create some technologies becoming the game changers for the industry (Black & Veatch 2016; Di Silvestre et al. 2018). Battery storage has started to play a broader role in energy markets, moving from niche uses to broader ones primarily providing power- quality services, and supporting renewable integration (Frankel and Wagnerm 2017; EY 2018; Thomas et al. 2018). Cheap and cheaper solar PV is already eroded some markets of utilities, has reinforced consumer motive for self-sufficiency and grid independence (MIT Energy Initiative (MITEI) 2016; Rachinger et al. 2019; Frankel and Wagnerm 2017). Then a smart grid changes the way of utilities to manage demand respond, conserve energy, maximise asset utilisation, improve grid security and reliability, and reduce its carbon footprint (Agnew, Smith, and Dargus 2018; Bhatti and Danilovic 2018; Rachinger et al. 2019).

Customer pull

Basically, the antecedent of technology disruption is only two things - technological 'push' and customer (or markets) 'pull' (Flügge, Janner, and Schroth 2006; Di Stefano, Gambardella, and Verona 2012). 'Technology push' refers to disruptions that come from emerging technology which plays a critical role to create new niece market by delivering better performance than the existing one. Its original source is R&D center, laboratory, university and other technology develo- pers. Meanwhile 'customers pull' is related to disruptions caused by market forces that result in users' exponential growth of such technology. It also forms a stimulated innovative progress to address significant needs of society such as current demand for clean energy (International Energy Agency 2019).

It is not easy for companies to keep their competitiveness when markets or customers change their preference. When the green life-style emerge recently, fossil-based power producers struggle to keep their contribution to the grid. Instead of technological advancement, the customer shift sig- nificantly contributes to the key success of new products for invading the existing market. Christen- sen has thoroughly described the importance of thinking and paying attention to find the right market segments, not only focusing to technology development (Christensen and Bower 1996). In addition, companies need to encourage customers to look for certain benefits from the products they use and make it as the basis of customer preference to choose some competing products (Flügge, Janner, and Schroth 2006). Products based on disruptive technology will disrupt if their per- formance increases to the point where it can also meet the requirements of the mainstream market or many customers need (Di Stefano, Gambardella, and Verona 2012).

Digitalisation

Different with 'digitization' which is defined as a physical, 'digitalization' is closely related to the way many of social life are restructured around digital communication and media infrastructures (Gbade- geshin 2019). The digital world is made up of three basic elements: data or digital information, data analytics and connectivity or data exchange between people devices, and machines via digital net- works (Galperova and Mazurova 2019). Digitalisation involves many various technologies from artifi- cial intelligence, natural language processing, 3D printing, block chain, expert systems, virtual reality, etc. Internet of Things (IoT) offers huge potential applications for automation, from designing and engineering installation of new plants to intelligent production management and smart mainten- ance system (Isaksson and Wennberg 2017 Isaksson, Harjunkoski, and Sand 2017). The increased digitalisation has disrupted various business activities by lowering barriers to funding, marketing and distribution, and enabling an increasing global flow of goods, services, and financial transactions (Isaksson and Wennberg 2017; International Energy Agency 2019). In this digital era, firms need to enhance their processes with digital technology and re-imagine their business models to increase productivity and maintain their competitive advantages (McGrath and MacMillan 2000; Isaksson and Wennberg 2017).

Before the digital grid, the flow of power supply was one way straightforward. Today, distributed generation mostly from intermittent renewable producing bi-direction power flow result in a volatile grid (World Economic Forum 2017, MIT Energy Initiative (MITEI) 2016; International Energy Agency 2019). Using more and better connectivity, information will be much more easily available, put all many various equipments from generation, transmission, distribution, and retail will become more closely integrated (MIT Energy Initiative (MITEI) 2016; Galperova and Mazurova 2019; Isaksson and Wennberg 2017). Utilities can benefit from the application of big data analytics which can help leveraging the optimisation processes going on in power grids and also to create new streaming revenue beyond the metre (Danneels 2004; Jacobi and Brenner 2018; Serrano-Calle et al. 2018). However, some drawback issues should be anticipated well. Most digitalisation programme needs huge investment yet their benefit cost ratio is still unclear. It has also extended the surface for poss- ible cyber-attacks that could threaten the system's reliability, increasing the grid security suscepti-bility (Danneels 2004; Amaro and Pina 2017).

Firm performance

'Firm performance' is most commonly measured by the maximisation of profit with the use of resources more efficiently and effectively (Christensen and Bower 1996; Afrianda 2024). There is a general consensus that the old financial measures are still valid and relevant but these need to be balanced with more contemporary, intangible and externally oriented measures (McGrath and Mac- Millan 2000). Despite this lack of specific method, there is some general guidance to assess the per- formance of firms should be balanced, including financial (e.g. cost production, revenue, investment cost, etc.) and non-financial (e.g. service quality, productivity, customer satisfaction, etc.). Some studies argue that the firm performance can be influenced by such technological changes (McGrath and MacMillan 2000; Afrianda 2023).

Hypotheses

A disruptive technology originally satisfies special market segments, then when technology is already mature and its performance meet the requirements of the mainstream market, so that dis- ruption is just occurred (Christensen 2000; Di Stefano, Gambardella, and Verona 2012). Additionally, a technology roadmap developed to generate technology innovation not only based on technology driver but also customer's preference (Flügge, Janner, and Schroth 2006; Di Stefano, Gambardella, and Verona 2012).

The rise of clean and green energy such as electric vehicles, wind turbine, solar PV and so on, is pushed by the de-carbonisation life style (World Economic Forum 2017; Bhatti and Danilovic 2018; Rachinger et al. 2019). Then demand arises for such energy storage for dealing with their intermit- tency. Customers want to utilise as much as possible renewable energy by using energy storage mainly battery system (MIT Energy Initiative (MITEI) 2016; Di Silvestre et al. 2018; Black & Veatch 2016; EY 2018). While global shift for decentralising everything include power system inspire most customers at certain area to eventually disconnect from the existing centralised electricity network (Frankel and Wagnerm 2017; EY 2018). It requests such distributed power generation that is able to produce electricity stand-alone (Thomas et al. 2018). Then the need for Solar PV and wind turbine is increasing. Therefore, pushing by 4.0 digitalisation era, a need to ensure avail- ability and reliability of power supply with efficient cost has accelerated the smart grid adoption at several regions (Amin 2013 Isaksson, Harjunkoski, and Sand 2017).

Hence:

Hypothesis 1: the customer pulls positively affect Solar PV.

Hypothesis 2: the customer pulls positively affect Battery storage.

Hypothesis 3: the customer pulls positively affect Smart grid.

Continuous development of ICT technologies in terms of speed, reliability and flexibility made it possible to transform traditional power into a completely digital environment (Isaksson, Harjunkoski, and Sand 2017; World Economic Forum 2017; Gbadegeshin 2019). The IEA report examines the impact of digital technologies on energy demand sectors, looks at how energy suppliers can use digital tools to improve operations and to help create a highly interconnected system (International Energy Agency 2019). Some studies show how digitalisation can contribute to cutting down the energy consumption in residential and public buildings by 'smart control' (Galperova and Mazurova 2019). Through digital platforms, consumers will be able to get connected, participate in and profit from the energy market. When applied to solar PV, industry 4.0 is enabling the effective manage- ment of an abundant but volatile form of energy generation, providing much needed stability and reliability (Amin 2013; Isaksson and Wennberg 2017).

In addition, survey found that majority of all stakeholders from the energy storage industry confirm their organisation defines digitalisation as a core part of their business strategy (Isaksson and Wennberg 2017; Gbadegeshin 2019). Digitalisation on energy storage system will further accel- erate the decentralisation of energy supply and be among the main drivers for the exponential growth of solar PV in the future. As solar PV becomes the most cost-efficient energy source around the world, storage and digitalisation will make PV and other renewable energy controllable and available at all times and allow more renewable to be integrated into the grid (Amin 2013).

Thus:

Hypothesis 4: the digitalization positively affects Solar PV.

Hypothesis 5: the digitalization positively affects Battery storage.

Hypothesis 6: the digitalization positively affects Smart grid.

The solar PV industry experienced a new record year of growth in 2016 reaching total capacity of 509.3 GW, or nearly 400 times the capacity in 2000, with a 34% growth year-on-year of new installa- tions. Cumulative installed capacity exceeded 401 GW by the end of 2017, sufficient to supply 2.1 percent of the world's total electricity consumption (Swenson 2016). Although capacity additions remained flat in 2018, solar PV generation increased 31% in 2018, and represented the largest absol- ute generation growth of all renewable technologies (Agnew, Smith, and Dargus 2018).

These green innovations are emerging not only in technology but in public policy, social prefer- ences, and business practices as well (Moriarty and Honnery 2016). The characterisation of renewable energy technology, such as PV rooftop solar, as a 'mortal threat' to utilities and utilities themselves as in a 'death spiral' reflects an awareness that unconventional risks have emerged (Graffy and Kihm 2014). The problem is clear: customers with rooftop solar buy less energy and pay less to utilities, becomes an energy producer rather than a consumer only. It put some western European utilities have produced negative price of electricity, made their share prices at stock market collapsed signifi- cantly over few years (MIT Energy Initiative (MITEI) 2016). When Americans are starting to see savings from solar, many traditional electricity suppliers are fighting back to retain their profit margins (Graffy and Kihm 2014; Agnew, Smith, and Dargus 2018; Thomas et al. 2018). Some utilities have applied demand-charge rates for their solar customers.

Then:

Hypothesis 7: Solar PV negatively affect utility financial performance.

Hypothesis 8: Solar PV negatively affect utility non-financial performance.

Some research has found that storage is already economical for many customers to reduce their peak consumption of electricity supplied by the utility (EY 2018). Access to adequate amounts of cheap energy storage will break the constraint that power must be generated at the same rate that it is used (Crabtree 2015). The existing utility market has been disrupted by the availability of cheap solar PV. Then cheap storage will be even more disruptive because combinations of storage with solar will likely able to arbitrage any variable rate design those utilities create (EY 2018). The pen- etration solar PV systems supported by battery storage could become one of the most disruptive influences to impact the electricity sector in decades (Agnew and Dargusch 2015).

Additionally, the drivers encouraging self-sufficiency and grid independence will have a strong influence on battery storage utilisation (Agnew and Dargusch 2017). A study conducted in Queens- land Australia that has the highest per capita PV installation rates in the world, found that the area faces the most potentially disruptive innovation from storage technology (Agnew, Smith, and Dargus 2018). Battery will serve as the catalyst for such disruptive business model innovations by offering distributed, on-demand, real-time flexibility and self-services (Ilieva and Rajasekharan 2018). It also plays a critical role in future low-carbon electricity systems, supporting renewable integration by balancing inflexible supply with demand (Schmidt et al. 2017). Consequently, it reduces demand because consumers make their own energy, reduce their dependency from the grid. Thus, the deployment of residential battery energy storage at certain scale, erode the dominance of the traditional centralised electricity supply model, put utilities under pressure (Frankel and Wagnerm 2017; Thomas et al. 2018).

Hence:

Hypothesis 9: Battery storage negatively affect financial performance.

Hypothesis 10: Battery storage negatively affect non-financial performance.

IEA describes that a 'smart grid is an electricity network that uses digital and other advanced tech- nologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users' (Adams, Bromley, and Moore 2014). Smart grid is huge concept and can vary significantly in terms of their design and layout (Amin 2013). It includes AMI, Demand response, Distributed automation, Analytic data, Energy storage, Transmission enhancement, and Micro grids (Adams, Bromley, and Moore 2014; Bhatti and Danilovic 2018). The IEA has identified five smart grid-specific drivers in the electricity sector: demand increase, pen- etration of electric vehicles, deployment of variable renewable energy sources, peak load increase, and ageing infrastructure (Adams, Bromley, and Moore 2014).

In essence, smart grids bring profound changes in the information systems that drive them: new information flows coming from the electricity grid, new players such as decentralised produ- cers of renewable energies, new uses such as electric vehicles and new communicating equip- ments such as smart metres, sensors and remote-control points (Bhatti and Danilovic 2018; Jacobi and Brenner 2018; Serrano-Calle et al. 2018). Smart grid is a key suite of technologies to deal with pressing current and future needs in the electricity sector and to enable the effective adoption of low-carbon energy technologies such as variable renewable energies and electric vehicles (Heinen et al. 2011). Benefits when investing into smart grid technology will occur in form of reducing network losses, decreasing power outages, extending population served, regulating consumer tariffs and integrating of new (renewable) generation capacity (Gior- dano and Fulli 2012).

Thus:

Hypothesis 11: Smart grid positively affect financial performance.

Hypothesis 12: Smart grid positively affect non-financial performance.

The twelve hypotheses construct a hypothetical conceptual model as the Figure 1. It explains the effect of some disruptive technologies to firm performance. The model's logic starts from the antecedents of disruptive technology which is driven by both customer pull and digitalisation push.

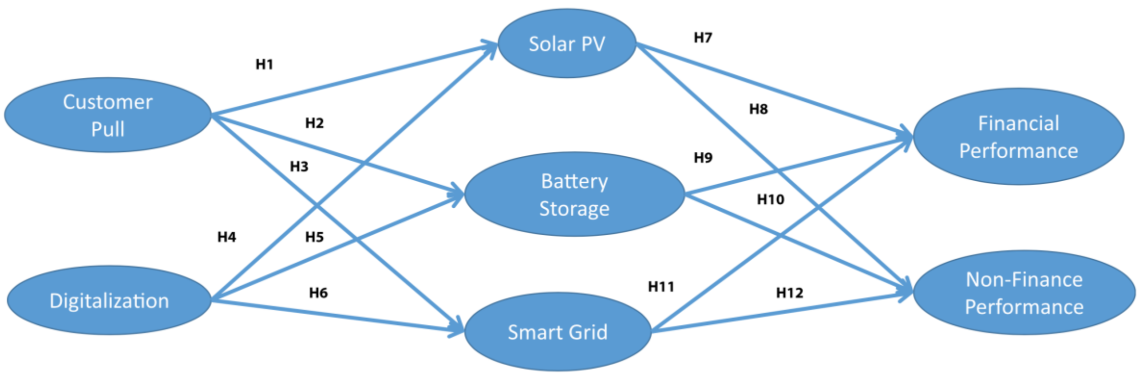

Figure 1. The Hypothetical Proposed Model.

METHODS

Research objective

This study investigates impact of disruptive technologies to the firm performance on the power utility with their two streams antecedents; customer pull and technology push. Along with the 4.0 era spreading out the globe, the technology push is represented by digitalisation. Then the three disruptive technologies have been selected; Solar PV, Battery storage and Smart grid. This research wants to test empirically what types of technology is really disruptive, and which have the most impact on firm performance both financially and non-financially.

Respondents and procedure

The data were collected from 118 business units of The Indonesian State Electric Company (PLN) through their 336 engineers as respondents. PLN has 'end to end' power utility supply chain from power generation, transmission, distribution, retail and customers. From 228 business units of PLN, 118 units or 51.5% have completed the survey correctly, 22 unit's feedback or 9.6% was not valid and other 89 units or 38.9% did not reply it. The number of unit analysis which exceeds 100 samples is an appropriate size to be analysed by a SEM (Structural Equation Model) (Wijanto 2008). Using LISREL version 8.8, this research model was assessed by a 'two- stage approach'. The first stage is analysing the measurement model using Confirmatory Factor Analysis (CFA). Then the second one is analysis of the structural model to define the relationship among all the simplified latent variables (SLF). Based on those results, the signifi- cance test can be conducted for each hypothesis to determine whether the hypothesis will be accepted or rejected.

Measurement

Referring to some recent studies, the disruptive technology on power industry is mostly rep- resented by PV solar, battery storage and smart grid (Black & Veatch 2016; Di Silvestre et al. 2018). Each technology has 5 measured indicators (Marica 2014; Jin, Jeong, and Yoon 2015), the customer pull has 8 observed variables (Zhou, Li, and Zhou 2004 Flügge, Janner, and Schroth 2006; Di Stefano, Gambardella, and Verona 2012;) and digitalisation measured by 6 items (Isaksson and Wennberg 2017; Galperova and Mazurova 2019; Gbadegeshin 2019). Then the firm's perform- ance is detected by financial and non-financial variables with 7 items (Marica 2014; Afrianda 2024). Overall, this research examined 36 items of statements to measure 7 latent vari- ables using 6 Likert-type scales.

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Result

The results of the descriptive statistical analysis at Table 1 show that skewness value between –1.82 and 0.21, and kurtosis is from –0.22 to 5.65. It means some respondents believe that their actual per- ceptions are similar not affected by their different background. Yet the largest deviation number (0.96) of non-financial performance within mean 3.33 shows that there is some significant different perspective for this factor. However, based on ANOVA test results, it is no variance for all variables in the respondent profile group referring to their distinguished factors: type, size and location of the unit, the occupation, age, educational background, and work experience of respon- dents. It is similar to other study (Afrianda 2024).

For testing the relationship between the measured variable with the number of constructs, then the CFA is used. For having a good fit, some of the GOFI (Goodness of Fit Index) indicators should be higher than the standard values (NFI, NNFI, CFI, IFI, RFI, GFI and AGFI) and others should be lower than their standard (RSMEA and Std RMR). Likely other previous study (Afrianda 2024), Table 2 shows that six of nine GOFI indicators are good fit, it means the overall fit of the structural model is good. Additionally, the SLF also confirmed that all indicators and the measurement for each latent variable have good reliability and validity.

Table 1. Result of Descriptive Statistic Analysis.

Construct	Items	Mean	Standart Deviation	Skewnesss	Kurtosis
Customers pull Digitalisation	8	5,30	0,65	-1,82	5,65
Solar PV	6	4,9	0,64	-0,4	0,11
Battery storage	5	4,68	0,65	-0,27	0,15
Smart grid	5	4,48	0,72	-0,1	0,03
Financial performance non-financial performance	5	4,64	0,67	0,02	-0,02
Construct	4	3,83	0,85	-0,09	0,04
Customers pull Digitalisation	3	3,35	0,96	0,21	0,61

Using same approach with other related previous study (Afrianda 2023), Table 3 shows the calculated structural coefficients and t-values for each latent variable, and the hypotheses result; nine hypoth- eses are accepted (t-value > 1.96) and other three is rejected (t-value < 1.96). Both customer pull and digitalisation affect positively significant to some disruptive technologies (H1, H2, H4, H4, H6). The insignificant effect of customer pull to the smart grid is supported by some previous studies empha- sised that smart grid is mostly driven by technology progress instead of customers' need (H3). The effect of all disruptive technology is significant to firm performance with different impact. Solar PV has negative impact to the firm performance both financial and non-financial (H7, H9). On the other hand, Smart grid affects the firm performance on a positive way (H10, H12). Then battery storage significantly affects to increase the firm performance (H8, H11).

Table 2. Result of GOFI values of the Structural Model Test.

GOFI indicators	Calculated values	Standard value	Conclusion
RMSMEA (Root Mean Square Error of Approximation) NNI (Normed Fit Index)	0.078	< 0.08	Fit is good
NNFI (Non-Normed Fit Index)	0.91	> 0.90	Fit is good
FCI (Comparative Fit Index)	0.95	> 0.90	Fit is good
IFI (Incremental Fit Index)	0.95	> 0.90	Fit is good
RFI (Relative Fit Index)	0.95	> 0.90	Fit is good
Standard RMR (Root Mean Square Residual) GFI (Goodness of Fit Index)	0.91	> 0.90	Fit is good
AGFI (Adjusted Goodness of Fit Index)	0.087	< 0.05	Fit is marginal
GOFI indicators	0.71	> 0.90	Fit is marginal
RMSMEA (Root Mean Square Error of Approximation) NNI (Normed Fit Index)	0.65	> 0.90	Fit is marginal

Table 3. Test Result of the Structural Research Model.

Hypotheses	Structural Coefficient	Calculated t-value	Conclusion
H1: Customers pull positively affect Solar PV	0.30	2.33	There is significant positive effect, hypothesis is accepted
H2: Customers pull positively affect Battery Storage	0.34	1.98	There is significant positive effect, hypothesis is accepted
H3: Customers pull positively affect Smart Grid	−0.00	−0.00	There is insignificant positive effect, hypothesis is rejected
H4: Digitalisation affect positively Solar PV	0.68	4.46	There is significant positive effect, hypothesis is accepted
H5: Digitalisation affect positively Battery Storage	0.76	4.86	There is significant positive effect, hypothesis is accepted
H6: Digitalisation affect positively Smart Grid	0.70	4.64	There is significant positive effect, hypothesis is accepted
H7: Solar PV negatively affect Firm financial performance	1.86	3.27	There is significant negative effect, hypothesis is accepted

H8: Battery storage negatively affect Firm financial performance	−1.87	−3.31	There is significant positive effect, hypothesis is rejected
H9: Smart Grid positively affect Firm financial performance	0.40	2.80	There is significant positive effect, hypothesis is accepted
H10: Solar PV negatively affect Firm non-financial performance	1.73	3.58	There is significant negative effect, hypothesis is accepted
H11: Battery storage negatively affect Firm non- financial performance	−1.81	−3.53	There is significant positive effect, hypothesis is accepted
H12: Smart Grid positively affect Firm non-financial performance	0.40	2.95	There is significant negative effect, hypothesis is accepted

CONCLUSION

The study has analysed the disruptive technology effects to firm performance on power utility indus- try. Its determinant factors have been examined into two streams; customer pull and digitalisation. Additionally, three disruptive technologies have been investigated; renewable energy, battery storage and smart grid. The effect of disruptive technology to firm performance is significant yet not always negative. In this study, battery energy storage potentially improves both financial and non-financial of firm performance. Digitalisation is proven empirically to be an antecedent for all dis- ruptive technologies. While the customer pull affects significantly both Solar PV and Battery energy storage but not for Smart grid development.

In conclusion, this empirical research confirmed that disruptive technology has different impacts to firm performance. Instead of having destructive effects on the existing business model, some technol- ogies like smart grid and battery storage are highly potential to improve the industry performance.

Practically this study will be useful for the firm management, who seek opportunity from the dis- ruptive technology’s ‘attack’ to their company. Indeed, the disruptive impact of each technology is different; it may depend on the type of industry. Instead of their negative effects, certain disruptive innovations have beneficial for the firm performance if the CEO or Top Management Team (TMT) know a way to deal with it. It is clear that they have to improve the capability of their technology business intelligence to adapt, integrate and reconfigure organisational skills both internal and external, resources and competences to match with particular disruptive technology.

The wave of 4.0 era put digitalisation as a catalyst to change the way of firm for doing a business. The choice is whether utilities need to disrupt themselves or they will be disrupted by others. The TMT does not need only skill for exploiting the emerging technology deeper but also for exploring it to be something new which is beneficial for their company.

DISCUSSION

Supporting some previous studies arguing that the main driver of disruptive innovation can be tech- nology push and customer pulls, this study shows empirically that digitalisation and customer preferences have significant impact to disruptive technology creation (Meuter et al. 2000; Flügge, Janner, and Schroth 2006; Di Stefano, Gambardella, and Verona 2012; Marica 2014 Isaksson, Harjun- koski, and Sand 2017; Galperova and Mazurova 2019; Gbadegeshin 2019; Rachinger et al. 2019). Digital technologies will be the key to the digital transformation of the energy system. Customer is empowered to participate in all supply chain of the utility through utilisation some digital inno- vation such as two ways metre, geographical systems, web portals and social media. All evidence moves backward to the origin of 'creative destruction' by Schumpeter (1938) describing that tech- nology innovation is main source for increasing the firm's competitive advantage. Later the rapid advancement technology become antecedent of technology disruption (Manyika et al. 2013 Afrianda 2023). Then firms adopt the emerging technologies in an attempt to simply sustain their competitive position (Wan, Williamson, and Yin 2015; Afrianda 2024).

While global warning has changed the life style of most people over the world, shift customers preference to be more clean, green and sustainable. It has created some startups of green energy in some regions. KiWi, for example, this US based startup has developed an online green investment and financing platform connecting global investors with solar project developers around the world. Whereas a Canadian start up, GBatteries, has developed an Artificial Intelligence to rapidly charge lithium-ion batteries without any compromise in cycle life by using the adaptive pulse charging algorithm operates in lower impedance periods. Moreover, a Brazilian startup, FOHAT, has devel- oped software solutions for regulating micro-grids based on block-chain technology integrating Dis- tributed Energy Resources and managing peer-to-peer energy trading. All samples explain that product based on disruptive technology initially to satisfy special demand of customers not directly enter to the mainstream utility market (Christensen and Bower 1996; Christensen 2000 Danneels 2004; Adams, Bromley, and Moore 2014; Li, Porter, and Suominen 2018).

It is not surprisingly that Solar PV is found to be the most disruptive for power utility firms. It dis- rupts the industry by two ways; technical and financial. Since 1980s, some studies taken place for reviewing the issues in relation to grid-integration of solar PV systems (Adams, Bromley, and Moore 2014; Moriarty and Honnery 2016 Swenson

2016; Agnew, Smith, and Dargus 2018). The solar PV intermittency, affect voltage quality, power losses, and the operation of other voltage-reg- ulating devices in the system. The high penetration rate of PVs in the distribution grid can potentially cause problems for node voltages or overhead line flows (Agnew and Dargusch 2015 Crabtree 2015; Agnew, Smith, and Dargus 2018). Other impact to disrupt utilities financial will rise when the pen- etration of PV has reached the grid parity status. According to Bloomberg's global benchmark 2020, the levelised cost of energy (LCOE) for solar continues to decline and has already reached the parity with wholesale power prices in California, China and parts of Europe. Although this disrup- tion just started in Indonesia, it is only about time, the lower LCOE of Solar PV will be serious threat to the dominant fossil fuel power generation especially coal fired power plants.

Other finding is Smart grid has a positive impact to firm performance, align with some previous studies (Black & Veatch 2016; Heinen et al. 2011; Giordano and Fulli 2012; Amin 2013). Providing infrastructure of Electric Vehicles and e-mobility services, Smart Meters and Smart Home Services, Smart grid foster investments and shift business value to electricity services at some Europeans uti- lities (Giordano and Fulli 2012; Adams, Bromley, and Moore 2014). Through AMI, Smart grid can con- siderably lower peak load and then higher utilisation of power utility industry assets in the US (Heinen et al. 2011). The Smart grid capability to decentralised and localised power generation systems with more penetration of renewable energy to the grid can change the entire process and structure of the energy market (Bhatti and Danilovic 2018). However, the successful of its implementation depend on three factors; financial challenge to provide sufficient investment for long time project pay back, technical challenge to match electricity supply and demand of grid, and managerial challenge to well manage and coordinate all stakeholders of electricity system across nation (Giordano and Fulli 2012; Amin 2013).

The growing market for consumer electronics and demand for electric vehicles (EVs) pushed storage prices drop much faster than anyone expected. Technically battery storage is able for improving power quality and supporting renewable energy integration. Financially, it highly poten- tial – combined with cheap renewable energy sources – to replace some fossil fuel power plants especially during peak session (EY 2018; Schmidt et al. 2017; Agnew, Smith, and Dargus 2018; Ilieva and Rajasekharan 2018; Thomas et al. 2018).

Battery storage can be deployed both on the grid and at an individual consumer's home or business. Their cheaper price will allow customers to 'draw off' electricity when the electricity sup- plied from the grid more expensive. It reduces demand because consumers make their own energy, has put utilities financially under pressure (Graffy and Kihm 2014; Crabtree 2015; Agnew and Dar- gusch 2017; Frankel and Wagnerm 2017). Utilities have fewer bill payers to cover their fixed invest- ment in the grid, yet they still provide backup reliability for the solar customers (Agnew and Dargusch 2015; Crabtree 2015; Agnew and Dargusch 2017; Ilieva and Rajasekharan 2018). On the other hand, battery can also benefit utilities by helping them to address the challenges in markets where loads are expected to be flat or falling mainly cause by the variable renewable energy. It could play a pivotal role in future low-carbon electricity systems, balancing inflexible supply with demand (Crabtree 2015; Agnew, Smith, and Dargus 2018; Thomas et al. 2018). Such ade- quate and resilient infrastructure of grid is a crucial requirement for energy transitioning to complete reliance on environmentally protective human energy systems (Di Silvestre et al. 2018).

In addition, some platform business models have already revolutionised and present a huge potential for energy storage-based management services to dynamically match supply and demand of energy, and cater for flexibility and at the end, increase efficiency, reliability and resiliency in the grid (Manyika et al. 2013; Crabtree 2015). Battery storage application will also present an opportunity for utilities in front of the metre or 'beyond the meter' services which can provide more benefit to the end user and possibly create new streaming revenue for utilities (EY 2018; Ilieva and Rajasekharan 2018).

Unlikely the hypothesis proposed that battery storage as a disruptive technology on power indus- try will impact negatively to the firm performance, this study argue that it has beneficial for both financial and non-financial utilities performance. In Indonesia case, the price of battery storage is still not affordable for solar owned utility customers. Furthermore, the rigid electricity price does not support a demand response mechanism so that the battery storage is not attractive for utility cus- tomers yet. On the other hand, the role of battery for smoothly integrate variable renewable energy to the grid, make it implementation by utilities is promising. PLN need such energy storage to overcome the excessive penetration of PV and wind turbine at several regions. They can solve the technical inter- mittency, so that will increase more renewable energy contribution and eventually can reduce the electricity price by replacing some existing expensive fossil fuel power generation.

This study also found that digitalisation role to enable disruptive technology on power utility is more critical than the customer demand. The t-calculated value data explain that the most disruptive technology for power utility firm is Solar PV. Its rapid penetration to the energy market around the globe, empirically deteriorate most utilities firm performance includes PLN. Whereas the negative t- value of battery storage shows interesting finding; instead of its disruptive capability which is com- monly has negative impact to the firm, the battery storage has potential positive to improve the financial and non-financial performance of utilities (at least in Indonesia context).

Indeed, there is a room to improve this study. First, the disruptive technology is determined as a 'content' of firm structure. It makes such technology has less dynamic for a better adoption. Second, this study was conducted at the power utility firm which is mostly highly regulated industry. The findings may not be applicable to the market driven industry. Third, this study does not provide any longitudinal or time series data yet, limit examination to cover the past, present, and future relationships.

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