Facade Integrated PV applications uptake in Non-domestic Buildings: A Sensitivity Analysis of Multi-criteria Performance Analysis

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Abstract

Integration of PV modules into the building envelope is obviously the paradigm shift in the building industry. PV modules with a greater degree of architectural appealing and facade requirements are slowly acknowledged. With the growing concerns of this technology, many more developments are introduced to eliminate the current obstacles. Besides, the system performances continuously shift due to various uncertainties in the industry, causing diverse decision choices. Therefore, this paper aims to investigate the potential uncertainties that alter the performances of the systems. Environmental aspect, architectural suitability and economic benefits are observed the most concerning performances of systems and are quantified using LCOE, NPV/kW and DPP, material offset and CO_2 emission savings. The sensitivity analysis is conducted on four uncertainties recognized in industry such as capital cost, electricity conversion efficiency, conventional facade material cost and financial incentives. Assessment is conducted for the thirty-six facade integrated PV systems in Australia, North America and Europe with the limited to non-domestic buildings. It is noticeable that decisions should not be compromised by looking only at single decision criteria. The results revealed that the influence of capital cost, financial incentives and conventional building material values are substantial that electricity conversion efficiency. The projects reveal favourable economic performances even with the absence of financial supports by taking consideration of both direct and indirect benefits. It is promising to replace conventional building materials with the PV modules. Learning from the current experiences would be the ideal solution to guide future directions on research, investment decisions and policy makings

Keywords: façade integrated systems, multi-criteria performance, sensitivity analysis, decision making

1. Introduction

Photovoltaic (PV) technologies are being recognised as the most promising application to generate green electricity. Unlike other PV applications, Building Integrated PV (BIPV) can be applied to various parts of the building structure such as walls, roofs, shades, windows and balustrades depending on the electricity generation capacity (Attoye et al., 2017). It is a decentralised energy technology that produces not only green energy but also performs as a building material (Osseweijer et al., 2018). PV modules being endorsing aesthetic appealing of buildings, growing attention is cultivated on facade integrated systems in the building sector. This further boosted with the development of high-rise buildings that are taller than wider, particularly in urban dense. A substantial untapped area is opened to harvest solar energy generating a significant share of the building energy demand by integrating PV into the envelope (Shirazi et al., 2019). However, there is a vast refusal to facade integrated system due to the number of reasons such as lack of awareness, poor performances, underestimating benefits, resistance to change, insufficient standards and technical complexities (Curtius, 2018;Attoye et al., 2017;Osseweijer et al., 2018). Architects, builders and building owners still worried about the performance of systems and its appropriateness as a conventional facade material technology developing massive barrier for the deployment (Attoye et al., 2017;Curtius, 2018). However, a limited number of facade integrated PV systems of architecturally pleasing and high-performance executes globally. Disseminating the performances of such system helps on rapid deployment.

The previous studies discussed a variety of performances of systems using real case information or simulations on a different scale. Environmental aspect, architectural suitability and economic benefits are observed the most involved performances for the choice of the system (Attoye et al., 2017;Curtius, 2018;IEA-PVPS, 2018). It is noticed that these performances continuously shift due to the uncertainties in the external and internal environment. The industry reforms by introducing innovative technologies cater to architectural fit, high energy efficiency and methods such as prefabricated systems (Attoye et al., 2017;IEA-PVPS, 2018). The policies are implemented cross value chain in domestic markets (Zhang et al., 2018). Accordingly, the steady growth of new technologies is forecasted almost achieving the best performance of such systems (Erika et al., 2018). Therefore,

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it is imperative to inform the effect of uncertainties on multiple performances. Therefore. this study aims to educate the influence of uncertainties on various performances of the system with the use of existing facade integrated systems across countries. Learning from the recent experiences would be the ideal solution to guide future directions on research, investment decisions and policy makings. The findings help on elevating the confidence level on system updates as the assessment is purely based on the real case information. A few studies used such a considerable number of real data in different regions to understand future investment directions and deployment strategies. The scope of this paper is limited to assess the performance of systems commissioned between year 2009 – 2018 in non-nondomestic buildings in western countries. Thereby, thirty-six projects in Australia, Europe and North America are assessed in terms of three performance aspects namely economic, environmental and structural value using five parameters net present value (NPV/kW), discounted payback period (DPP), levelized cost of energy (LCOE), material offset (MF) and CO_2 emission saving. A sensitivity analysis is conducted on most common uncertainty factors of capital cost, electricity conversion efficiency, material cost and financial incentives by creating a range of scenarios to understand their impacts on system performances. The research outcome is a practical reference for multiple stakeholder cross value chain to establish on their proposals on facades integrated PV systems.

2. Multi-criteria Performances

Integration of PV modules into the building facades provide multiple benefits despite the clean energy generation. PV facades are conventionally made up as walls, glazing, claddings and other external structures such as lovers and balconies (Attoye et al., 2017). Multiple performances are obviously the key decision criteria for such system uptake. The previous studies conducted numerous assessment using various parameters to inform the performance of facade system and enhance the confidence in the acceptance of such technology. Attoye et al. (2017) classified performances as economic, environmental and design-related benefits. Economic benefits are capital cost associated savings and environmental benefits are greenhouse gas emission savings. Some the design-related benefits are daylights, aesthetic quality and sun protection (Attoye et al., 2017). The performance of thermal control, aesthetic and daylighting functions are attracted by the practitioners (Attoye et al., 2017;Zhang et al., 2018). It is noted that various parameters are used to quantify these performances. The most studies employed NPV, LCOE, DPP, internal rate of return (IRR) and capital cost to assess the economic performances (Sorgato et al., 2018;Gholami et al., 2019;Arnaout et al., 2019). Environmental benefits are assessed in terms of lifetime energy pack periods or CO_2 emission savings (Zhang et al., 2018). The cost of conventional building materials with the BIPV module are compared to identify the net benefits of the structural suitability of new technology (IEA-PVPS, 2018;Bonomo et al., 2017). With the consent of multiple parameters, this study employed five parameters that investigate the performance of economic, energy, environmental, and structural value of the facade integrated PV applications. They are LCOE, NPV and DPP as economic aspects, material offset as structural value and CO_2 emission savings as environmental aspects. The below describes these metrics.

LCOE: Levelized cost of energy represents a cost of energy generation throughout the lifespan (Shirazi et al., 2019;Wang et al., 2011). The mathematical LCOE model symbolises the ratio of total lifecycle cost over total lifetime output energy and unit is cost/kWh. This is more explainable than cost/kW which ignores the lifetime performances (Wang et al., 2011). LCOE is generally compared with retail electricity price (Zhang et al., 2018). The studies used various cost parameters in LCOE analysis. The intension of this assessment is to elaborate on the lifetime cost aspects of facades integrated systems with the presence of both direct and indirect costs. Thereby, The lifecycle costs are included as capital cost, material replacement cost, maintenance and operation cost, salvage value, incentives and inverter replacement cost (Wang et al., 2011;Corti et al., 2020;Gholami et al., 2019;Weerasinghe and Yang, 2020). The capital cost represents the cost of modules, balance of system (BOS), installation, and procurement that spent at the initial investment (Wang et al., 2011). Material displacement is a benefit acquired due to the replacement of PV with conventional building materials. This benefit is added to reflects the performance of PV modules as a building material. The idea is embedded in the calculations by various researchers believing different aspects such as 1) Gholami et al. (2019) deducted the equivalent material cost from the project investment cost to described the total investment cost 2) Corti et al. (2020) used incremental cost considering offset of material cost to module cost. The financial incentives that received at the initial and following years are added as a benefit in the calculation. The operation and maintenance cost is an annual cost spent on services, performance monitoring and other maintenance. Inverter replacements are performed every ten years

(Sorgato et al., 2018;Yang and Carre, 2017). The salvage value refers to the value of the systems at the end of project life (Shahsavar and Khanmohammadi, 2020). Time value of money is indicted, and real interest rate is used in the calculation. The lifetime energy performance is identified using annual electricity generation over time with the inclusion of annual energy degradation rate.

NPV: Net present value is the most popular economic parameters in investment decisions. NPV denotes the net economic value of the project that deducts lifecycle costs from lifecycle incomes (Gholami et al., 2019). Lifecycle cost identified in LCOE is used as capital cost, material displacement cost, lifecycle maintenance cost and replacement cost, salvage value and incentives. Lifecycle incomes are two types namely energy bill offset and revenue by selling electricity to the national grid (Wu et al., 2018;Yang and Carre, 2017;Bonomo et al., 2017). The energy bill offset is the value of the amount of electricity consumed from the system which is a deduction from the national supply. This is valued at the rate of retail electricity price. The national electricity price fluctuation is counted in the calculation(Yang and Carre, 2017). The excess electricity sell to the national grid is identified and monetised using Feed-in-Tariff (FIT) to obtain its economic benefits.

Discounted Payback Period (DPP): Discounted payback period refers to recovery periods of initial investment which is a significant parameter of decision making (Wu et al., 2018). The lifecycle costs are deducted from the lifecycle incomes annually to identify the period that fully pays off the cost (Sorgato et al., 2018). The same cost and income components used for the NPV is applied to DPP. The lifecycle cost parameters are capital cost, annual maintenance cost, inverter replacement cost, material displacement and lifecycle incomes are energy bill offset and excess grid supply. The short payback period is always promising in the investment.

Material Offset: Material offset is identical to the structural value of the system. Judging that value signifies the characteristics of materials such as aesthetic appearance, colour pattern, transparency and building requirements, cost of both PV modules and building materials are compared to identify the significant benefit of the replacement. The suggested formula is the deduction of the cost of equivalent conventional facade material with the total cost of the PV system. Unit is cost/m^2. The cost of installation is assumed as similar in both materials. Positive value signifies the benefits as BIPV is cheaper than facade materials.

CO_2 Emission Savings: This metric is used to explain the investors' commitment to sustainability and environmental aspects. Lifetime energy payback period and greenhouse gas emissions rate that blend both embodied and operational energy are the most common parameters identifying environmental preference. Due to the complexity of identifying projects specific embodied energy in multiple projects, the operational energy is taken into consideration. Thereby, CO_2 emission savings is calculated as a ration of electricity generation to total building demand as a percentage value.

The immense effort is being put forward to enhance the aesthetic value of modules along with satisfying building material requirements over the years. The new technologies that provide more esthetic appearances are well accepted by the users (Sánchez-Pantoja et al., 2018). Further, increasing module efficiency that leads to improving the electricity conversion efficiency facilitated to enhance the performance of systems to a great degree. However, architectural design objectives such as daylight, visual impact sometimes can be compromised with the energy performances and maximum output of the modules (Attoye et al., 2017). Decreasing cost of modules and other subsystems leads to accelerate the system uptake as the capital cost is the most contributing factor in the deployment (Curtius, 2018). The government policies addressing each stakeholder have proved rapid growth in different economics (Zhang et al., 2018). Recent years there is a technology advancement for cost reductions and improving system efficiencies. Further, colour, pattern texture and integration methods such as prefabrication, low maintenance cost are launched as a result of technology developments (Arnaout et al., 2019). Poor performances, cost, government incentives are some of the critical drivers of implementation of systems. The factors are subjected to uncertainties caused by the changes in future conditions. It seems that capital cost, electricity conversion efficiency, financial incentives and traditional material value are highly volatile in the industry. Therefore, these factors are selected to test in this paper. These are uncertainties in the market, technology development and policy aspects.

3. Real Case Information

The paper aims to understand the influence of uncertainties on the performance of facade integrated applications. Initially, a data of façade integrated PV projects are gathered from publicly available records such as websites

(Onyx Solar, 2016), databases (SUPSI/ISAAC, 2013;Eurac, 2013), articles (IEA-PVPS, 2018), books and journal articles (Maturi and Adami, 2018)). The project-specific data including, capital cost, annual energy generation, building energy demand, module area, system capacity, material displacement value, rebate, salvage value, inverter replacement cost, FIT, discount rate, electricity price are required performing the calculations. The projects that provide most of the data are selected in the analysis. Annual energy generation, system capacity, module technologies and area are confirmed data for project selection. When data are unavailable, approximate values are taken places. The capital cost is unavailable in nine projects and value is allocated considering 1) 1.2% of construction cost (IEA-PVPS, 2018) and 2) referring similar projects by location, technology and year. The total building energy demand is unfound in five projects where it is assumed 5% of self-sufficiency for pilot BIPV projects. Due to unavailability of data, the standard cost is applied for few parameters like 1) operation and maintenance cost as 1% of capital cost (Sorgato et al., 2018), 2) inverter replacements as 10% of capital cost and assume constant (Sorgato et al., 2018;Yang and Carre, 2017), 3) salvage value is 5% of the capital cost (Shahsavar and Khanmohammadi, 2020), 4) lifespan as thirty years (Wang et al., 2011) and 5) annual electricity degradation as 0.5% (James et al., 2011). The equivalent building material of façade systems is identified as a curtain wall (Aluminium frame with glass) and balustrade with tough glass for balconies. The average cost of curtain wall for Australia, North America and Europe are 897, 1056 and 1272 AUD/m^2(Weerasinghe and Yang, 2020;Rawlinsons, 2018;Spon's, 2018;RSMeans, 2018). All values are charged to the project commissioned year. Also, the project-specific information such as electricity prices, FIT and discount factors are gathered by the project commissioned year from the publicly available information such as Worldbank (2020), TradingEconomics (2020), PORDATA (2020), PVTECH (2020).

Details of the solar facade projects employed this analysis are illustrated in Figure 1, which is grouped based on various characteristics of the applications. The research consisted of thirty-six projects and thirty-three projects are facades that replaced curtain wall, rain screen, double skin facade and three projects are balconies. Only six projects received financial incentives where three projects are fully funded and the remaining projects received 45%, 30% and 48% of capital cost as a rebate. The location of the projects is groped based on Australia, North America, and Europe. Most projects are in Europe (thirty-one) while four and one projects located in North America and Australia. Systems are categorised on the type of buildings namely commercial, educational and apartment buildings. There are sixteen, seven and thirteen of them, respectively. Moreover, twenty-four projects installed at the initial stage and remaining twelve projects are attached in refurbishment stage of the building. Pie chart showed the commissioned year of the projects as the projects implemented from 2009 to 2020 is selected for the assessments. The capacity of the projects ranges between 5 to 700 kW. The modules of facade applications are made of different technology and transparency levels. The modules of twenty-five projects used c-Si technology while eight and three projects are made of a-Si and CIGS technology.

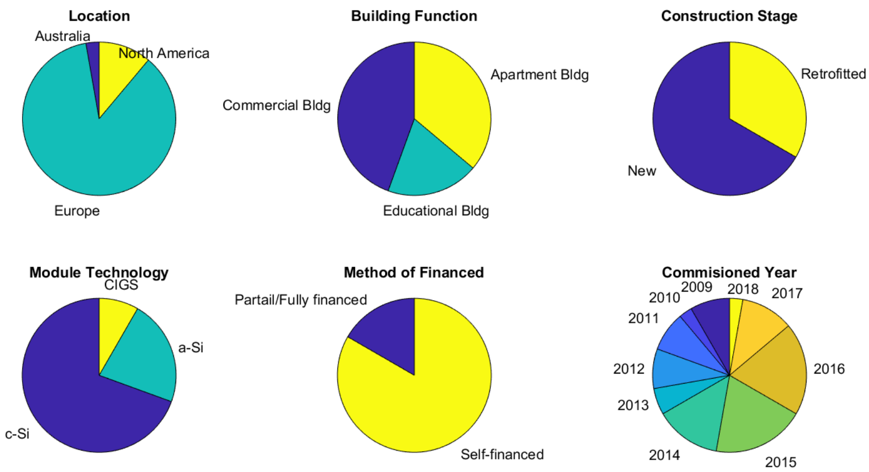


Figure 1: Details of Facade Integrated Systems

4. Sensitivity Analysis

Sensitivity analysis is typically used to assess the uncertainties of model output that are derived from a variety of inputs (Shirazi et al., 2019). This study aims to ascertain the influence of uncertainty factors on five performances. The analysis is conducted keeping thirty-six case as the base case and change selected input parameter to a wide scale that range from minimum to maximum possible values. The median value of the projects is then imported in each scenario to understand the effect of parameters on the performances. MATLAB application is employed to execute the calculations. The below section describes the uncertainty factor.

Capital cost: Capital cost is the most crucial information for investment decisions as the decisions are sometimes made on just looking at it only. The capital cost represents the total cost of the system, including hardware cost (BIPV modules, inverters, and mounting system etc.) and labour, installation and another relevant cost that incurred at the initial stage. BIPV modules stand for a major share of capital cost. However, the cost of solar facade is often debated in many studies. According to BuildUp (2019), the capital cost of opaque and semitransparent façades are approximately 850 and 550 €/m^2 in Europe. The capital cost of the cohort is ranged between 272 to 2,382 AUD/m^2 which is a wide range with an average price of 886 AUD/m^2. The authors highlighted that distribution of capital cost is in an acceptable content which is sometimes lower than someone of the conventional materials. The cost of the modules depends on diverse characteristics such as transparency, patterns, colour, shape and technology (Erika et al., 2018). Aesthetically appearances with high-performance modules are obviously expensive than standard facade applications. Further, inverter and battery display significant cost share in the capital cost and change parallel to the module cost. According to BuildUp (2019), the capital cost is expected to decreases over time. Considering the uncertainties in the capital cost, a wide range that distributes between -80% to +100% of the base value is developed to perform the sensitivity analysis.

Electricity conversion efficiency: Electricity conversion efficiency is an electricity generation capacity of the systems. Amount of electricity generation is an important decision criterion particular in the urban dense(Shirazi et al., 2019). Electricity conversion efficiency depends on the solar irradiation levels based on location and orientation combined with hardware performances (Zhang et al., 2018). The efficiency of the module technology works an essential contribution. It is noted that high transparency levels, colour and patterns may lower the system efficiency (Erika et al., 2018). Currently, three types of module technologies are recognised namely 1) crystalline technologies 2) thin film and 3) innovative technologies (Zhang et al., 2018). The power efficiencies of these technologies are between 4% to 25% (Zhang et al., 2018;Joseph et al., 2019). High energy efficiency with architectural and aesthetically suitable modules are the future of this industry. Impact of energy efficiencies on five performances is identified in this sensitivity analysis. Due to the availability of the information, the conversion efficiency is defined in annual electricity generation of systems. The base value is changed between -80% to +100% of base value devising worst case to best case scenarios. A diverse annual final yield is observed in current projects and they spread between 98 to 1,110 kWh/kW.

Conventional material prices: Investment of active solar facade is judged by comparing standard facade materials. Multiple facade materials by various colour, materials, appearance and performances can substitute the PV modules. The current façade integrated systems are compared with the average value of the curtain wall. According to SUPSI (2015), the expenses of the curtain wall are between 500 -1100 €/m^2 and the cost of high standard stone cladding are 300 - 600 €/m^2 in Europe. The depending on the material used for the comparison, a variety of benefits can be achieved. Therefore, looking at multiple disparities between a conventional material princess, a range of values are assigned to determine the effect of costs on five performances. The lowest value represents -80% of base value and the highest value is double of the base value (+100%) of selected facade materials. This enables to resolve the effect of multiple building materials on system performances.

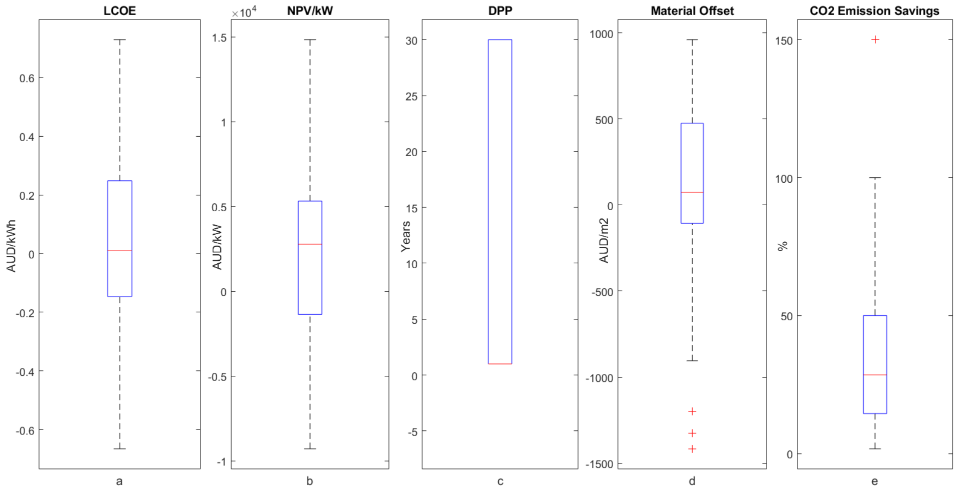
Financial incentives: Many incentive schemes, particularly from the government, are being announced for renewable applications. The government's supports for investments observed the rapid growth of this technology (Zhang et al., 2018). Various policies are implemented targeting multiple stakeholders in the value chain to promote domestic distribution. Cash incentives for initial investments, FIT for long term benefits, loan schemes and other policies are some of them. This study considers the cash incentives given to the building owners or investors. The effect of financial aids for initial investments on five decision performances is estimated in the sensitivity analysis. A range is developed as self-financed to fully funded projects. The sensitivity analysis ignored the current rebate to develop hypothetical cases identifying the effect of the different share of capital costs as financial incentives.

5. Results and Discussion

The data distribution of real cases and the uncertainty of capital cost, electricity conversion efficiency, material offset, and financial incentives on system performances are described in this section.

5.1 Multi-criteria Performances of Systems

Figure 2 portrayed the distribution of five performance criteria of thirty-six facade integrated PV systems. As showed in Figure 2 (a), most of LCOEs are distributed between 0.15 (negative) - 0.25 AUD/kWh with the average value of 0.1 (negative) AUD/kWh. The average electricity rate (0.2347 AUD/kWh) is higher than most of LCOEs. This suggested that the cost of electricity production of PV facades is cheaper than to national production. Further, half of the projects possess negative LCOE indicating that lifecycle incomes diminish the cost. This is a positive indication of the performance of the systems. NPV/kW is observed a range in the box plot as most lie between 938 (negative) to 5319 AUD/kW with the median value of 3,515 AUD/kW. Although optimistic performances are noticed, few extreme worst and best projects are also underlined in the cohort. The distribution of DPP is



extended between one year to thirty years considering the project lifecycle. However, the majority sit in the shortest payback period. This emphasised that facade integrated systems are feasible in terms of DPP. Most of the material offset values are scattered between (104) (negative) to 475 AUD/m^2. The average material offset is a positive indicating that in most cases, the cost of the traditional facade is expensive than BIPV. The distribution of CO_2 emission is scattered between 14% to 50% with a median of 28% in the box plot. This implies that most projects consume PV electricity for less than half of the building demand. However, few projects display high self-sufficient percentage. Overall performance of five parameters showed positive indications for many of the façade systems. This can be drawn that much of the facade integrated systems are favourable in relation to energy, environment, and structural value performances under the current condition. Next, sensitivity analysis is performed employing these values as base cases to estimate the influence of driving factors on system performances. The results are discussed below.

Figure 2: Multi-criteria Performances

5.2 Levelized Cost of Energy (LCOE)

Levelized cost of energy (LCOE) signifies the cost of electricity generation over the lifespan, which is generally compared with the retail electricity prices. The electricity prices of the projects are between 0.1310 – 0.4013 AUD/kWh. LCOE is compared with median electricity price: 0.24 AUD/kWh. Electricity prices are varied upon the project commission year and the country. The average electricity prices based on region Australia, North America and Europe are as sequentially 0.258, 0.234 and 0.148 AUD/kWh. It seems that Australia shows the highest electricity prices and North America is the lowest. Figure 3 depicted the distribution of LCOEs of selected uncertainty factors. It appears that LCOEs increases with the surge of capital cost. Declining trends of LCOE is shown with the rise of financial incentives, energy conversion efficiency and conventional material cost.

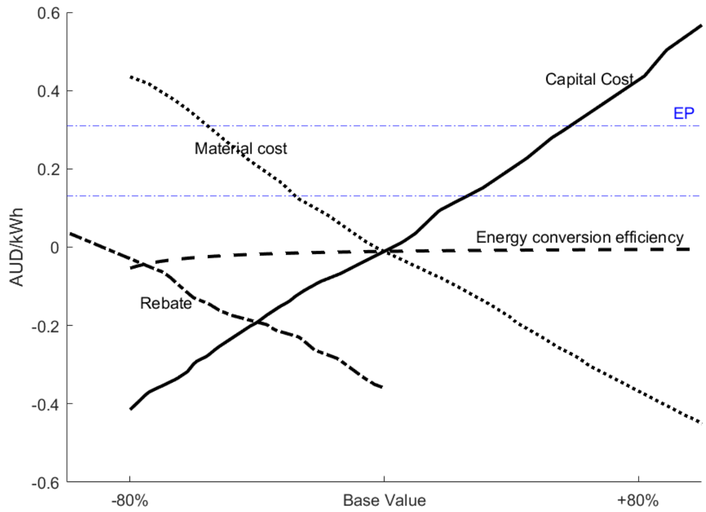


Figure 3: Distribution of Levelized Cost of Energy

LCOE distribution in capital cost is observed a significant move indicating 0.0054 AUD/kWh per 1% unit of change. The adverse LCOE is identified when the capital cost is beyond 1,309 AUD/m^{2,} representing 48% increase to the base value. It implies that capital cost more than 1,309 AUD/m^2 triggered an adverse performance. Negative LCOE is identified with the fall of the capital costs. As discussed above, negative LCOE represented an income source where lifecycle cost is recovered from the benefits. The maximum capital cost to achieve negative LCOE performances is 902 AUD/m^2. Projects are more favourable after this point. Energy conversion efficiency noticed a slight growth of LCOE with increasing values. The variance of annual energy generation is within the acceptable levels as it is lower the marginal electricity prices. LCOE varied by 0.0002 AUD/kWh for 1 % of change of annual energy generation. The trend of LCOE remains less than the average electricity price during the variance of energy generation between -80% to +100% of the base value.

The diverse share of financial aids on investments displays a decreasing trend of LCOE. LCOE is 0.035 AUD/kWh without any financial supports which is lower than the electricity rate indicating favourable performances. Financial aid for complete reimbursement is the most favourable performances resulting in negative LCOE of 0.35 AUD/kWh. The slope of the results represents 0.004 AUD/kWh for a one % share of capital cost reimbursement. LCOE lies in satisfactory performance region, which is less than electricity price whatever the financial aids. This suggested that the projects are feasible with respect to LCOE in the absence of financial incentives. The increasing cost of conventional façade materials demonstrated a decreasing trend of LCOE. It is noted that 0.005 AUD/kWh of LCOE with the 1% unit of variances. It seems that favourable LCOE achieved with the substitute of conventional materials which are higher than 587 AUD/m^2. The negative LCOE is noticed after 1,066 AUD/m^2 of the cost of the traditional materials.

According to Figure 3, capital cost represented a substantial influence and electricity conversion efficiency resulted in the least effect on LCOE. The second effect is observed in traditional facade material trend, which closes to the capital cost. However, material cost represents a positive relationship while the capital cost is otherwise with LCOE.

5.3 Net Present Value/kW

NPV/kW described in terms of benefit per system capacity for the comparison due to the various capacities of projects in the cohort. Figure 4 illustrates the distribution of NPV/kW across the variance of capital cost, electricity conversion efficiency, rebate and conventional material cost. Electricity conversion efficiency, rebate and material cost is noticed a positive relationship while capital cost represents a reverse connection with NPV. The trends dispersed between a wide range of AUD/kW.

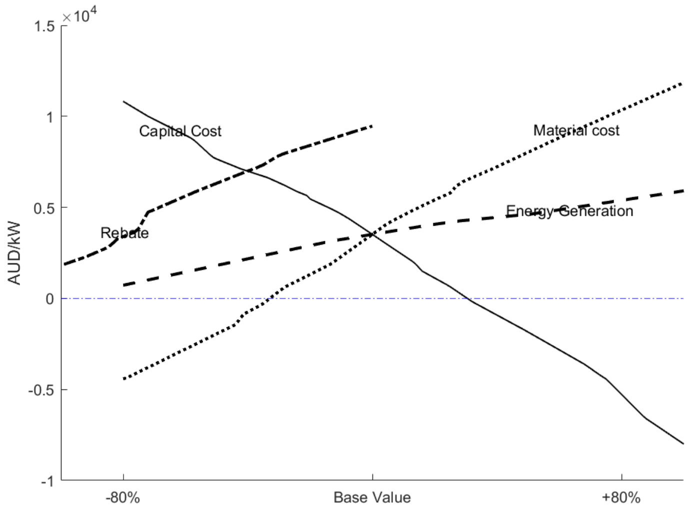


Figure 4: Distribution of Net Present Value /kW

The declining trend is observed in capital cost variation which is about 102 AUD/kW fall for 1% of the unit increase. The drop obviously increases the performances of NPV/kW. The average capital cost is 885 AUD/m^2 in the cohort. The results revealed that capital cost more than 1,150 AUD/m^2 (+30% base value) results in negative NPV/kW performances. The variance of electricity conversion efficiency displays an upward trend. According to Figure 4, the current efficiency is acceptable to attain positive NPV/kW of most of the projects while increasing values elevate the NPV/kW. It is spotted an NPV/kW of 28 AUD/kW for the unit change of electricity conversion efficiency. Further, the self-financed projects receive favourable performances which are about 1,866 AUD/kW. With the increasing share of financial aids, the projects reach substantial positive NPV/kW. Averagely, fully financed projects achieve NPV/kW of 9,667 AUD/kW. This resulted that projects promise positive NPV/kW without financial supports when both direct and indirect benefits are counted. Conventional material prices correspond to a significant effect in the NPV. It fluctuates over 93 AUD/kW for 1% change. The material prices less than 766 AUD/m^2 (-33%) indicated an unfavourable NPV/kW performance. This implies that traditional façade material replacement is encouraging if it is over 766 AUD/m^2. According to the results, the most considerable effect is observed in the capital cost, whereas the material cost, rebate and electricity conversion efficiency affect NPV/kW consequently.

5.4 Discounted Payback Period

DPP described the investment recovery period which is the most concerning factor on decisions. Figure 5 illustrated the distribution of DPP along with the four uncertainty factors. DPP is calculated to the 30 years of lifespan. Figure 5 indicated that inverse relationship of capital cost and positive relationships with electricity conversion efficiency, rebate and material values with the DPP. An increasing capital cost adversely influenced the discount factor as lower capital cost always create short DPP. Having a one-year payback period is A reward as the cost is recovered within the first. The capital cost which is beyond 1,150 AUD/m^2 is adverse as the project received lengthier payback periods. It seems that electricity conversion received minimal force on the payback period. With the lowest annual energy generation, 25 years of DPP is achieved. This is feasible as it is less than the project life. The one-year payback period remains during the change in energy generation efficiency. According to Figure 5, DPP is constant during the change of financial aids. This indicates that with or without financial aids, the projects can still achieve a short payback period. The distribution of the payback period in material offset is significant. The results revealed that a minimum of 766 AUD/m^2 material value is essential to achieve a one-year payback period. Expensive building materials offer a positive performance of DPP.

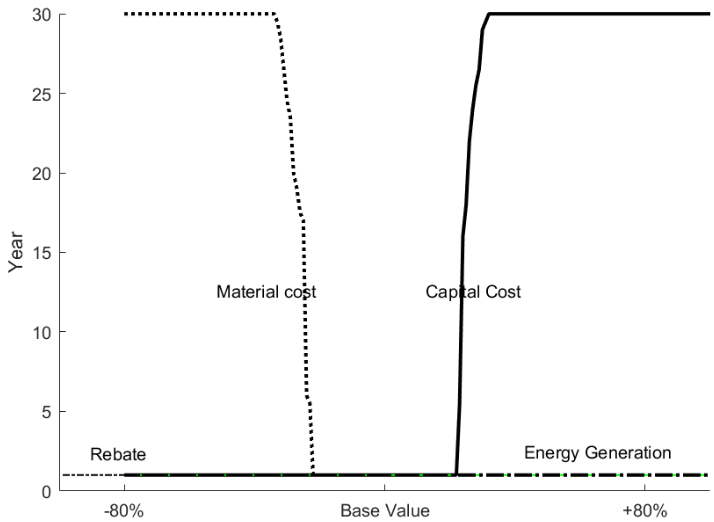


Figure 5: Distribution of Discounted Payback Period

5.5 Material Offset

Material offset value described a comparison of facade materials with BIPV modules. The positive value is a profit to the investor as the cost of systems is less than the equivalent building material. Figure 6 depicted the result of capital cost, rebate, electricity conversion efficiency and material cost on material offset values. Material offset distribute between 700 (negative) to 1,200 AUD/m^2 for building material variance of -80% to +100% of base value. The capital cost and material cost observed a considerable variance, while rebate and electricity conversion is negligible. Rebate and electricity conversion efficiencies are unrelated to the structural aspects of the building materials.

Further, increasing capital cost represents adverse performances while conventional material cost factor is otherwise. The capital cost is observed 8.7 AUD/m^2 variance of the material offset. The fall of material offset with the rising capital cost is noticed in Figure 6. The material offset value is unfavourable after the capital cost of

1,035 AUD/m^2 (+17%). This indicates that too expensive systems are a detriment to use.

The distribution of material cost over the conventional facade materials noted an upward trend. It is revealed that

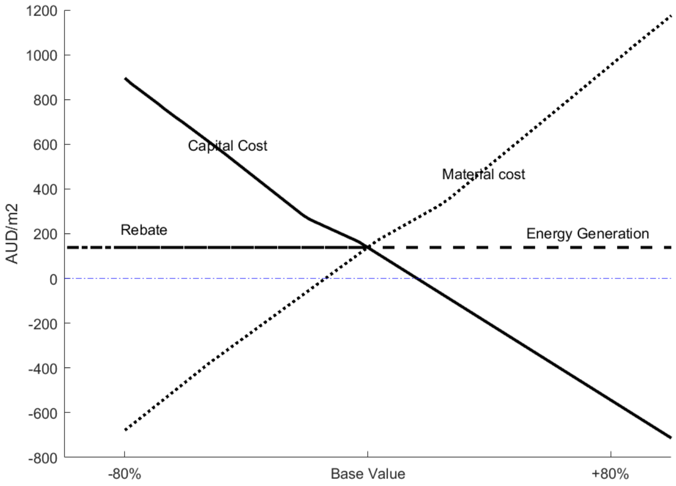


Figure 6: Distribution of Material Offset

increasing values of traditional material of facade increase more positive material offset performances. For examples, the replacement of expensive building material cost with BIPV modules is always beneficial. The material offset of 11 AUD/m^2 is received with 1% change of conventional materials. As indicated in Figure 6, the cost of conventional building materials which are less than 944 AUD/m^2 is adverse. The highest effect is recognised in the facade cost instead of capital cost.

5.6 CO_2 Emission Savings

CO_2 emission saving is an indication of sustainability criteria on decision making. The parameter represents the ratio of total electricity generation to building energy demand. The high value defined self-consumption building as consuming more electricity from the BIPV systems while feeding excess to the national grid. Figure 7 represents the variance of driving factors on CO_2 emission savings. As indicated, only electricity conversion efficiency influences CO_2 emission savings while others are irrelevant. The distribution of CO_2 emission savings is 15% to 56%, with an average of 30%. It is observed an upward trend of CO_2 emission savings for the variance of electricity efficiency. Increasing efficiency improves the amount of electricity generation, which is eventually expanding CO_2 emission savings. This offset the conventional electricity requirements implying environmental benefit aspects. It is identified 0.28% variance of CO_2 emission savings with the electricity conversion efficiency.

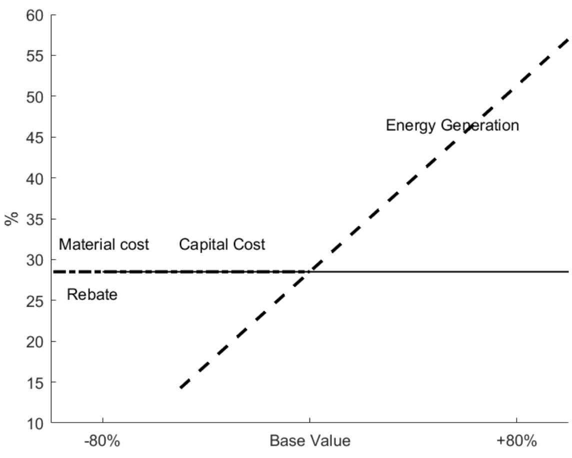


Figure 7: Distribution of CO_2 Emission Savings

6. Conclusions

Facade integrated PV systems promise the great degree of aesthetically appealing designs in the buildings to generate a significant share of building energy demand. It is an opportunity to construct renewable energy with no land use and less infrastructure using the untapped area of building facades. Yet, the architects, building owners and other building professionals doubt on the performance of such systems creating publicly unacceptable technology. Many developments are being emerged in the industry during the recent past escalating performance of systems. Due to the volatility in this market, uncertainties could govern diverse decision choices for practitioners. The study attempts to inform the influences of uncertainties on system performance that lead to the decision of system uptake. The sensitivity analysis is conducted contemplating possible circumstance execute in the industry. The results revealed that the performances of façade integrated PV systems are diverse. The effectiveness of BIPV performances are based on the balance of multiple criteria. It is noticeable that decisions should not be compromised by looking only at single decision criteria. The interesting results of sensitivity analysis are the influence of capital cost, financial incentives and building material values are substantial compared to electricity conversion efficiency. The capital cost more than 1,300 AUD/m^2, 1150 AUD/$m^{2,}$ 1035 AUD/m^2 showed adverse LCOE, NPV/kW and DPP and material offset performances respectively. Increasing the energy efficiency of modules improve the performance of all kind except building materials. The projects reveal favourable economic performances even with the absence of financial supports due to the taking to consideration of both direct and indirect benefits are counted. It is favourable to replace conventional building materials with the PV modules. This study is limited to investigate only four uncertainties, although multiple drivers could affect the performance of the systems. Further, only five performances are developed due to the availability of information on existing projects. Therefore, the outcome of this study lies within a limited scope.

With the increasing development of buildings in the urban dense and attention of sustainability technologies, façade integrated systems will have a massive demand among the building sector. Hence, technology developments are unstoppable in this industry, providing high-performance applications. It is forecasted many more uncertainties in this industry. This study offers a practical reference to expand the BIPV uptake in different economies by looking at the significant effect of the key uncertainties on decision criteria or multiple performances of systems.

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