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THE POTENTIAL OF INTEGRATING PHOTOVOLTAICS IN BUILDING FAÇADES- CASE DUBAI

LAHTI UNIVERSITY OF APPLIED SCIENCES
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ABSTRACT

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Abstract

Awareness of global warming coupled with the ever-increasing demand for a new energy source has generated a strong interest in the use of renewable sources of energy. In this thesis, photovoltaic solar energy is produced as one solution. This thesis assesses the potential of PV panels to be deployed in the facades of multi-storey buildings in Dubai. To reach the main goal, different types of PV technologies are compared to opt for the PV system that is most suitable for the UAE situation. The comparison is made with the aid of PVsyst software among three types of PV modules (Mono, Poly crystalline and Amorphous-Thin film), commercially available at the time of writing this thesis. It gives the impression that polycrystalline PV-modules are the best choice for BIPV Facades in Dubai, as demonstrated from the output and cost results. Furthermore, it seems that there is a potential for substantial monetary savings and a reduction in GHG emissions, moreover a less than 5-year payback period could also be an attractive benefit for integrating PV into high-rise buildings facades in Dubai.

Keywords

Photovoltaic, Building integrating, Greenhouse gas emissions

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LIST OF ABBREVIATIONS

AC	Alternative Current
Al-Saafat	An evaluating system for the green buildings in Dubai
a-Si	Amorphous Silicon panel
BFIPV	building façades integration photovoltaic
BOS	Balance of System
BIPV	Building Integration Photovoltaic
BFIPV	Building façades integration photovoltaic
CIGS	Copper indium gallium selenide solar cell
CdTe	Cadmium telluride solar cell
CO_2	Carbon dioxide
DCCE	Dubai Carbon Canter of Excellency
DC	Direct Current
DEWA	Dubai Electricity and Water Authority
DGBR	Dubai Green Building Regulation
E Array	Energy produced by the PV array (input of the inverters)
E_Grid	Energy injected into the grid, after inverter and AC wiring losses
Eff Arry R	PV array efficiency related to the irradiance on the Collector's area
Eff Sys R	System efficiency E_Grid related to the irradiance on the Collector's area
LID	Light Induced Degradation
LCE	Life cycle emissions
I_{mpp}	Current at maximum power point
I_{sc}	Short Circuit Current
IPCC	Intergovernmental Panel on Climate Change
K	Thermal constant
MWh:	Mega Watt hour
µm:	micrometer
nm	Nanometer
MPPT	Maximum Power Point Trackers
GaAs	gallium arsenide solar cell
GHG	Greenhouse Gas
GDP	Gross Domestic Product
Glob Eff	Effective Global collector
Glob Inc	Global irradiation in the collector plane

GlobHor	Horizontal Global irradiation
Kw_p	Kilowatt peak
Kwh	Kilo Watt hour
PR	Performance Ratio in %
P	Power
PCU	Power Conditioning Unit
PVsyst	Photovoltaic System software
STC	Standards Test Condition.
T_{amb}	Ambient average temperature
UNFCCC	United Nations Framework Convention on Climate Change
V_{oc}	Open Circuit Voltage
V_{mpp}, U_{mpp}	PV voltage at maximum power point
Y_a	Array yield Energy production of the array
Y_r	Yield Energy production at "nominal" efficiency which also defined as the array P_{nom} (nameplate value) at STC.

1 INTRODUCTION

Urbanization is an integral part of development in the modern world. In heavily populated area, due to a scarcity of land resources the urban areas are witnessing a growth in high-rise towers. These buildings are densely inhabited and are major consumers of energy. They are also considered a source of greenhouse gas (GHG) emissions throughout the use of power generated from fossil fuel-based sources (EU 2010; DOE2014). According to the 2020 Horizon goals, this demand must be tackled locally by availing of CO2 emission free and abundant energy sources and technology. Solar photovoltaic (PV) is among all renewables the one that best suits a cityscape's electricity load profile. In addition to this is the fact that solar irradiance reaches very high levels in Dubai. In contrast, the cost of PV power plants in the urban environment presents challenges, such as the high cost and scarcity of ground area which, imposed on the urban fabric to grow vertically. Therefore, the most appropriate and straightforward methodology is building integration PV(BIPV) (Scognamiglio 2012; Brito & et al 2013).

In this research the Author set out to explore the potential of facade integration PV from many aspects. This research paper aims to analyse climate-change and the electricity consumption mutual impacts in Dubai. As well as to evaluate the potential of integrating Photovoltaic in high-rise buildings facades in Dubai. By discussing the present status of different Solar Photovoltaic technologies as well as the facades types. The writer intends also to examine the performance of monocrystalline, Polycrystalline & thin film technologies used for Solar PV in a skyscraper building in Dubai by using Photovoltaic System software (PVsyst). It also aims to analyse the cash savings, related payback period as well as the amount of Greenhouse Gas (GHG) emission possible reduction as a result of using Solar PV Facades in multi-storey buildings in Dubai.

The theoretical part of this thesis elaborates on the targets of design prototype Photovoltaic system from different aspects and provides a band of necessary facts and analyses the possibility for entering the renewable energy market in Dubai. The writer shows his desire to study the opportunity for Nocart company to compete in Dubai market. In this thesis, the author aspires to answer the following questions: Does building façades integration photovoltaic (BFIPV) will affect climate change? How will it do so? What is best method of PV system implementation in the facade? Is technically possible? Analyse and evaluate the conducted feasibility study for the proposed project to determine whether it will be, within the estimated cost, profitable or not?

By answering these questions, the writer inspires to break the circle among the electricity demand in high-rise buildings with respect to the increase in GHG emissions and the resulting climate change, as well as disclosing business opportunities for BIPV in Dubai.

1.1 Methodology

This research aims to present an in-depth understanding about the impacts of building integration photovoltaics on climate change and to analyse the profits and Dubai market access potential. thus, the writer intends to utilize a mix method between the qualitative and quantitative mythologies for gathering and analysis the information from Varity sources. This thesis structure base on variety sources of data such as of researches papers, books, articles and websites to establish most of this research pillars. Nevertheless, the primary sources of information were collected from interviews and calculated with aid of the PVsyst program.

In this paper, the Author intends to use the qualitative method to fill the gap of information about the major thesis challenges concerning to the interrelationship between climate change and buildings electricity consumption increasing for towers and PV regulations in Dubai, the current available technology in the market and the estimated prices of photovoltaic systems' equipment. Therefore, the writer aims to conduct a certain number of interviews with experts from Dubai Carbon institution in Dubai, (UAE) and Nocart company. The interviewer will perform a semi-standardized interview with open-ended, already prepared, questions.

Since the study aspires to provide the feasibility study for the most suitable BIPV façade system for the case study, the writer employs the quantitative methodology for monitoring PV systems performances and comparing among variety types of PV modules (Mono, Polycrystalline and Amorphous-Thin film). The Author plans to run a simulation for the designed PV systems to evaluate the power performance, cost, and profitability of the proto-type system with the help of PVsyst software for a specific building in Dubai. PVsyst is used in this study to assess the comparative output of monocrystalline, polycrystalline & amorphous (as thin-film PV panel) technologies as applied to facades of high-rise buildings in Dubai.

2 CLIMATE CHANGE ISSUES

2.1 Climate change

“Is it time to act?" Climate change is imperative, an urgent measure to identify global warming as a serious issue presides over many political and economic agendas. The United Nations has a crucial role to play in understanding and encouraging world leaders to take responsibility for the impact of climate change, which poses a serious threat to the planet's economic growth and ecosystem as well as the survival of humankind (United nations 2014). Climate change indicates any change in climate over time, due to a natural variable and/or a result of human activity. It is related to the accumulative of CO2 in the atmosphere, which may change the concentration of greenhouse gases and prevent solar irradiation from being reflected out of the atmosphere. The effects of climate change are clear, according to a report by the Intergovernmental Panel on Climate Change (IPCC). The average global temperature has risen by 0.76 degrees Celsius and sea level has risen by 17 centimetres since the 19th century (IPCC 2007.)

The climate change causes fall into two categories: natural and human cause climate change. Natural causes are related to natural phenomena such as volcanic eruptions, ocean currents that move carbon dioxide (CO2) across the Earth, tropical changes associated with changes in the angle of the Earth's slope, continental drift (Yuen& Kumssa2011.) The human causes associated with anthropologic activities (due to cities, population, economic growth,) such as; building development, land use change, transport, agriculture, and waste and sewage participation. However, researchers have shown that human activities, fossil fuel burning energy production, are the main contributor to climate change (IPCC 2007; World Bank 2010; Yuen & Kumssa 2011.)

As an effort to unify the global response to climate change, the United Nations launched United Nations many conferences and summits on environment and development so as to stimulate countries leaderships to pursue economic development approaches and to find appropriate methods to halt the depletion of irreversible natural resources and reduce the resulting environmental pollution (United Nations 2013). In the same context, the United Nations Framework Convention on Climate Change (UNFCCC) was opened for signature as a non-binding obligation to reduce the concentration of greenhouse gases in the atmosphere, thereby limiting the impact of human activities on the Earth's climate system (UNFCCC 2013).

In 2015, the Paris Convention (COP21) was aimed at strengthening the global response to climate change risk through, first and foremost “curbing the increase in global average temperature to well lower than 2 ° C above pre-developing era levels, as well as following strategies to diminish the rise in global warmth to 1.5 ° C over the pre-industry levels and reducing greenhouse gas emissions (United Nations 2015). Most of the world countries have committed themselves officially to this agreement, however the implementation of this convention is differentiated in terms of responsibilities and proportionate capacities, in the light of different national circumstances (UNFCCC 2018.)

The expected impacts of climate change on the environment and human lifestyle are fluctuated in intensity and frequency. That increase in global mean temperature (or what is known also as global warming) is assumed to lead to a variety of secondary impacts, such as: changes in precipitation patterns, sea level rise, Arctic sea ice, melting glaciers, permanent freezing, sea surface and large lake temperature increases, as well as floods due to increased rainfall in some areas and severe drought in other areas. Changes in ecosystems, changes in the frequency and force of hurricanes, acidic seawater, changing farming patterns, increase in extreme weather events, disease expansion and the opening of new commercial routes are all possible effects (National Earth Science Teachers Association 2012). Climate change threatens all countries, where developing countries are the most vulnerable. Developing countries are likely to bear 75 per cent of the costs of damage caused by climate change (World Bank 2010.)

In 2010, the UAE was ranked as having the highest carbon footprint per capita in the world (IPCC 2007.) In addition to that the subtropical dry climate of UAE increases its vulnerability to climate change. The main threats of climate change, which may have impacts on urban development in the UAE, are: increased temperature, rising sea level and lower precipitation. The UAE is expected to face a rise from 2.1 to 2.8 degrees Celsius in temperature by 2050 and about 4.1-5.3 degrees Celsius by 2100. This increase is likely to affect most sectors of urban development such as human settlements, agricultural products, health and energy. Secondly, the rise of the sea in the form of floods, erosion and flooding poses significant risks to the UAE (World Bank in 2007).

The UAE may lose about 1-4% of its land area and 2-4% of its GDP and this will affect 5-12% of its total population. Dubai is projected to be the second most vulnerable emirate in the UAE, with potential loss of 217 km2 approximate (5-6%) of its area as a result of 1-meter rise in sea level scenario. In addition, the country is expected to experience an extreme scarcity of rainfall resulting from its geographical location in a hot arid region. The increasing demand for water in the United Arab Emirates associated with population growth, economic growth, irrigation and low water resources management will increase the demand for desalination, which lead to another set of challenges associated with increased energy consumption and biodiversity change of Coastal Ecosystem (Environment Agency of Abu Dhabi 2009). The Government has therefore focused on the Energy sector as the main source of greenhouse gas emissions to reduce emission levels. Consequently, climate change policies aim at reducing energy demand, improving energy efficiency, switching to carbon-free technologies within green economy concept (MOE 2010).

2.2 Energy to climate change relation

Nowadays, more than half of the world's population is living in cities; and, they generate almost 80% of global economic output, and nearly 70% of global greenhouse gas emissions are related to energy. By 2050 the number of inhabitants who live in urban areas is expected to become around two thirds of the world's population, as a result of that cities will release larger amount of greenhouse gas emissions (GHG) (World Bank 2010). The energy and services sectors and other pillars of any city's sustainability consequently are threatened by the negative impact of climate change. Climate change, like other environmental issues, is the most complex challenge facing policy makers today (Otto-Zimmermann 2011.)

Extreme heat climate induced energy demands are expected to produce a potential additional burden on the energy sector. The Potential Climate Impacts on energy are organized and discussed according to several distinct themes: demand, generation, distribution, and energy infrastructure. Temperature elevation, especially in hot areas, is expected to intensify the demand for electricity during the peak cooling period, particularly in the warm afternoon weekdays. As a result, the loads of peak per capita are expected to rise at about 20% by the end of this century (Wei. et al 2012). On the other hand, a warming climate would drop the capacity and efficiency of power plants. It has been demonstrated that the power plant capacity is decreased by 0.5% to 1% for every 1 °C increases in ambient air temperature.

In addition to that, power transmission lines inspect incremental power losses as the temperatures of conductors increase. Sathya, who studied the effects of about 5 °C air temperature increases on transmission lines, suggested that loses might be more significant, that they could reach 7% to 8% of peak capacity losses (Sathya et al, 2012). Finally, high ambient temperatures can affect the performance of the transformer adversely (IEEE, 2007). The transformer efficiency might be reduced by about 0.7% for each 1 ° C temperature above (Li. et al 2005). In lighting from above (subchapter 1.1 and 1.32), there is a mutual inter-relation between the climate change and the electricity sector. A climate change temperature induced increase has significant effects on electricity demands and vice versa. The Diagram bellow summarizes that relation. National and local governments have avital role to play in addressing climate change and shaping the development to be sustainable. The responsibility of city governments and policy makers is to understand impacts, develop mitigation and adaptation strategies, and find appropriate tools to measure city development towards specific climate targets. Hence, making building infrastructures of urban areas more sustainable, and investing in low-carbon urban planning and development strategies could significantly reduce greenhouse gas emissions (IPCC 2014).

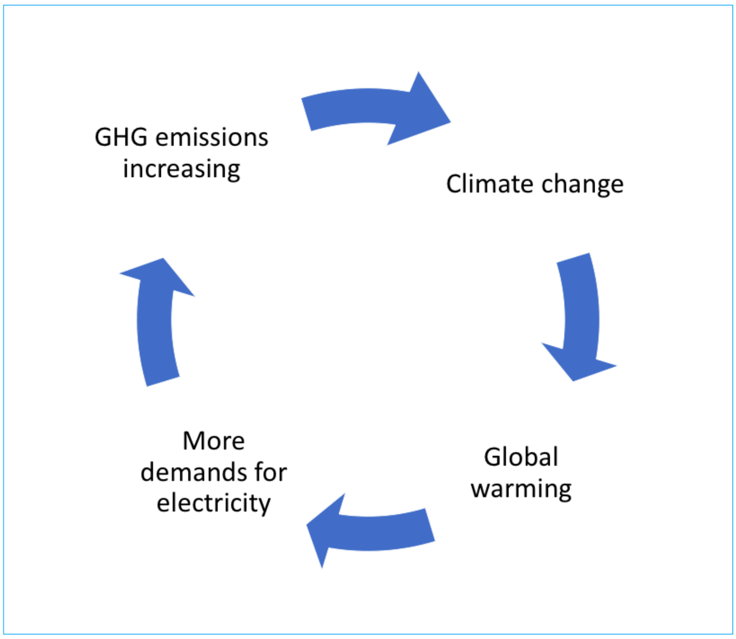


FIGURE 1. The climate change and electricity interrelation (By the author)

Many adaptive measures may be taken to offset future climate change to energy issues relation in urban areas. Despite the above-mentioned, production and distribution power loses in different segments of the energy sector, on-site power generation could reduce and mitigate the influence of climate change on electricity. According to Welsh (2010), the decentralization method of power generating could be one option to reduce losses in the power distribution system (Welsh et al. 2010). On the other hand, the production of electricity through the use of renewable technology is one of the most important solutions that many researchers believe are able to eliminate and mitigate the problems of climate change (Scognamiglio 2012; Brito et al 2013.)

3 DUBAI

Dubai is one of the seven emirates (Abu Dhabi is the capital, Sharjah, Ajman, Fujairah, Ras Al Khaimah and Umm Al Quwain) bounded together in 1971 under a federal constitution to form the United Arab Emirates (UAE). Dubai covers an area of 3,885 square kilometres of the total area of the United Arab Emirates, making Dubai the second largest emirate in terms of size and the most populated city in the United Arab Emirates. Dubai is situated in the southwestern corner of the Arabian Gulf, shared the border with Abu Dhabi and Sharjah emirates (as in Figure 2). Dubai is identified by its semi-arid subtropical climate with plenty of sunshine, moderate winter and very little rain during the year (Government of Dubai 2018).

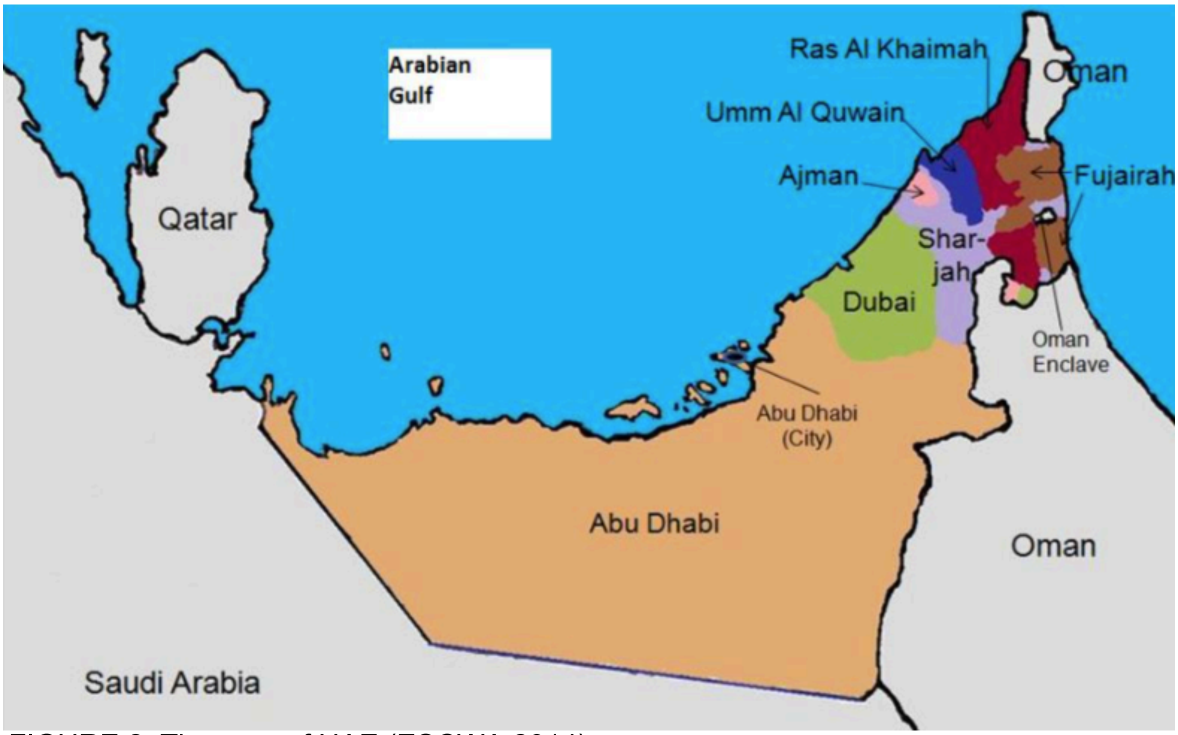


FIGURE 2. The area of UAE (ESCWA 2014).

The Population of Dubai has been rising about 40 times in the number of inhabitants, since the establishment of the UAE in 1970, to reach about 9.590,641 million inhabitants in 2018 (World meters 2018.), whereas the urban area extended rapidly to 400 times bigger urban areas than the original master plan of Dubai, most of that expansion and population growth was because the economically growth and attracting overseas investors. Therefore, the vertical expansion was crucial to absorb the rapid population, as well as satisfy the desire to build a statement of modernity and economic prosperity (Ogaily 2015).

Dubai has an open economy with one of the highest per capita incomes in the world and a sizeable annual trade surplus. The country's free zones, which offer 100 per cent foreign ownership and taxes' exemption, are a major means of foreign investment in the country. The funds can convert and transacted freely to and from Dubai (Masood 2016). Now a day, Dubai's economy is no longer depends on oil, nevertheless is more diversified, heavily reliant on several diversify sectors such as trade, real estate, services and finance. The central geographic position of Dubai between Asian and European markets makes Dubai play an essential role in the international trade mechanism. Furthermore, its also allowed to become one of the popular tourist attractive destination (Dubai 2018.)

Globally, economic opulence, population and urban development have always been coupled with high-energy requirement (BPIE 2011.) Therefore, the built environment sector had shown provision of standards and codes that regulate the new constructed buildings such as Dubai Green Buildings regulation (DGBR) in 2015 (SCE 2015.) While these efforts have focused mainly on new constructions, the existing buildings, which are attended to endure for the next decades, were neglected in the DGBR. Although it represents the biggest consumer of electricity in Dubai (Dubai 2015.) the new building blocks will make up 0.5- 2% of the total construction stock and will contribute with about 10% to 20% of the gross increase in energy consumption by 2050.

3.1 Current electricity situation in Dubai

During the last decades, due to the population growth and urban development in Dubai, the electricity demand has been increased dramatically from 3,228MW in 2004 to reached 8,232 MW in 2017(DEWA 2017). The rising in electricity demand is projected to persist with about a 10% rise annually for the coming future (Masood 2016.) Electricity and water sectors are the largest source of GHG in Dubai, these are responsible for about 33percent of the emission in Dubai (DCCE 2018).

In the last few decades, the awareness of green gas emissions has been escalating in the United Arab Emirates. So, to achieve sustainable development in the UAE. The UAE's strategy for a green economy is primarily based on three main groups: a low-emission development pattern, more energy efficient use, and renewable alternative resources, the Green Economy Initiative was launched in 2012 by His Highness “Sheikh Mohammed Bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and ruler of Dubai” (UNDP & Dubai carbon 2014).

Dubai Water and Electricity Authority (DEWA), which is one of the five federal companies responsible for developing, executing and delivering power facilities in the emirate of Dubai. DEWA owns and operates 13 plants in the emirate, with a total capacity of over 10,200 megawatts. Most of the existing power plants in Dubai are gas fired, because Dubai is non-oil city in UAE, that impose on them to purchase its fuel needs from open markets which in turn effects the electricity fees by an additional fuel price variation. Moreover, Urban Constructors textual response for the most electricity consumption in Dubai. The building sector (commercial and residential) accounts for more than 87% of electrical consumption In the Emirate with 29.33% and 47.55% respectively (DEWA 2017). In addition to this is that, constructors accounts for 35% of total greenhouse gas emissions in Dubai (UNDP & Dubai carbon 2014.)

Therefore, to maintain the engines of low-carbon economies, the need for promote a sustainable energy resource and to support energy diversification, were expressed in the national vision of the United Arab Emirates 2021. That represents a promising alternative in the country to achieve sustainable development and reduce reliance on fossil fuels (Government of UAE 2018).

3.2 Dubai target concerning climate change

Combating climate change is a cross-sectorial task that should be mainstreamed into programmable approaches, supportive policies, initiative and strategies plans (European commission 2018), that can reduce and mitigate climate adverse changes and increase city resilience (Robber 2010.) Dubai government has demonstrated a commitment to developing and implementing solutions to reduce carbon emissions. In 2015, Dubai set itself the goal of integrating sustainable energy solutions into energy supply and demand, commensurate with the emirate's growing needs in a sustainable way. Dubai is committed to playing its part in developing and implementing solutions to reduce its carbon footprint. Therefore, number of major power projects in the field of legislations, demands management strategies and renewable supply of energy have been launched in Dubai in order to meet the emirate’s existing and future visions of clean and sustainable community.

3.2.1 Electricity demand reduction

Dubai government enacted regulations and laws such as Dubai Green building regulations (DGBR) and a mandatory rating scheme (Al-Saafat) to encourage energy conservation in Dubai, these regulations have been implemented to promote sustainable building practices. Although these regulations have been imposed by Dubai Municipality for all new construction in the emirate, missing from the target group are all the existing buildings which are the main electricity consumer and of GHG producing (DGBR 2011; SCE 2015). Enhancing the efficiency of energy usage is being more recognized as one of the key factors to meet the sustainably of the country's increasing energy demands. Thus, Dubai has enacted a number of laws and programs to modernize its regulatory framework. The effectiveness of the price increases in electricity tariffs in conjunction with the introduction of slab tariff" the higher the percentage, the greater the recognition" in Dubai, helped to reduce the growth in demand for electricity and relieved pressure on the sector. Dubai has gradually reduced most of its electricity subsidies. The incentives were provided by reviewing the electricity fee structure consistent with the increase in the cost of energy and the phase-out of government subsidies for the electricity tariff (SCE 2015).

3.2.2 Improving the efficiency of infrastructure

loss in electricity distribution occurs at each stage of the energy delivery process, starting in the earlier step of electricity generation in the power plants passing to next step which is the destitution (represented by substations and transmission line system) and ending up with the client's meters. Though, losses associated with the cable's conductivity exemplify only one type of electricity transmission and distribution losses. Since The transmission line losses are the highest during the electricity delivery stages. Nonetheless the electrical losses are referred to commonly as "electricity transmission lines losses", The average system line losses range from 6 to 10 per cent on most US utility networks, but they increase dramatically during the peak hours when power lines become heavily charged. But, that effortlessly could be reduced up to 20% By just evading a fraction of the electricity consumption at peak hours. Consequently, decreasing in the power transmission line losses is an available possibility to improve the efficiency of power suppling and dropping the linked gas emissions (NACAAI 2015). As part of its efficiency improvement strategy, DEWA managed to reduce the percentage of transmission losses in DEWA's electricity line from 7% to 3.3% per cent, while increased the generation efficiency by 28.86 per cent between 2006 and 2017 (DEWA 2017.)

3.2.3 Renewable energy

In 2015 as part of the clean Energy Strategy, Dubai has set its own targets to provide 25 per cent of its total electricity requirement from solar energy by 2030. The share of clean energy is intended to be gradually increased to reach 75 per cent by 2050. The strategy aims also to make Dubai a centre of clean energy and green economy with the least carbon footprint in the world. Dubai entities have embarked on translating goals of diversifying energy sources and raising the percentages of renewable energy usage in two main approaches (Government of UAE 2018).

On the mega scale, and as an important step for achieving Dubai's objectives in energy resources diversification. Mohammed bin Rashid Al Maktoum Solar Park has been established as the largest single location project in the world, aiming to provide in stages 5000MW PV electricity capacity by 2030. In The solar park, a mixture of photovoltaic and concentrated solar power technologies will be used to provide the inhabitants of Dubai with clean energy. The first two phases of the project supplied DWEA's network with 210MW from photovoltaic modules, which in turn contributed to a major yearly reduction of about 229,000 tonnes of carbon dioxide emissions in Dubai. Upon completion of the solar park the reduction of carbon dioxide emissions will reach over 6.5 million tonnes annually (DEWA 2018).

On a smaller scale Shams Dubai initiative was launched in 2014 to support diversification of the energy mix, encouraging the use of clean and renewable energy sources. This initiative aims to encourage home owners and building owners to generate on-site electricity by using photovoltaic solar systems, an effective way to reduce demand by meeting part or all of the building's energy requirements. The surplus is exported to DEWA's network to adjust them against the electricity bills (DEWA 2018). On the other hand, the renewable energy, (represented by photovoltaic Solar Energy), was embedded in the green building code of Dubai Municipality which states that it is mandatory for all new buildings to generate at least 5% of their electricity on-site by utilizing grid connected-rooftop Photovoltaic systems (Green building regulation 2011). However, this will collide with the fact that rooftop photovoltaic systems are not able to provide the required 5% which is mandatory in DGBR, especially in high-rise buildings electricity (Appendix 2). It follows from the above that there is a necessity to exploit the façade of the buildings in case we want to generate more electricity than minimum percentage of PV, which stated in the DGBR, to promote the PV market as well as accelerate the transition to green economy.

4 PHOTOVOLTAIC

The sun is an energy-rich resource and research has long been undertaken on how to to generate electricity from it. Solar cells are used to convert sunlight directly into electricity through a photovoltaic effect (Kothari et al. 2016). The photovoltaic solar cell is a semi-conductor device that converts photovoltaic power to electricity immediately (Archer. et al 2001). Often, it can be manufactured by combining two layers of semiconductors, one with a positive charge (holes) and the second with a negative charge (electrons). The PV operation principle is based on the photovoltaic effect properties. When light photons collide the photovoltaic cells, some of the light photons absorbs by the absorber layer in the PV cells (depends on the PV cells efficiency), The light energy absorbed by the photovoltaic cell stimulates the charges caries (electron-holes) to generate, as a result an electric field will be occurred in the semiconductor material PN-junction (see Figure3).

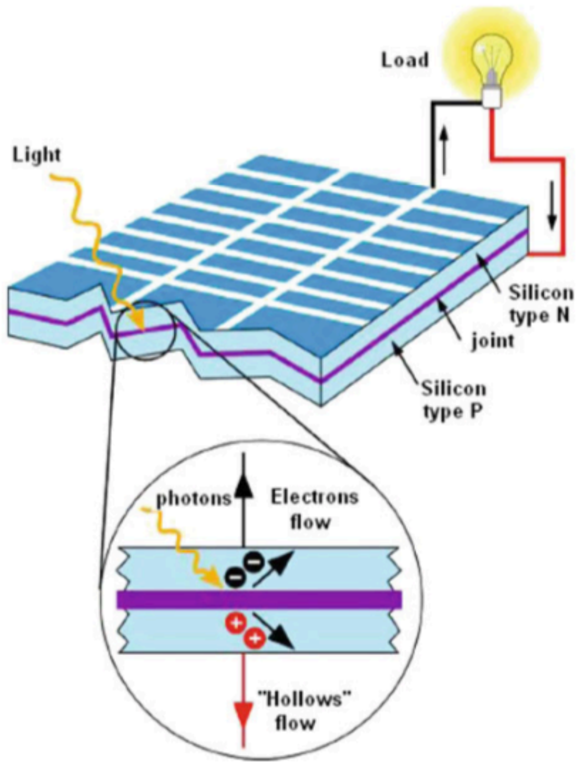


FIGURE 3. Photovoltaic solar cell performance (Papadopoulou 2011)

Electrons get affected by this field and tend to flow to the cell metals contacts surface, this electron flow which terms to as Direct Current (DC), which can be immediately used (most of cases current regulator is needed) or saved in the battery (Archer et al. 2001; Randall 206). The single PV cell output is inconveniently low about 0.5 Volt and 4.5-Watt power.

Therefore, to satisfy the electrical requirements for voltage, and power for a variety of higher voltage applications, a number of PV cells are connected in series (to increase the voltage) and parallel (shunt) electrical patterns (to increase the current), forming up what is called a photovoltaic module or in the majority cases (crystalline silicone base PV) could be refers to as PV panels. (Messenger 2010; Rabiul 2014). The formation of PV cells, modules and arrays are shown below in Figure 4.

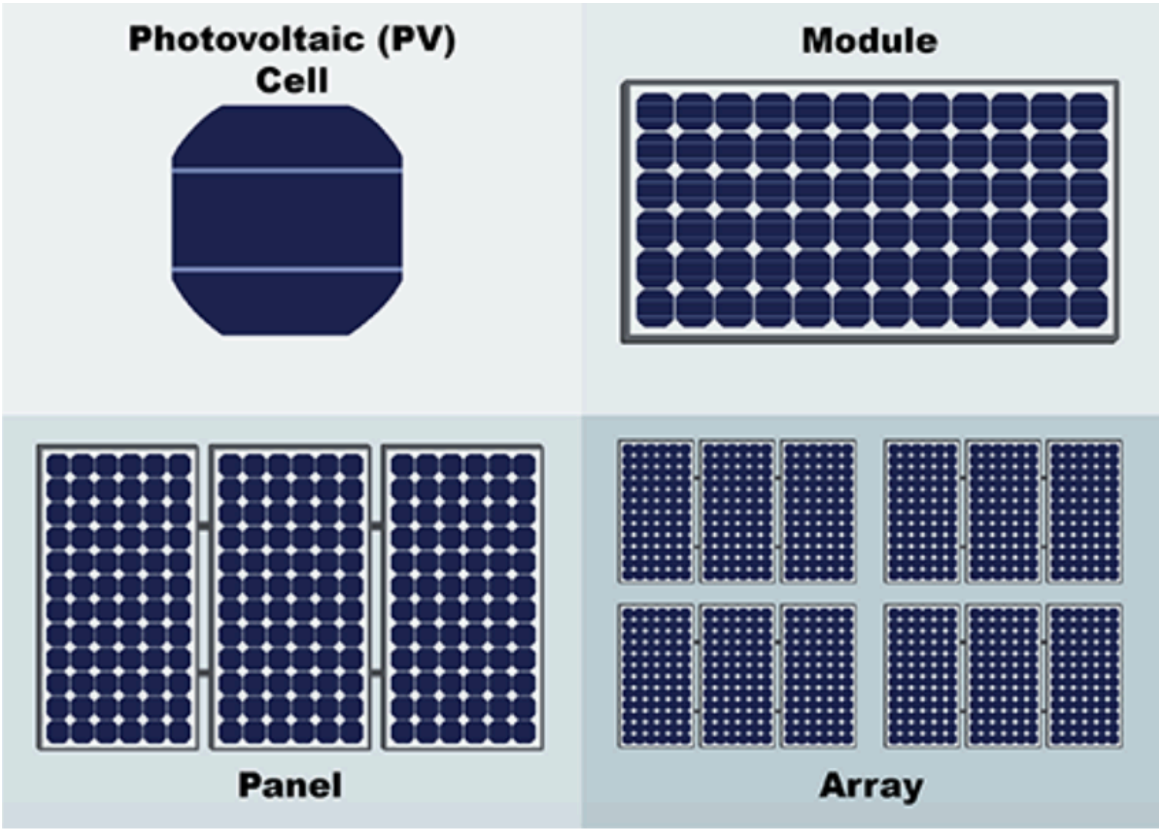


FIGURE 4. Crystalline-base Photovoltaic (Fsec 2018).

For standardization and comparisons purposes (due to ununiform solar irradiation in different part of the world location), PV cells are tested under standard test conditions (STC). That Refers to the amount of solar irradiation at sea level, with 1.5 atmospheric mass (AM), which is 1000 W/m2. Hence, the output power at the manufacturer PV datasheet refers to the power output of the PV panels under Standard Test Condition (STC), however any changes in one of the above may affect the output power (Mäki 2012).

photovoltaic solar cells can be Theoretically represented as a diode (Figure 5). But there is no ideal solar cell in practice. Therefore, parallel resistance and series resistance are added to the model. The series resistor is used to model the power loss series due to the current rotation between the conductive materials and the photovoltaic cell connections, while the effects of leakage currents in the p-n junction lead to the formation of the parallel resistor (Carmel. et al 2013).

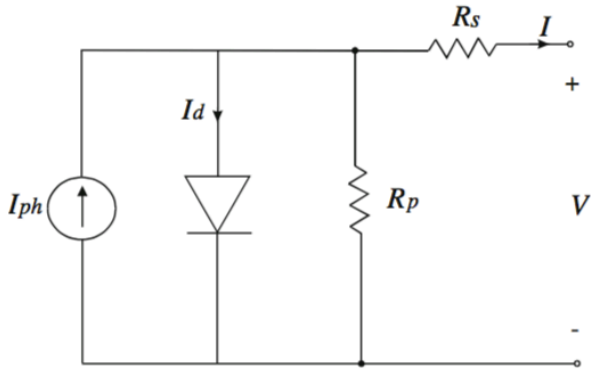


FIGURE 5. Practical PV cell equivalent circuit (Piazza & Vitale 2012).

The performance of photovoltaic cells, such as: (Voc Open Circuit Voltage, Isc Short Circuit Current, Vmax, Imax ...etc.), is usually given by PV venders under Standards Test Condition (STC). The I-V curve shown in (Figure 6) illustrates that the current reaches the peak value when the load resistance across the two ends of the cell is zero, that is referred to as a short circuit current (Isc). Nevertheless, the highest voltage value is obtained when the load resistance value is very high, which refers to the open circuit voltage (Voc) (when current is zero). Power is a product of current and voltage (p = V * I). The maximum capacity occurs at a certain point in the knee position of the I-V curve, which represents the maximum power (MPP). At this point the current and voltage are respectively referred to as Imax and Vmax. To ensure the highest PV generating power harvesting at a certain time most of the modern inverters include a maximum power point tracker (MPP tracker) Use. (Messenger et at 2010; Rabiul et al 2014)

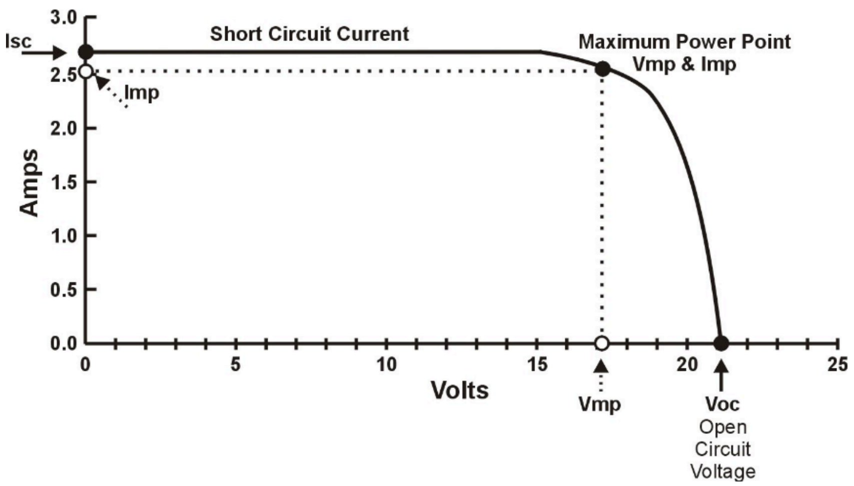


FIGURE 6. I-V curve diagram of Photovoltaics cell (Duffie & Beckman 2013)

In the case of the best photovoltaic solution, the I-V properties of the solar photovoltaic cell play an essential role in the design of the PV system. These curves are based primarily on the type of PV materials and the effects of external variables such as temperature, amount of radiation, shading, etc. (which will be discussed more in the next subchapter 3.6.2). Furthermore, based on the high electrical consumption of multi-story buildings (commercial and residential), and the limitation of the roof space (the roof is needed for the system's equipment well as the building cooling and heating system), there is a need to use all the applicable area of the building façades, that will be taking into consideration in the design. Therefore, a high efficiency type of panels working at the maximum I-V characteristics is crucial for deployment of PV panels in multi-story buildings, otherwise the efficiency of the total system decreases.

4.1 Photovoltaic types

In the last few decades, due to technological advances in the field of photovoltaic cells, PV cells have experienced remarkable progress in efficiency and large cost reductions (NERL 2018). Currently, there is a wide range of photovoltaic types which could be categorised based on PV cells materials (Tiwari et al 2016). Crystalline Silicone-based PV cells (mono crystalline and polycrystalline), which belong to the first generation, rely on the use of highly pure semiconductor materials, such as crystalline silicon (c-Si). Pure materials cause less defects and can produce high-efficiency solar cells. However, high quality materials require more expensive production processes, which makes the cost per solar cell larger as well. Due to advances in technology, the raw material usage for silicon cells has been reduced significantly during the last 13 years from around 16 grams for each watt peak to about 4 grams for each watt peak, which allowed efficiencies to be increased, thinner wafers and wires as well as larger ingots to be produced (Wirth et al 2015).

- Mono-crystalline (single-crystalline) silicon-based PV cells are created in a Czochralski process in which alloys are manufactured in cylindrical ingots. To shaping the cylindrical silicon ingot and obtain the square shaped of silicon wafer (Tiwari et al 2016). Single crystalline PV modules is the most mature PV cells available commercially with 18.4%to 19 conversion efficiency. As a result of the maturity and stability of crystalline based PV modules most of reliable manufacturing companies offer a 30-year power output guarantee, with less than 13% degradation rate in performance (Soltik 2018).

- Poly-crystalline (Multi-crystalline) silicon-based Photovoltaic solar cells are made by pouring hot liquid of silicon into square moulds that are later left to be cooled down under certain condition to form the ingot solid blocks, which are dissected to create polycrystalline silicon cells. These cells are less expensive compared with monocrystalline solar cells (Tiwari et al 2016.) Although they demonstrate slightly lower conversion efficiency than Monocrystalline cells, at about 15.5%. however, researcher has succeeded in producing 22.3% in the lab (NERL 2018.) The mature in technology and the high stability causes venders to offer guarantees for these products (polycrystalline modules) that they will operate with no less than 87% of the efficiently indicated in the product datasheet for a 30-year period (Solitek 2018). In 2017, multi-crystalline cells are the most commonly used types, accounting for around 62% of the total PV production globally (Fraunhofer 2018).

The second generation of photovoltaic technology is thin-film solar cells. They are manufactured by a process of depositing extremely thin layers photosynthesis materials on glass metal, plastic or any substrate materials in a thin layer. Since thin film cells are much thinner (10nm to a few μm) compared to crystalline cells (200-150 μm), it implies less material utilization for making cheaper solar cells; these solar cells are manufactured using cheaper processing technology. As a consequence of using less pure materials than in the first generation, A reduction in performance occurs. Although the efficiency of solar cells is lower, the cost-per-watt price of second-generation PV technology is much lower (Tiwari et al 2016; Mohanty 2015).

- Copper Indium Gallium Selenide (CIGS) cells could use fixable methods in production (by vacuum or non-vacuum process). It has high scope for efficiency improvement in the future. Recently, researchers succeeded to attain about 23.3% conversion efficiency for concentrated CIGS and 22.9% for non-concentrated CIGS cell. (NERL, 2018), however, there are many obstacles that hinder the market expansion of CIGS such as; the high manufacturing cost compared to the low conversion efficiency (between 7%-11%), as well as the low space efficiency and utilizing of scarce elements like Indium, as well as humidity issues (Mohanty 2015.)

- Cadmium telluride (CdTe) is the dominant thin film technology with a majority of the thin film market share (Wirth et al 2015). The cell's lab efficiency has improved to attain 22.1% in recent years and may be comparable to crystalline in the near future (NERL 2018.) Despite that, serial connection is easy in CdTe production, the low price of electricity generating and low rate of degradation (0.9%yearly) could also be a promising issue. However, it Contains a toxic material Cadmium element, which is a major issue in this type of cells, in addition to the low availability of Indium which may obstruct the high-scale production (Tiwari 2016; Mohanty 2015).

- Cadmium telluride (CdTe) is a non-crystalline silicon-based cell, silicon-based devices avoid drawbacks of CdTe and CIGS modules such as the toxicity of metals like Cadmium and the need for carefully controlled manufacturing issues. However, amorphous silicon has drawbacks such as low conversion efficiency (of about 5% to 8%), that makes it low in space efficiency, it requires about 15 square meters to generate one kilowatt (Mohanty 2015).

- Other types of thin-film PV device are gallium arsenide (GaAs) photovoltaics single-junction. it belongs to multi-junction technology, often processed on germanium wafers as substrate, GaAs PV are the most efficient solar cells today. The record conversion efficiency is between 25-30%. However, due to the expensive commercially manufacturing process, it is being used mostly concentrator PV technology and in space applications (Mohanty 2015).

Other emerging PV types that are under development, which belong to the third generation, covers a wide range of new and innovative ideas, such as quantum-dot solar cells, the dye-sensitized solar cell is a type of photo-electrochemical system, where a semiconductor material based on molecular sensitizers is placed between the anode and the electrolyte. organic PV technology is based on material. It focuses on improving the energy conversion efficiency and the light absorption factor of the second generation of solar cells while maintaining the cost of production close to the second-generation solar cells. A great deal of this new technology is already well known. Despite of that, it takes time for the products to establish themselves in the market (Tiwari 2016; Mohanty 2015).

Since this thesis aims to analysis the possibility of integrating PV modules in building façades, the author focuses on the currently market available technology. Commercially, there are only two main types of photovoltaic technology available on the market today. Firstly, the most mature and dominant market PV products today are the crystalline wafers Silicon-based cells, either as Monocrystalline or polycrystalline modules. Second Thin-film PV panels such as; Copper indium gallium selenide (CIGS) (concentrated and non-concentrated), Cadmium telluride (CdTe) and Amorphous silicon(a-Si) (Fraunhofer 2018).

4.2 Photovoltaic system typologies

The typical nature of photovoltaic generators allows us to achieve specific goals ranging from operating small appliances to multi-kilowatt power systems to supply electricity in the main distribution network or to generate megawatt power in large centralized PV plants. there are several possibility of solar PV system configuration patterns as shown in Figure 7 (Dzimano 2008). However, an overview of photovoltaic systems allows them to be classified generally into two types, stand-alone system and grid connected systems (Messenger 2010).

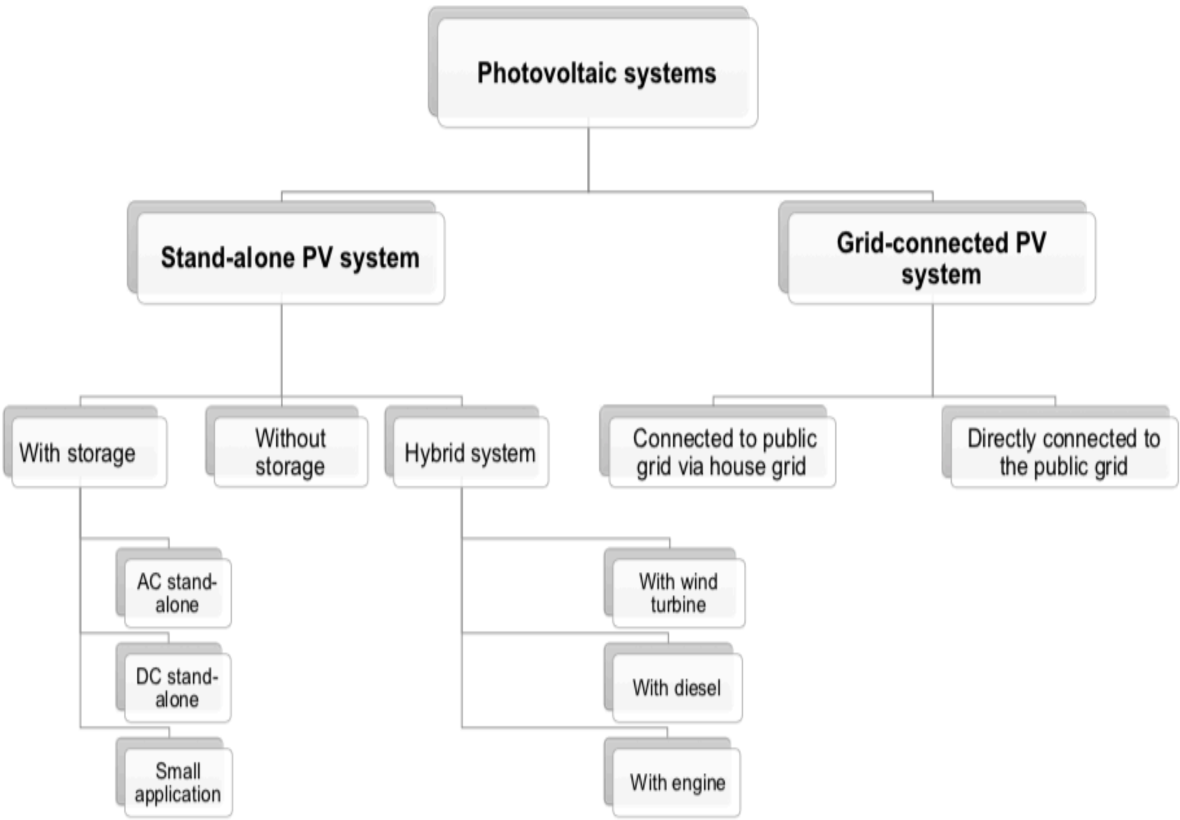


FIGURE 7. Photovoltaic systems categories (Dzimano 2008)

Due to the fact that the available area in towering buildings is scarce and expensive, as well as the high cost of utilizing battery as storage methods account for 40-45 % of the system cost (Appendix 1). Grid-connected (utility-interactive) systems appear to be the most appropriate applications for multi-store buildings (Messenger 2010). Thus, if the building consumes more energy than photoelectric supply, the building will draw the additional electricity required from the utility grid. In the case of generating more electricity than the building consumes, the surplus electricity can be fed back to the utility grid (Thah 2003). However, there are some regulations governing the delivery of photovoltaic generating electricity to the grid, especially to avoid the network harmony problem. Utility companies in each region determine these regulations and the rate of repurchase of energy from PV panels (in case of Dubai DEWA is the responsible of that) (DEWA 2018). In the following subsections, some components of the PV system are described and studied. As this master thesis focuses on the building's façades integrating Photovoltaic grid connected system, the required components of this particular system are examined, such as; photovoltaic modules, inverter and others supplement devices, with specially focusing on the BIPV cell.

4.3 Key component of solar PV system

A solar PV grid-connected system consist of the following components:

I. PV panels (Building integrate Photovoltaic (BIPV))
II. Power Conditioning Unit (PCU): This is a general term for devices that convert the energy derived from arrays to energy suitable for the building.
    - Inverter: To convert DC into AC, because all of the appliances in the building work with AC. The inverter has to be matched with the wattage output of the solar panels. There are two main distribution strategies. In a centralized strategy, all of the modules are connected to one large inverter, while in a distributed strategy each module or string is equipped with its own inverter. The latter design is usually referred to as a "string inverter". Since in multi-story buildings PV panels may be placed in different parts of the building, a string inverter is often a good alternative.
    - Maximum Power Point Trackers (MPPT): These electronic devices track the maximum power at any time based on I-V curve characteristics. Although they add extra cost to the system, they are effective in maximizing system efficiency.
    - Kilowatt Hour Meter (2-way meter): Although in some cases one-way meters are used for economic reasons, they are not reliable in large scale productions. In addition, the end-user should also be aware of energy variations.
    - Array DC disconnect: These are devices that allow halting of the flow of electricity from the array during system maintenance. Disconnects are required as part of the final electrical inspection of the system.
    - AC breaker panel (fuse): A fuse is required for safety and protection pur-

poses.

- Protection devices: They include the protection relays and devices used to protect the system from surge creation or overloading.

III. Wiring of the components: This includes the building electrical panel, and all the electrical connections (Thah 2003; Mertens 2018).

4.4 Mounting Methodology

The façade is the face of the building and defines the appearance of the buildings to the public, which act as a building shield against the external environment. The facade can protect buildings from solar radiation as well as reduce heating / cooling loads and improve daylight distribution (EU Parliament Council 2010.) PV represents the essential part of the PV system, in order to be suitable for multi-story building façades integration (Eiffert & Kiss 2000), it must be carefully selected and identified depends on;

a) Low installation cost, BIPV panels installation in buildings cost slightly more than the conventional envelop material, thus PV system integration cost can be offset against the expenses of the building element, it replaces (Kiss & Kinkead 1995).
b) Space efficient deployment, BIPV does not require additional use of land, as the facade of the building is used to accommodate photoelectric panels in this design (Gevorkian 2006).
c) Maintain or improve the Aesthetic and main building architecture aspects, BIPV in the façades is limited by design, glass to glass PV panels integrated smoothly into the building design with less required for main design modification (Luque 2011).

PV could be integrating, in the same way as glass, into most of the building façade types. however, based on the above mentioned, there are several building facades that are suited perfectly for solar PV integration like; Rainscreen, double-skin and the wall curtain façade (Frontini 2015; Brito 2013; Roberts & Guariento 2009).

4.5 Design with Photovoltaic

The photovoltaic solar system acts aesthetically on the electricity generation and helps in improving the energy performance of the building. Building Integration photovoltaic into façades is a very promising application area, as the BIPV modules were priced very similar to conventional envelop materials of the façade. This carries a promise of "free PV", for example, a building with built-in PV at no extra cost compared to the traditional building (Frontini 2015; Brito 2013).

4.5.1 Aesthetic and design aspect

BIPV in façades supply not only the electricity required for running the building, but also satisfy architectural and other functions of the building envelope, e.g. protection from the weather, thermal insulation, sun shading, protection from glare and screen for privacy. In principle, it is possible to use photovoltaics (PV) in any area of the building envelope that is exposed to direct sunlight (Welle 2010). However, a fuse of PV installation in such way where solar energy technology and structure are equal partners in a symbiotic system, could be appearing in Building integration PV systems. The Integration concept of a PV system considers the electricity output and the aesthetical aspects to the same extent and harmonies these with the building design as a whole (Thomas 2003).

Building construction is restricted by different building legislation conditions, which apply depending on the type of application, and these have a decisive influence on the design and construction. All PV technologies are permitted to be installed in building façades (solar PV modules with or without a frame) (Appendix 2). Glass is the main component in traditional PV modules, as well as materials that control buildings design and construction. For this reason, the diffusion of photovoltaic systems is heavily influenced by the rules and ideas governing the use of glass in the building (Weller 2010).

Several of the current commercial PV modules are suitable for these applications, because they are the same size and shape as tinted, laminated glazing units. However, in case of unfamiliar design criteria, Customized modules are also possible for high-rise buildings. Tailor made PV modules could be fabricated to a specific size, strength, transparency, shapes and other criteria (Appendix 1). PV panels can transmit a comfortable amount of diffused light by adjusting the spaces of individual C-Si-based cell or the slots in thin film. Although, PV glazing usually has much less transparency than regular glass, which may impact the amount of daylight in the building, therefore, a wise adaptation of PV system in design is desirable (Weller 2010).

4.5.2 Functional characteristic

Electricity generating on site is the sole function of PV integrating into building façades, that impose not only tacking the aesthetic aspect (as in the sub chapter 3.6.1) in account, but the output yield in order to analyse the feasibility of the system. The principal factors that influence the efficiency of BIPV systems in multi-story buildings include: site and location, orientation and tilt angle, temperature, Balance of System (BOS) efficiency performance of inverters, wiring, shading, dirt and dust.

- Site and location of the project

Location and regional isolation are the primary determinants for evaluating the feasibility of a PV system because the greater the amount of global irradiation reached the surface, the higher the electrical yield. Global irradiance consists of Direct irradiance, and Diffuse irradiance, which arrives at a surface from clouds and haze, also contributes to Photovoltaic system output (Roberts& Guariento 2009; Luque et al 2011).

- Tilt angle of PV panel:

The main reference point to determine the tilt angel on a specific site is latitude, but other factors should be considered as well. Sun paths vary with time of the year for summer and winter solstices. In general, the shallow inclination angle is often shown to produce more energy in the summer months, while the sharp angle is more efficient in the winter months. The optimal fixed tilt angle is the compromise between the maximum limits that allow the delivery of the largest power on an annual basis (Roberts & Guariento 2009; Gregg 2005). Unlike a ground- or rooftop-mounted PV system, a vertical BIPV installation most likely considers non-optimal tilt (Luque 2011.)

- Orientation of PV module;

Azimuth, or deviation angle from south, effects energy production as same as the tilt angle. Highest-performance is typically obtained when the array is tilted and properly aligned to the south (Luque 2011). Whereas, PV integrated into the building façades have normally a tilt of the building, which is mostly 90°. As a consequence, the PV efficiency will be reduced when compared to the optimum tilt for the same module. Even though, the vertical installation has an effect on PV performance, whereas less critical is the orientation, anywhere between the southeast and southwest. That gives a wide range of space for designing and generating more electricity (Roberts & Guariento 2009).

- Shading;

The main operational principal of PV system is the illumination, the absent of light as result of shadowing (partially or totally) has direct impacts on reducing power output. Today, partial shading is no more an issue, to avoid possible partial shading power reduction PV panels are providing with bypass and block diodes (Di Piazza & Vitale 2012). Buildings´ tendency for over-shadowing each other should be tackled within an urban area's development master plan. So, urban planning should consider the ranging in building tall while design process taller buildings should be placed on the northern side and stepped down progressively to lower. On top of that, it is recommended in the early design stages to examine a particular building for its BIPV potential (Roberts & Guariento 2009; Luque 2011).

- Dust, Dirt and Sand:

Dust and can accumulate on the surface of the solar system, obscuring some sunlight and reducing production. The amount of dust or sand on PV panels is as same as normal glass. sand and dirt are usually associated with the environmental location where the PV panel is installed (Luque 2011). Thus, in a city like Dubai with an arid climate, the solar PV systems are more likely to be vulnerable to accumulate dust and sand on their surfaces. In order to reduce the impacts of Dust and Sand, PV panels manufactured with sand and dust resisting coating materials (Solitek 2018).

- Temperature;

The efficiency of photovoltaic module changes inversely with the temperature. That negative variation differs in each type of photovoltaic module for instance; in C-Si-based PV cell reaches 0.5% deterioration in performance efficiency for each 1 °C increase above STC, while in thin–film modules lost about 0.21% per 1 °C (King et al. 1997). Thus, to keep the PV temperature dawn, reduce the heat related losses and sustain the performance, ventilation is highly advised when it is possible (Quesada 2012.)

- Inverters:

to optimize the operation of the PV system, Inverters are another component after the PV module which has a direct impact on the efficiency of the total PV system. During the design of the system, special attention must be paid to selecting the inverter. Co-operation between the PV arrays and the inverter that guarantee operate within the maximum voltage range is strongly recommended to overcome inverter damage or oversize in design. Photovoltaic output voltages must be within this range in different conditions and weather throughout the year. Excellent PV system performance requires efficient Inverters; high efficiency conversion rate is highly required to improve design and reduce related losses. Due to technological advances, inverters performances reach a high rate of conversion efficiency, about 95-97% (Papadopoulos 2012). It seems that the distributed inverter strategy has lower losses and higher reliability. A single distributed inverter failure does not completely shut down the BIPV system, because it operates separately. However, this strategy may not be the best economical alternative. Based on previous discussions, central configurations are the most common way to put inverters in the system. Today, central inverters are mostly used in high-power systems in several hundred kW or MW (Luque 2011).

- Wiring and mismatch:

The BOS components are of great importance for optimal operation of the PV system. However, the exact configuration of components, the professional composition of these components are the main challenges (Urmee 2016). In general, loss of energy through the length of DC cables based on nominal values shall not exceed 1% of the nominal value of the PV system. This standard usually leads to a larger cross-section. Furthermore, in the DC current side, a switch must be installed that works to isolate the inverter from the PV array (Papadopoulos 2012). Creating awareness of safety issues and quality control are strongly recommended on a regular and independent basis (Urmee 2016).

In this study, optimizing the BIPV system in a façade is the main target, many PV software packages are available to stimulate and evaluate the effects of the above-mentioned factors. The researcher opts for utilizing PVsyst software to analyse the system output, as well optimizing the design.

5 CASE STUDY

In this chapter the potential of integrating PV systems into building façades is explored from different aspects of electricity production (electricity saving), economically (the feasibility of the system) and the environmental payback. The study model is based on an already existing 55-story-building located in Dubai, UAE, where the first 4 levels of the building (car parking) have been omitted in the area calculation. The building is oriented to the south (on 25.25° N, 55.27° E), with almost no shading around it. For the purpose of this base case, it is assumed that PV panels are installed on three sides of the building façade, the south (0° azimuth), west (90° azimuth) and east (-90°azimuth) (subchapter 3.6.2), with 60% of the façades area to allow more space for architectures to implementing their ideas as illustrated in figure 8. However, full integration with using 100% of the area is also possible as in figure bellow.

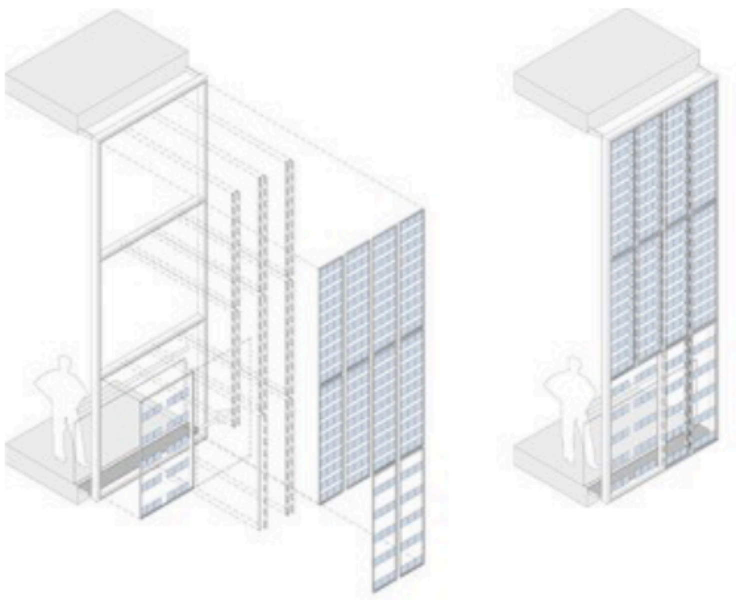
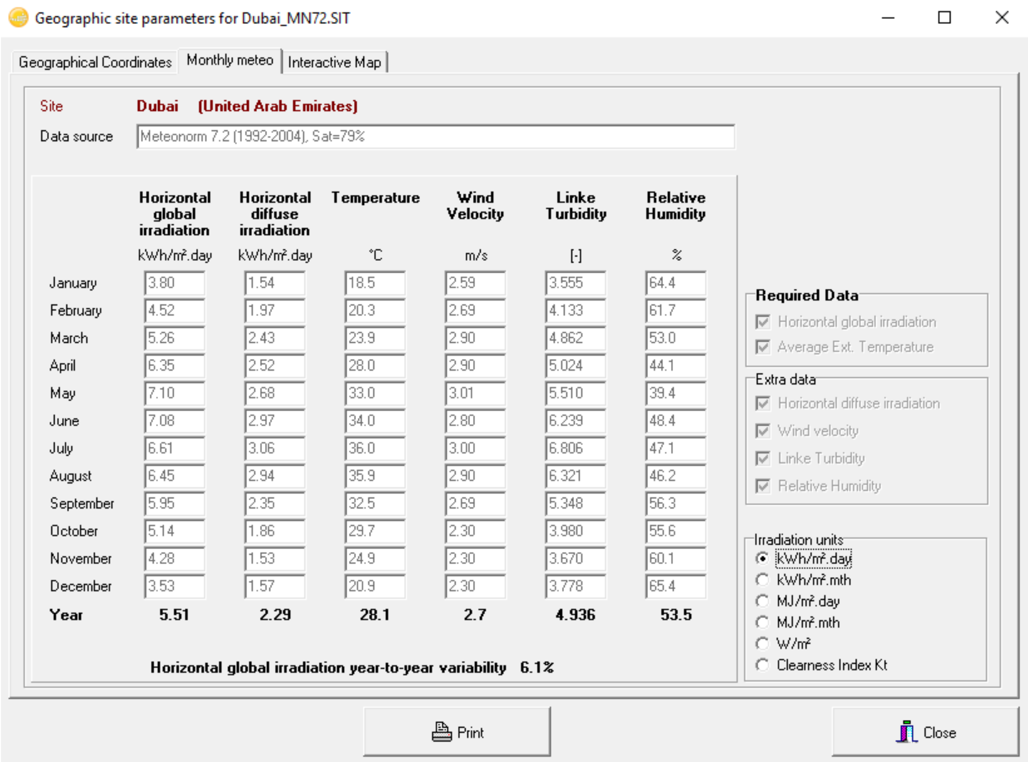


FIGURE 8. Building Facade integrating photovoltaic design (Carpenter& Lowings 2018)

The writer aimed to conduct a comparison between three types of PV modules (Mono, Poly crystalline and Amorphous-Thin film), commercially available at the time of writing this thesis, and to evaluate the monetary saving as part of the selective PV module feasibility study. It is assuming that all the PV generating electricity will be consumed by the building itself, and the design will be fully integrated into the buildings (PV will be part of the façade materials). So, the conventional building average cost of envelope (glassing) and the electricity tariff in Dubai have been considered to estimate the payback time of the system in this thesis.

To stimulate the system design, optimize the assembling and assessment the PV production of electricity for the building façades in case Dubai, PVsyst has be used. (PVsyst is a software used to assess and simulate the performance of Solar PV power project in a particular location). In this case study, PVsyst was used to analyse three different models and determine the productivity for each PV system separately. Moreover, the ambient conditions, metrological data and geographical location for the study case, were obtained with aid of PVsyst program, as per Figure 9.



	Horizontal global irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke Turbidity	Relative Humidity
	kWh/m².day	kWh/m².day	°C	m/s	[-]	%
January	3.80	1.54	18.5	2.59	3.555	64.4
February	4.52	1.97	20.3	2.69	4.133	61.7
March	5.26	2.43	23.9	2.90	4.862	53.0
April	6.35	2.52	28.0	2.90	5.024	44.1
May	7.10	2.68	33.0	3.01	5.510	39.4
June	7.08	2.97	34.0	2.80	6.239	48.4
July	6.61	3.06	36.0	3.00	6.806	47.1
August	6.45	2.94	35.9	2.90	6.321	46.2
September	5.95	2.35	32.5	2.69	5.348	56.3
October	5.14	1.86	29.7	2.30	3.980	55.6
November	4.28	1.53	24.9	2.30	3.670	60.1
December	3.53	1.57	20.9	2.30	3.778	65.4
Year	**5.51**	**2.29**	**28.1**	**2.7**	**4.936**	**53.5**

FIGURE 9. Monthly metrological parameters for Dubai (PVsyst software 2018)

Geographical site parameters such as: the amount of irradiation (Horizontal global irradiation and Horizontal diffusion irradiation), wind, ambient temperature and humidity as well, were calculated with the help of PVsyst software. The built-in PVSTST metrological data (for the Dubai case the author selects _MN72.SIT_do to the high accuracy about 6 km) allows the application of climatic information and obtained accurate data for the specific location. In the end of simulation, PVsyst provides also a detailed report of 6 pages included in this study (still it could be more or less based on the intentions of the author, and design requirements) for each system type.

5.1 The simulation processes

In this subchapter the author intends to use PVsyst to produce a simulation for the PV system-based case. To configurate a PV system for the Dubai case, all parameters which may affect the production of PV panels along with additional parameters such as type, inverters and balance of the system effects, etc. as specified in Chapter 3 (literature review sections). During the configuration process and PV system assembled, meteorological data and geographical location for case study building had been identified by the author. To run the simulation the author configurated the PVsyst simulation input parameter as below.

The creating of geographical location and the meteorological data for the project (for specifying Dubai case building). The simulation relies totally on the Meteo file with hourly created data; these can be either chosen directly from the built-in database or could be defined as new site which can be located anywhere on the globe. In this research the author selected the project location of the case building in Dubai and imported the metrological data for the specific region in Dubai as in fig.7. For this case study Meteonorm 7.2 has been nominated as the most accurate data source for the study case building, because the nearest meteorological file for the building was within 6 Km (for the sake of accuracy it is recommended that a Meteo-file be in the vicinity of less than 20 km from the site in question).

After building up the metrological data and defining the project name (for Monocrystalline, Polycrystalline, Amorphous (a-Si) systems), the author proceeds to configure the system input parameters (orientation, system assembly and loses) as described below:

1. The PV orientation and mounting method.

In this research the author aims to Ensure smooth integration and reduce the additional installation cost. Thus, a fully integrating of PV in the building façade has been chosen by the author, due to the fact that most of the buildings are constructed vertically, the fixed angle with vertical position was applied in this study. Besides he intended to utilize as maximum area of the building façade as possible with minimum effect on the architecture main design a serval orientations concept is considered to utilize 60% of the building case. As shown in Figure 10, the author used several orientation methods with vertical mounting tilt. The sub-arrays have been defined in the direction of Orientation#1 (Tilt 90^o, Azimuth -90^o), Orientation#2 (Tilt 90^o, Azimuth 90^o) and Orientation#3 ((Tilt 90^o, Azimuth

-90^{o}) respectively refers to south, east and west façade orientations with vertical tilts. Although the non-optimal mounting tilt of PV panels reduce the indicates amount of radiation. Nonetheless, in the case study, it reaches 1147kw/m ^{2} per year as in Figure10.

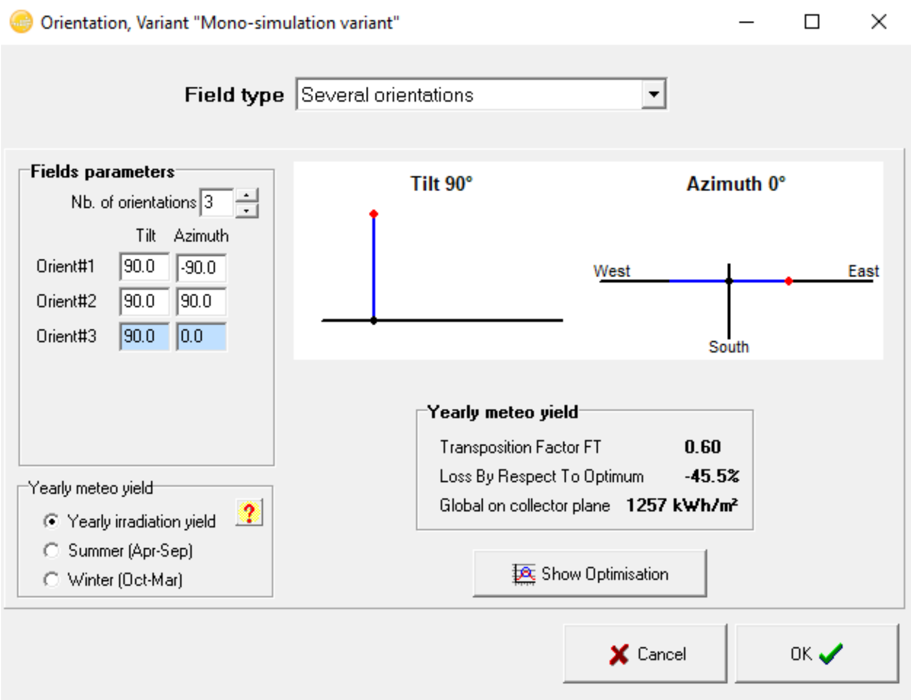


FIGURE 10. Tilt and orientation for Mono simulation (PVsyst software 2018)

2. System assembling and design

The basic parameters in this subsection must be defined are the type and number of PV modules and the type and number of inverters that have been used. The efficiency of the PV panels plays essential role in this study (how more PV system power output how better). In this part of configuration, (as illustrated in Figure11 the author selected three different types of now available PV modules to compare among three simulations systems outputs. The nominated PV panels for different system simulations are;

I. Mono Crystalline (Si-mono) PV module (JKM 370M-72), with 370Wp output power peak (dimension 1956mm by 992mm), thickness(40.0mm) and weight (28.50). (Appendix 3)
II. Poly Crystalline (Si-poly) PV module (JKM 350PP-72-DV), the output power is 350Wp, (dimension 196.8 mm by 992mm), thickness (6.0mm) and weight (28.50). (Appendix 4)
III. Amorphous- Thin-film (a-Si: H single) PV module (MPV105-S), 105 W modules (1300mm by 1100mm), thickness (7.0mm). (Appendix 5)

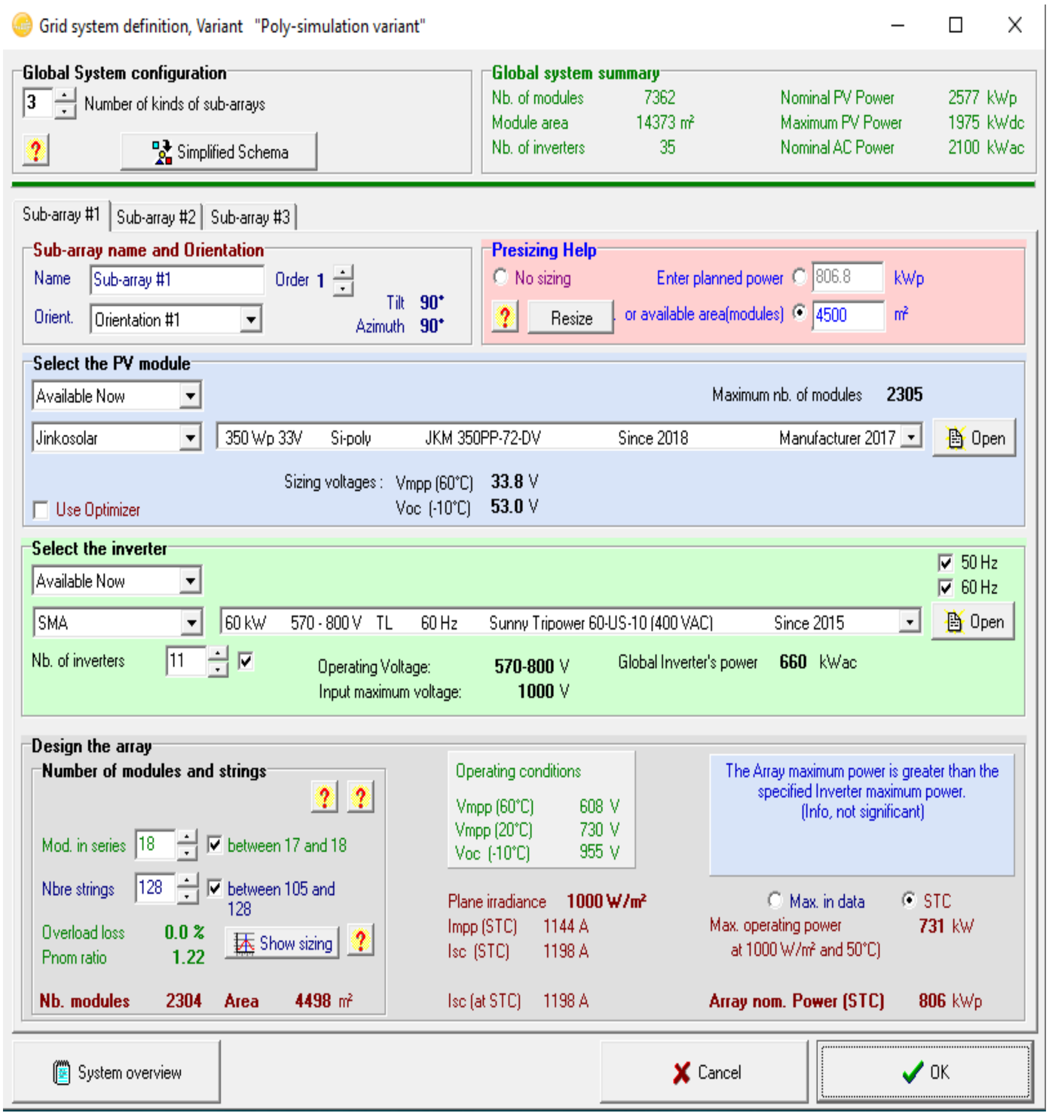


FIGURE 11. Grid connected system variant definition (PVsyst software 2018)

It seems that the array design (the combination of the number of PV panels which are connected in series (sting) and parallel) varies in each simulated system from one module type to another, depend on the module output V_{mpp} and I_{mpp}. For each individual system three sub-arrays have been defined and sized on 60% of the building façades, except the North side of the building. Aimed at conducting a rational comparison between the system results, the three-systems were examined on similar area size. The output of PV array is a DC source need to convert to AC power to be used in house and/ or supply to utility grid.

On behalf of the installation in the study the author (based on the performance, PV array output voltage, as well as its' cost, size and reliability) opts for Sunny Tri-power 60-US-10 (400 VAC) inverter. The Operating Voltage rating range between (570-800 V), the output power was 60.0 KW ac for each unit. The number of units depends on array DC output with respects to AC power output and that determined based on the ratio of ((1.22: 1) PV modules output to system output level) (Appendices 3,4,5). In this study it indicates that there is a variation in number of inverters for each system. The Mono crystalline used 37 units of inverter, polycrystalline need 35 unites to supply the generated power to the grid while Thin-film PV system required only 16 units.

3. System loses

   To optimize the PV system design, the author takes possible losses into consideration. Diagnosis and analyses of losses is considered as one of the mandatory parameters, which must be identified before running a simulation, otherwise an alert massage appears and allows no simulating process to operate. Based on this study case, the writer defines the thermal parameters for the system, as consequences of semi-integration mounting system which has been selected with an air duct behind, the default value of thermal losses factor was 20W/ m^2. K (K: is thermal constant). Wire length and cross-section calculated are highly recommended to reduce wire related and mismatch losses.

   For this reason, the author sets the default value of the DC Circuit wire loses (called as ohmic losses) 1.5% as a default at STC. That represent the loses in D wires connect between PV modules and inverters inputs. the alternative current (AC) circuit wiring losses, from the inverter to the power injection point, is limited by length and cross-section of the cable used. Since the inverter units, which is founding in the electricity room of the building, the author selects 200m length for AC cable, while the size of cross-section is restricted to the current value.

   For other types of loses, the writer considered the default values in calculation such as Module quality, LID and Mismatch losses. The module quality diminishes by 0.8% as deviation of the average effective module efficiency by respect to manufacture specifications. Moreover, the modules loss about 2% by respect to the manufacture flash test under STC in the first operating hour, which is referred to as Light Induced Degradation (LID). In addition to that, when modules running at fixed voltage (not relevant when MPPT operation) the module mismatch losses will be considered as 2.5% as default. However, at MPP that may reduce to 1.0% as default. Moreover, the module mismatch on strings voltage is calculated as 0.1% at MPP. The soil losses factor is very essential for the Dubai case study location, the yearly soiling loses factor of 3% was applied by the author. Based on the synthesized information from Meteonorm 7.2 PVs PVsyst built-in database, PVsyst identified about 7.3 days unavailability of the system, which means about 2% losses. Finally, it is noteworthy that all the mandatory parameters are in green to run the simulation as in Figure 12.

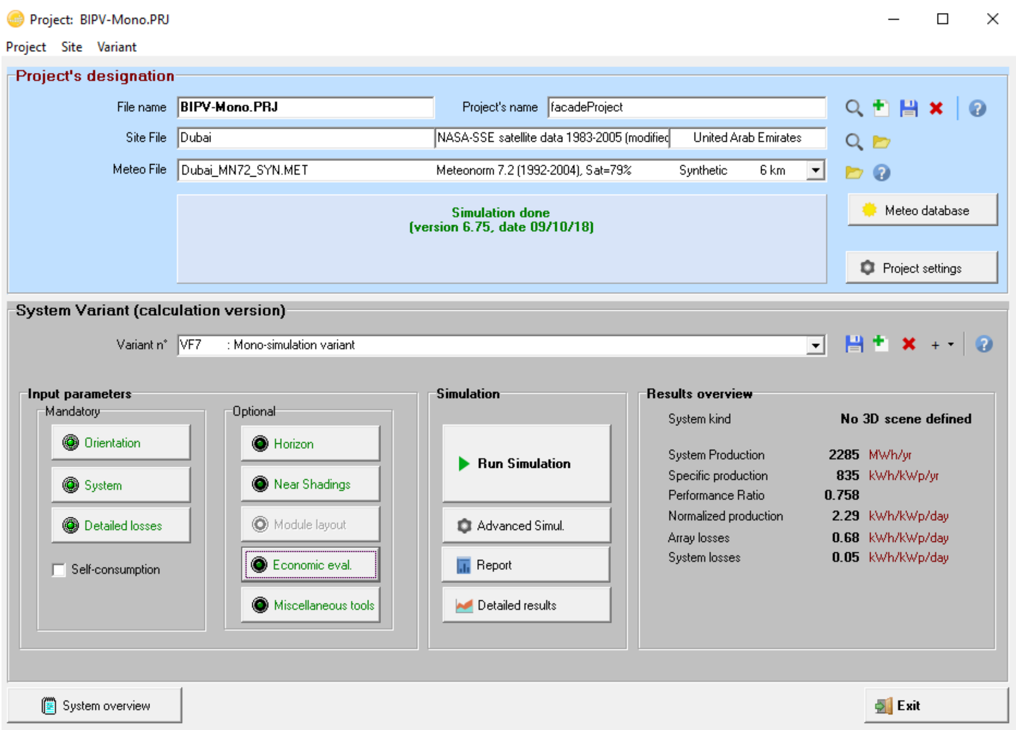


FIGURE 12. PVsyst simulation window (PVsyst software 2018)

The results of the execution of simulations of the 3 types of PV modules produce 3 reports for the case study, each consisting of 6 pages. The first two pages of reports include the simulation inputs parameter which has been entered by the author to fulfil the specific purpose of the project design and requirements. (As mentioned earlier like Geographic situation and Meteo data used, plane orientation, general information about shadings (horizon and near shadings), components used and array configuration, loss parameters, etc.). The pages 3 of the reports produce the main results of the simulation, with a monthly table and graphs of normalized values. In page 4 the simulation reports provide a specific and detailed translation for the possible system losses in an easy to read diagram over a one-year period of operation. The estimated savings in CO2 emissions are presented with calculations over 30 years lifespan in the fifth page of the report. last but not least, aging and PV system degradation is seen in the final page of the reports pages number 6.

For system standardization and design optimization purposes, the author presents the single-line diagram as shown in Figure13 to illustrate all the parts needed for assembling a functional grid connected system. The Balance of the system includes the inverter (most of the available today inverter include a built-in MPPT), circuit breakers, interfaces, DC-disconnectors, AC-disconnectors.

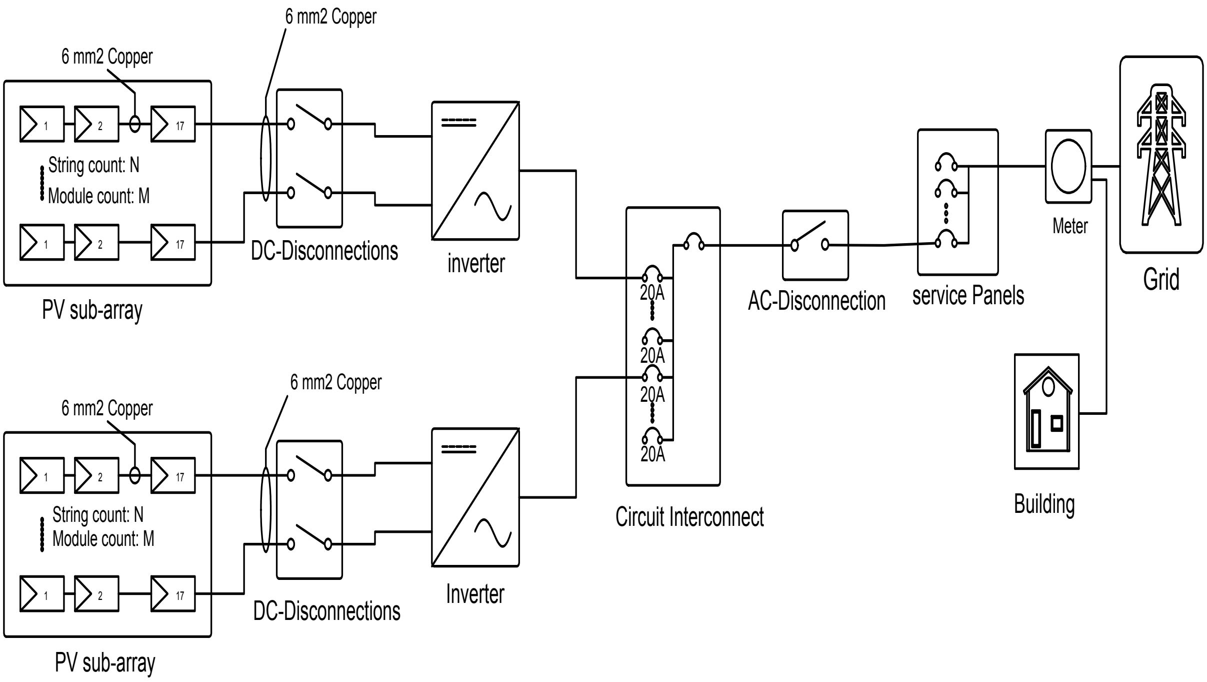


FIGURE 13. Single-line diagram of PV system (By the author)

5.2 Results

The main results of the simulation state in page 3 and 5 of the reports the yearly produced energy, the specific production (P_{nom} at STC) and CO2 emissions avoided. However, the author customized the reports to produce an accurate and clear feasibility study. He intends in the next paragraphs to interpret the results of PVsyst simulation reports. As discussed before, the first two pages of reports show that what kind of data the researcher has chosen to run PV Simulations. The author provides the main system results, in the 3rd page for each system simulation report, it shows that the monocrystalline system supplies the utility grid with 2365 MWh/year, whereas the polycrystalline system would produce 2264 MWh per year, feeds to the grid. While the thin-film system supplies the end user with only 903MWh annually. The Performance Ratio (PR [%]) is taken as an indicator for the designed prototype systems 79.72%, 78.43%, 77.65% for Polycrystalline monocrystalline and thin-film systems respectively.

Capacity of systems (Specific production (P_{norm})) is necessary for evaluating the system profitability and affordability (calculating the initial cost of the system. In page 3 of the simulation reports the capacity for system display is on the top right of the paper. The monocrystalline system records the highest Power capacity of 2737 KWp, whereas it is slightly less for polycrystalline at 2577 KWp. Conversely, the thin-film system registered the lowest P_{nom} value 1056 KWp among the other tested systems. Still on the same page the bottom contains a thorough table with main system variables, which are given as monthly values and the overall yearly values also. The yearly value can be an average, like for the temperature (T_{amb}), or an aggregate like irradiation (GlobHor, GlobInc, GlobEff) or energy (EArrat, E-Gridrid, EffArray and EffsysR).

It is noticed that there is a deviation in the results of the modules, even when they have been tested under similar conditions and have the same system's equipment (such as inverter, wires, etc..). As a consequence of systems loses and the inverter conversion efficiency, the PV generating DC energy (from E-array) is converted to AC with some reduction in power. the total energy production to the grid [MWh/y] (E- Grid) is the main indicator for the evaluation of the PV system's profitability. The author analysed systems behaviours through comparing the annually losses diagram in page 4. These diagrams present apparent step by step explanations of losses from starting with the Horizontal Global irradiation (GlobHor) to end up with the energy injected into the grid (Egrid) as in pages 4 diagrams. Although there are many similarities in losses diagrams for the 3 systems, they are variant in others. Unlike the crystalline based PV system, the efficiency of the thin-film PV system seems to be less affected by temperature. Thin film shows the lowest PV thermal losses 5.5% compared to 8.2% for monocrystalline and 8.5% for polycrystalline systems. In controversially, thin-film registers the highest PV loses in efficiency 3.5%, which occurs by irradiation levels, with respect to 2.4% and 1.8 for monocrystalline and polycrystalline systems respectively. Table1 illustrates the productivity and losses of each single tested system.

TABLE 1. BIPV façade in Dubai simulations results.

	PV installation	PV System capacity MWh	Annual production (E-Grid) MWh	losses per year
1	Monocrystalline	2469.1	2365.4	103.7 MWh
2	Poly crystalline	2363	2263.8	99.8 MWh
3	Thin-film (Amorphous)	939.7	903.334	36.366 MWh

Additionally, the Author aims to project the CO_2 balance for each individual system, correspondingly, to evaluate the amount of CO_2 saving from PV system utilization as in table 2. The author calculates the system production emission, the amount of replaced CO2 per KWp and the CO_2 emission balance a for 30-year lifetime for UAE for each system separately. (see appendices 3-5)

TABLE 2. System CO_2 emissions

	The Simulated PV System type	**System production MWh/year**	**Produced emissions tCO2**	**Total Replacement co2 emission tCO2**	**Total CO2 emission balance tCO2**
1	Monocrystalline	2356.44	5009.03	46338.9	35197.6
2	Polycrystalline	2263.77	4733.82	44347.3	33744.8
3	Thin-film	903.33	2245.75	17696.1	13108.6

The writer exhibits systems aging for the tested system as in the last page of simulation reports. Degradation losses varied during the tested period among the tested systems. Over the 20 years period, it seems that monocrystalline system will lose about 9.87%, while polycrystalline system efficiency is expected to be reduced by 10.31%, and thin-film will lose about 7.65% as degradation losses (See appendices 3-5).

5.3 Analysis of results

In this study, the possibility of designing a BIPV façade system for warm and humid climate was tested. To evaluate the most suitable installed system based on the used PV module types for the same tested area and conditions. The productivity per square meter and the cost of KWh for each system are the essential factors in profitability analyses. The average monthly production of electricity for each simulated system is presented as in Figure 14 for vertical BIPV facades in Dubai.

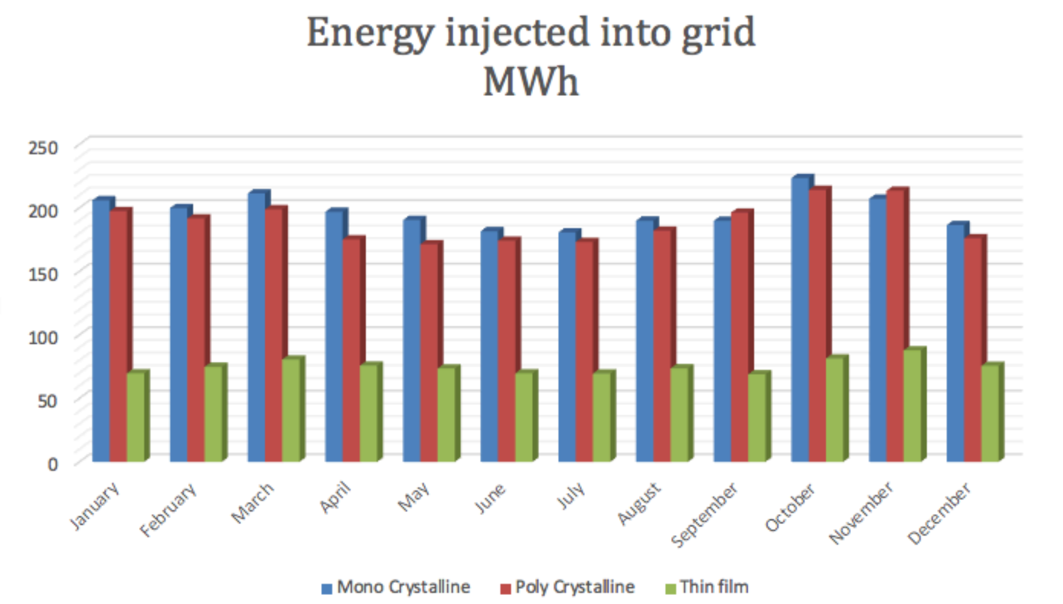


FIGURE 14. Result analysis comparison diagram for the production for Mono crystalline Poly crystalline and Amorphous- Thin film Ejected to the grid (by the Author.)

Regarding the values in the diagram, it is seen that the output energy depends to a large extent on the PV modules type. For the case study, PV produces more energy in winter than in summer. It is seen that there is not a big difference in the monthly energy production between Monocrystalline and Polycrystalline. Even though monocrystalline generates more energy most of the year, polycrystalline shows higher production for the two months September and November respectively. On the other hand, thin-film produces much less energy than others. In general, there are no big variations in energy production during summer and winter for each module. It is seen that the maximum monthly energy yields are recorded in March, October and November, while a bit less is recorded in January, February, April, May, August, September and December for the 90^{o} tilt angle. On the other hand, the minimum monthly energy yield for all orientations occurred in June and July.

The highest monthly energy yield is recorded in October; it is 223.6 MWh for the Mono module and 214.0 MWh for the Poly system and 85.81MWh for the thin-film. While, the lowest monthly energy yield is recorded in June; it is 166.5 MWh for the Mono system, 161.0 MWh for the Poly system and 63.67 MWh for (a-Si) thin-film. Regarding June and July, the predicted energy yields are lower than what they should be, which affects the module temperature, since the forced convection does not occur for the modules in this period, so the module temperature becomes higher while the output power becomes lower, as does the energy harvest. The monthly power output variation profiles for vertical tilt with several orientations mounting methods in Dubai, indicate that Crystalline-base gives overall higher output per MW, in respect to area installed, as compared to a-Si thin film PV. The reasons for that difference are the electrical and thermal characteristics of the PV module, such as electrical efficiency, material of heat capacity, thermal behaviours and spectrum response (chapter 3)

5.3.1 Payback and monetary potential saving

The reimbursement period depends on several factors, the most significant are the cost of the PV technology, the local electricity (Tariff) charge and the price of replacement envelop elements. As per the earlier section the crystalline PV modules systems supply more energy for the case study, than (a-Si) thin-film. The initial investment for PV system calculated based on companies' average prices as shown in the table below.

TABLE 3. The cost of PV system components (average prices)

	System equipment	**Description**	**Estimated-Price€/watt**
1	PV Panel	a. Mono-crystalline b. Poly-crystalline	0.42 €/watt 0.38 €/watt
2	Inverter	SMA Tri-power 60-US-10	0.11 €/watt
3	Supports	Hangers, screw, etc.	0.11 €/watt
4	Other expenses	AC breaker, Lightning arrestor, Safety Cut-off switches, Charge Controller, interface	0.11 €/watt
5	Installation cost	Labours, equipment	0.10 €/ watt

In Table 3, the monetary saving and initial capital investment could be the determining factors for opting between the most suitable crystalline panels for Dubai. The first column (system equipment) shows the type of system required components of the system and in the next column appears the description of the component. The following columns display the price per watt for each component (for systems with more than 100KWp). PV Assimilation into a building shrinks the expense of power generated by the solar PV system, because the panel in the façade combination serves both as a conventional building envelop frontage properties as well as an electricity source (as in subchapter 3.6). Hence, the cost of supports can be avoided. Based on the above information, the costs per system were assumed as fallow:

The estimated system costs per watt for a greater than 100KW system with monocrystalline PV panels is 0.85 €/ watt and 0.80 €/ watt for polycrystalline.

TABLE 4. System estimated prices

	System type	**System Capacity (KWp)**	**System price KW / €**	**System price € / m^2**
1	Monocrystalline	2737	2 326 450 €	162.11 €/ m^2
2	Polycrystalline	2577	2 061 600 €	143.43 €/ m^2

Table 4. illustrates that PV prices per square meter for polycrystalline and monocrystalline record about 143.43 €/ m^2 and 162.11 €/ m^2 respectively. It is noteworthy to indicates that the price of monocrystalline solar BIPV, for similar area of façades, is more than polycrystalline system cost. Nevertheless, polycrystalline produce slightly less electricity than monocrystalline as in Figure14. Accordingly, the price of polycrystalline PV system produces a great potential to reduce initial investment and attain a monetary saving for the owners. Aimed at assessing the electricity bill savings, it is assumed that all the PV generating electricity will be consumed by the building itself. Subsequently, the local cost of utility power tariff in Dubai has been taken in account to calculate the potential monetary savings by the system in Table 5.

TABLE 5. Electricity tariff in Dubai for commercial and residential sectors (DEWA 2018)

Consumption(kwh)/ month		
1	0-2000	23
2	2001-4000	28
3	4001-6000	32
4	6001 &Above	38

The local tariff for electricity ranges from 23 to 38 AED fills/ KW (0.055-0.09 €)depending on the electricity consumption per year. Since the monthly electricity supplied by the PV system is exceeding 6001 KWh, thus the (38 AED fills) will be used in the calculations. In addition to this is that, a 6.5 fills AED (0.0155 €) the cost of fuel will be added to the electricity bill. which will vary based on the rate of increase or decrease in the actual cost of fuel delivered to DEWA power plants, which varies according to the rate of rise or drop in the actual prices of fuel delivered to the Dubai Electricity and Water Authority power plants. Moreover, it is noteworthy that 5% VAT is applicable on these tariffs.

Bill saving = ((local tariff+ fuel charge) *yearly PV production injunction to grid) + 5%VAT……... (1)

TABLE 6. Bill saving for electricity generating from Polycrystalline system

Electricity total bill (AED)	**1006771.00**
VAT @ 5%	50338.55
Total Bill including VAT(AED)	1057109.55

Based on the DEWA website calculations the total electricity bill saving has been extracted for the polycrystalline system, which is equal to 1057109.55 AED (287 844 €) per year. (DEWA 2018).

In contrast, due to (retrofit of existing buildings) replacing the conventional envelop coating (glazing) and evaluate the profitability of PV system the building envelop cost must also be evaluated. According to a study conducted by Tibi & Mokhtar (2015) where they discuss a glass curtain wall in high-rise buildings in the UAE from different perspectives such as, thickness, thermal characteristics, and average prices, the study produces several types of glass and their prices. Therefore, based on this study the average price for glass in UAE has been estimated at about (38.86 €/ m^2 –76 €/ m^2) 57 €/ m^2 (Tibi & Mokhtar, 2015)

The Payback period can be calculated as follows;

The initial investment for a 2577 KWp polycrystalline system can be calculated by subtracting the cost of Glass Façade from the Solar PV Cost.

The initial investment Capital = (the Solar PV Cost) – (Cost of Glass Façade) …. (2)

Due to the fact that, the total used façades area is equal to 14373 $m^{2.}$

The initial capital = (2 061 600) – (57 *14373)= 1 242 339 €

Based on the results of equation (1) and (2) above, it is demonstrated that the payback period will be less than 5 years. To get an accurate payback estimation the author has taken into consideration the GHG emission calculation.

5.3.2 CO_2 emissions savings

The PV system provides a direct environmental advantage and also serves as a statement of environmental interest. An important environmental benefit is a discount in CO_2 emissions (Thomas et al 2003). PVsyst allows to estimate the saving in CO_2 emissions expected for the PV installation. This calculation is called life cycle emissions (LCE), which represent the CO_2 emissions associated with a given energy value. By assuming that the electricity generated from the photoelectric system will avoid the same amount of electricity from the utility grid. Also, due to the fact that the carbon footprint of the photoelectric system per kilowatt-hour is considerably less than the electricity from a conventional fossil fuel power plant, there will be a net saving of carbon dioxide emissions. Thus, the total carbon balance for a PV system is the difference between produced and saved CO_2 Emissions. in the table below, PVsyst shows detailed information about how much the polycrystalline system has saved CO_2 per KWp.

TABLE 7. System Life Cycle Emission for polycrystalline PV system

Item	Modules	supports
LCE	1713 kg CO_2 /KWp	4.36 kgCO_2 /kg
Quantity	2577 KWp	73620 kgCO_2
Subtotal [CO2]	4413166 kg	320653 kg

From the table above, the results, based on 2677Kwp a polycrystalline system in Dubai, were a 320653-ton total saving of CO_2 emissions over the 30 years lifetime while considering the 1.0% system annual degradation. Therefore, each square meter of PV panel will avoid 1451.8 kg of CO_2 emissions annually. The results of BIPV Solar Facades for the high-rise buildings in Dubai highlighted an opportunity for substantial savings in electricity costs as well as reduction in GHG emission.

6 CONCLUSIONS AND RECOMMENDATIONS

The conclusions are made based on the results obtained (simulations reports, interviews, and PV values). The purpose of this study was to analyse the suitability of vertical facades and features in the urban environment for PV solar power generation in Dubai. Hourly solar irradiation on every unit area of vertical building façades for the representative building in the city of Dubai are calculated by using PVsyst-software to describe the topography of the landscape and local typical meteorological year by year data sets. Based on these results, the author concluded that polycrystalline PV-modules are the best choice for BIPV Facades in Dubai, as demonstrated from the output and cost results. Moreover, the research establishes that there is a potential for substantial monetary savings & a reduction in GHG emissions if solar PV are used in high-rise buildings facades in Dubai.

The concept can also be applied for similar buildings in other emirates of the UAE as well, due to the similarity in climate condition and the amount of insulation; however, the differences in electricity tariffs must be take into consideration. The payback period of less than five years is also very attractive. The BIPV façade system return of investment (ROI) could be considered as a new source of income for the stockholders (buildings owners). BIPV represents a form of central distributed generation of captive consumption, because output will be consumed in the high-rise building itself, which in turn avoids transmission infrastructure costs and losses. In addition to that, on site PV power generating will reduce the pressure on the utility grids, particularly at peak demands periods. On the other hand, electricity generating from PV has almost no negative environmental effects. BIPV façades in Dubai represent about 32000t CO_2 emission savings during the PV lifecycle operation. That means 1451.8 kg of CO_2 emissions annually (that would have a direct impact on global warming, and thereby on climate change).

Furthermore, as Dubai Green buildings category under the DGBR certification process, with regarding to electricity, at least 5% of the total building electricity consumption to be supplied from PV solar power. Therefore, BIPV in the façade facilitates the high-rise buildings in meeting GBR standards in Dubai. On top of that, saving in land resources is also an advantage of using BIPV façades. Additionally, the BIPV integrating in the façade of the high-rise building in Dubai will affects the GDP of the emirate. Dubai is a non-oil federalism in the UAE, as stated in chapter 3 (which makes the importing of fossil fuel imperative on the government of Dubai to run power plants to generate electricity). Thus, the BIPV installation will increase the GDP by reducing the amount of imported gas and fuels.

Based on the interviews, a recommendation is made to enter the PV market from the perspective of marketing strategy and relationship, although sustainable development is difficult without government support. However, political and technological updates play an important role in long-term development. The Green economy plan, which has been approved by the government of Dubai, has a significant impact on promoting the development of the PV market in Dubai. Shams Dubai initiative offers a net metering as an incentive for embracing PV as a source of electricity in buildings. Dubai has presented a series of policies on the development of photovoltaic installation guidelines. In order to access the Dubai PV market, Nocart as a consultant and supplier company must learn about local policies as well as how to cooperate with local approved companies for the execution of projects. A good network can facilitate reaching the potential clients and targeted projects.

On the other hand, the search for projects is the most important step for the company to prove itself in the Dubai market. While Nocart targets the owners of the building as potential customers, it is best to check the most suitable financing method for the high-rise building owner. In addition, it is recommended to establish partnerships with local companies to seek a cooperation opportunity. Since the projects are under the control of the Government of Dubai (design approving, permissions obtaining, and grid connected process), it is important to contact Dubai Electricity and Water Authority (DEWA), Dubai Carbon Centre of Excellence and Dubai municipality to be familiar with roles and regulations. Networking is the key factor in getting involved in the Dubai market.

In order to make contacts with the Dubai government foreign companies can ask a broker to express the intention of entering the Dubai market. The middleman can be an agent, a familiar person with wide knowledge and good contacts in Dubai. Typically, the Dubai government welcomes the foreign companies to enter the market. A company representative can easily meet with associated government members, or construction companies for an additional and detailed negotiation. The company may also contact construction companies to promote their services and products (a persuasive salesman with professional knowledge is strongly recommended). It is good to visit these companies to explore the potential, partnership building or even network expansion. Besides, the product sales strategy in Dubai can be based on agents and direct sales. Regardless of the type of sales methods to be adopted, maintaining a good business-to-business relationship and business-to-government relationship is very much recommended. Collaboration with local companies can help build an industrial alliance, which will certainly help develop long-term operations in Dubai.

In conclusion, the BIPV façade has great potential in Dubai from different perspectives, as illustrated above. In regard to climate change, the BIPV façade could be suggested as one of the solutions to climate related issues. The study indicated that the system is economically affordable, technically possible to be achieved and with a great amount of CO_2 saving it could be highly considered as environmentally friendlier. In contrast, to ensure that all the benefits of the BIPV solar façade are utilized, further research is needed for Dubai to standardize the integration of photovoltaic solar panels into buildings. In addition, the solar panel fixing methods in the façade need further development to facilitate better tilt inclusion with less affecting on their main functions as an interface, in addition to preserve a proper integration and lower costs as well.

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APPENDICES

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APPENDIX 1

General information of interviewee

First name: Jukka

Last name: Keski-Oja

Name of company/organization: Nocart Oy

Department: Technology

Current working position: Support Manager

Field of expertise: Electrical engineering

Location of working place: Lahti

Website of company/organization: www.nocart.com

Email address: jukka.keski-oja@nocart.com

1. What is the most fitting entry mode to Dubai market for NOCART Company?
   - ☐ Projects Execution
   - X Products supplying
   - ☐ Consultancy services
   - ☐ Something else

2. What is your evaluation of Dubai PV market? Does Dubai have a potential market for Building Integrated Photovoltaic Technology (BIPV)?

   Dubai has very high level of solar irradiation and is very suitable for BIPV as the payback time is comparatively low. The urban area is also limited of space on the ground and rooftops are small in terms of power production for a tall building. The BIPV is the most feasible way of producing renewable energy in the urban area.

3. Do you think that Dubai has a potential market for the development of renewable energy business particularly for BIPV in façade?
   The façade installation is almost the only option to install PV as the land restrictions and small rooftop spaces.

4. What makes NOCART compete the already existing companies in Dubai market?
   ☐ Competitor Price
   X High Quality of Product and services
   ☐ Market knowledge
   ☐ Networking
   ☐ Others………

5. Who are the target customers in Dubai market?

   Private owned industry so not to get involved in public tender processes which are very highly competed within. Targeted power range is from tens of kilowatts up to megawatt sized installations.

6. How does NOCART intend to introduce itself in Dubai market? Which form of incentive methods would be used by NOCART?
   Nocart would be product supplier and on behalf of local entity the projects would be handled locally. Installation work will be done by locals and the supervision is on behalf of Nocart.

7. From your evaluation of Dubai renewable energy market, what are the chances of NOCART to compete with other companies?

   Competing with other companies is possible in the selected BIPV model and the glass-glass technology used in the panels. Also, with the advantage of our PMU we can install more solar compared to traditional inverter-based technology. Even an option is available with the PMU to create island grid or enhance the power quality on site.

8. Are there any constraints, impediments or challenges (e.g. regulations / policies /finance? etc.), which may hinder the progress of NOCART entering Dubai market?
   There is a risk of local import tax for equipment coming abroad. The energy price is always a question regarding the payback time of the investment. Dubai has a

strong economy and financing the projects with creditable customers should be no problem at all.

9. Could you estimate the area (in square meter) is needed for each 1 kwh to be generated from PV system?1 KW_p of solar takes about 7 square meters of installation space. In Dubai a 1 KW_p system produces roughly 1600 kWh of electricity annually.

10. Is the rooftop PV system sufficient to provide 5% of the high-rise (above 50 floors) buildings electricity?
    In my estimate the roof area only is far too small to provide even 5 % of a 50 story buildings energy. Another point is that the roof space is typically heavily utilized for air conditioning and other building technology i.e. antennas and lightning rods.

11. From your experience, what (is / are) the best or commonly use PV designs method (software/ website) for Building integrating Photovoltaic in façade? Why?
    We have been using an online tool funded by European Union called PV-GIS. It is for free and because it is publicly financed software the results for our customers are unbiased.

12. Are you satisfied with the interview? Could you please explain the reasons for your answer?
    Yes, I am. The questions were clear and well-formed, and it was easy to answer to them.

13. Could you please give feedback, suggestions for further changes and improvement?
    You are doing a good job with the thesis. You may add more financial figures in your thesis to make readers understand the economics of BIPV.

APPENDIX 2

General information of interviewee

First name: Tai

Last name: Al-Khairi

Name of company/organization: Dubai Carbon Centre of Excellence

Department: Solar Department

Current working position: Solar Project Manager

Field of expertise: Mechanical Engineering

Location of working place: Dubai

Website of company/organization: www.dcce.ae

Email address: taia@dcce.ae

1. What is your Perception of climate change as a phenomenon (particularly on Dubai climate?
   The UAE is already subject to extreme climatic conditions that can be considered a vital phenomenon. Moreover, one can notice that the vast heatwave is hitting the region where the temperature reaches up to 60 degrees Celsius, and the sea water level rising also an issue, this can be an alarm for the region to react to the alarm that is being set by the environment that global warming is a vital issue.

2. What is the primary source, which contributes to this phenomenon in the case of Dubai?
   Dubai is considered as one of the fastest growing cities in the world where the population increase, and the infrastructure development is playing an essential role in the region. This can be growth can be considered a catalyst for the phenomenon of climate change, however, due the to the vision of the leaders of the UAE, one can notice the severe measures that are being taken to limit the effects of this phenomenon. The UAE is taken the initiative to adapt to those changes by targeting areas such as the Coastal Zones, adaptation for Water Resources and

Dryland Ecosystems.

3. From your knowledge could suggest the most suitable renewable way to generate electricity for urban environment especially high-rise buildings? Why?
   Wind can be considered the most suitable renewable way due to the high altitude of high-rise buildings, and solar can be vital as well if the surface area on the roofs allows it. However promising technologies that are being studied and considered to integrate the PV on the building itself can change the future of renewable energy in high rise buildings.

4. From your experience, is the Photovoltaic Solar Energy concept known among Dubai's planners, and inhabitants?
   Yes, to some extreme ways and can be considered the leading city in the region of the GCC and middle east, where a lot of initiatives such as Shams Dubai. This leading initiative supports “the vision of HH Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and Ruler of Dubai, to make Dubai the smartest city in the world”. It also supports diversifying the energy mix by promoting the use of clean and renewable energy sources to build a sustainable future for the Emirate. The initiative encourages household and building owners to install PV panels to generate electricity and connect them to DEWA's grid. The electricity is used on site, and the surplus is exported to DEWA's network.

5. What is your evaluation of Dubai PV market? How?
   The market of Photovoltaics in Dubai is Promising

6. From your experience and perception, what was the customer's reaction for Photovoltaic systems implementation?
   Highly interested due to the excitement, and to support the initiatives and vision that is being implemented by the leaders of the UAE.

7. What was the most implemented PV solar system in Dubai? Off-grid/on-grid/hybrid (Rooftop/façade system)? And why
   On-grid system, due to the feasibility of it. The Off-grid solar system is considered to be one of the most straightforward and most cost-effective systems to install; where the hassle of Batteries and charge controllers is eliminated.
8. Could you estimate the Area (square meter) is needed for the installation of 1kWp to be generated from the PV system?

Depending on the PV panel dimension, however polycrystalline PV panel need an approximate of 7 square meters.

9. Is the rooftop PV system sufficient to provide 5% of the high-rise (above 50 floors) buildings electricity?
   Due to the high demands of electricity as well as the small area of roof in multi-story buildings the Roof top mounting system will not be able to supply the 5% of the high-rise building electricity required , where the surface area of the roof plays an important role cooling and other equipment's are occupied .

10. Are there any incentives methods for (companies/ individuals) concerning PV in Dubai?
    Net Metering, Shams Dubai initiative encourages household and building owners to install PV panels to generate electricity and connect them to DEWA's grid. The electricity is used on site, and the surplus is exported to DEWA's network.

11. Are there any limitations, obstacles, and challenges (such as; Policies /building regulations, finance) that may hinder the progress of photovoltaic integrating into the building in Dubai's private and nongovernmental sectors?

12. What's the best (or widely use) PV software designs method in Dubai? Why?
    the most effective PV design software are the PVsyst, and Helioscope, theses provide wide detailed reports about the prototype simulation.

13. What kind of opportunities do you think that Dubai governments may offer to a foreign company regarding PV solar technology?
    Dubai governments are very incentivized to provide a niche market in PV solar technology and have an open mind when it comes to it.

14. What does Dubai's government expect or required from international companies to be approved officially in Dubai?
    This information can be found on www.shamsdubai.com

15. Are you satisfied with the interview? Could you please explain the reasons for your answer?
    Yes! Due to the fact interest in these areas can be an essential incentive to promote renewable energy.

16. Could you please give feedback, suggestions for further changes and improvement?
    Everything seems bright and concise! Excellent work.

Thank you very much for your interest and your participation

APPENDIX 3

Grid-Connected System: Simulation parameters

Project : **facadeProject**

Geographical Site	**Dubai**		Country	**United Arab Emirates**
Situation	Latitude	25.20° N	Longitude	55.27° E
Time defined as	Legal Time	Time zone UT+4	Altitude	4 m
	Albedo	0.20		
Meteo data:	**Dubai**	Meteonorm 7.2 (1992-2004), Sat=79% - Synthetic		

Simulation variant : **Mono-simulation variant**

	Simulation date	13/10/18 18h35
	Simulation for the	**1st year of operation**

Simulation parameters	System type	**No 3D scene defined**		
3 orientations	tilts/azimuths	90°/-90°, 90°/90°, 90°/0°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Arrays Characteristics (3 kinds of array defined)

PV module Si-mono	Model	**JKM 370M-72**		
Original PVsyst database	Manufacturer	Jinkosolar		
Sub-array "Sub-array #1"	Orientation	#1	Tilt/Azimuth	90°/-90°
Number of PV modules	In series	17 modules	In parallel	136 strings
Total number of PV modules	Nb. modules	2312	Unit Nom. Power	370 Wp
Array global power	Nominal (STC)	**855 kWp**	At operating cond.	776 kWp (50°C)
Array operating characteristics (50°C)	U mpp	621 V	I mpp	1249 A
Sub-array "Sub-array #2"	Orientation	#2	Tilt/Azimuth	90°/90°
Number of PV modules	In series	17 modules	In parallel	136 strings
Total number of PV modules	Nb. modules	2312	Unit Nom. Power	370 Wp
Array global power	Nominal (STC)	**855 kWp**	At operating cond.	776 kWp (50°C)
Array operating characteristics (50°C)	U mpp	621 V	I mpp	1249 A
Sub-array "Sub-array #3"	Orientation	#3	Tilt/Azimuth	90°/0°
Number of PV modules	In series	18 modules	In parallel	154 strings
Total number of PV modules	Nb. modules	2772	Unit Nom. Power	370 Wp
Array global power	Nominal (STC)	**1026 kWp**	At operating cond.	930 kWp (50°C)
Array operating characteristics (50°C)	U mpp	658 V	I mpp	1414 A
Total Arrays global power	Nominal (STC)	**2737 kWp**	Total	7396 modules
	Module area	**14351 m²**	Cell area	12640 m²

Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Sub-array "Sub-array #1"	Nb. of inverters	12 units	Total Power	720 kWac
			Pnom ratio	1.19
Sub-array "Sub-array #2"	Nb. of inverters	12 units	Total Power	720 kWac
			Pnom ratio	1.19
Sub-array "Sub-array #3"	Nb. of inverters	13 units	Total Power	780 kWac
			Pnom ratio	1.31
Total	Nb. of inverters	37	Total Power	2220 kWac

PV Array loss factors

Grid-Connected System: Simulation parameters

Array Soiling Losses — Average loss fraction 3.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	8.4 mOhm	Loss Fraction	1.5 % at STC
	Array#2	8.4 mOhm	Loss Fraction	1.5 % at STC
	Array#3	7.8 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System loss factors

	Wires: 3x2500.0 mm²	200 m	Loss Fraction	2.5 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction	2.0 %

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

Project : **facadeProject**

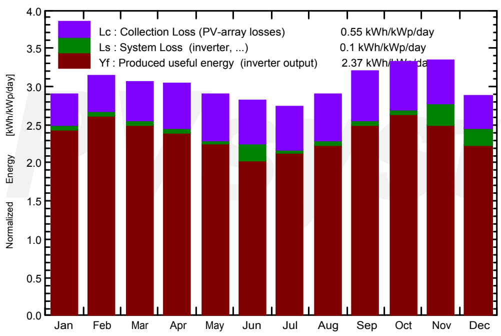
Simulation variant : **Mono-simulation variant**

Simulation for the 1st year of operation

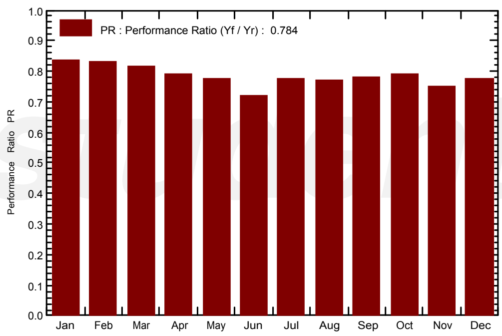
Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/-90°, 90°/90°, 90°/0°		
PV modules	Model	JKM 370M-72	Pnom	370 Wp
PV Array	Nb. of modules	7396	Pnom total	**2737 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	37.0	Pnom total	**2220 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**2365 MWh/year**	Specific prod.	864 kWh/kWp/year
	Performance Ratio PR	78.43 %		

Normalized productions (per installed kWp): Nominal power 2737 kWp



Performance Ratio PR



Mono-simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	117.8	47.70	18.46	90.0	83.57	211.4	205.9	0.836
February	126.6	55.10	20.30	87.7	81.30	205.0	199.8	0.832
March	163.0	75.30	23.93	94.6	87.09	216.5	211.3	0.816
April	190.4	75.60	28.03	91.0	82.92	201.6	196.9	0.790
May	220.1	83.20	32.96	89.9	82.02	194.8	190.5	0.775
June	212.4	89.20	33.95	84.8	78.25	185.7	166.5	0.718
July	204.9	94.80	35.98	85.2	78.36	184.6	180.7	0.775
August	200.1	91.00	35.85	90.1	82.22	194.1	189.9	0.770
September	178.5	70.60	32.47	96.2	87.88	209.7	204.9	0.778
October	159.3	57.80	29.74	103.2	95.12	229.0	223.6	0.792
November	128.3	46.00	24.95	100.1	93.03	228.6	205.5	0.750
December	109.4	48.70	20.84	89.3	83.01	208.4	189.9	0.777
Year	2010.8	835.00	28.17	1102.1	1014.77	2469.1	2365.4	0.784

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

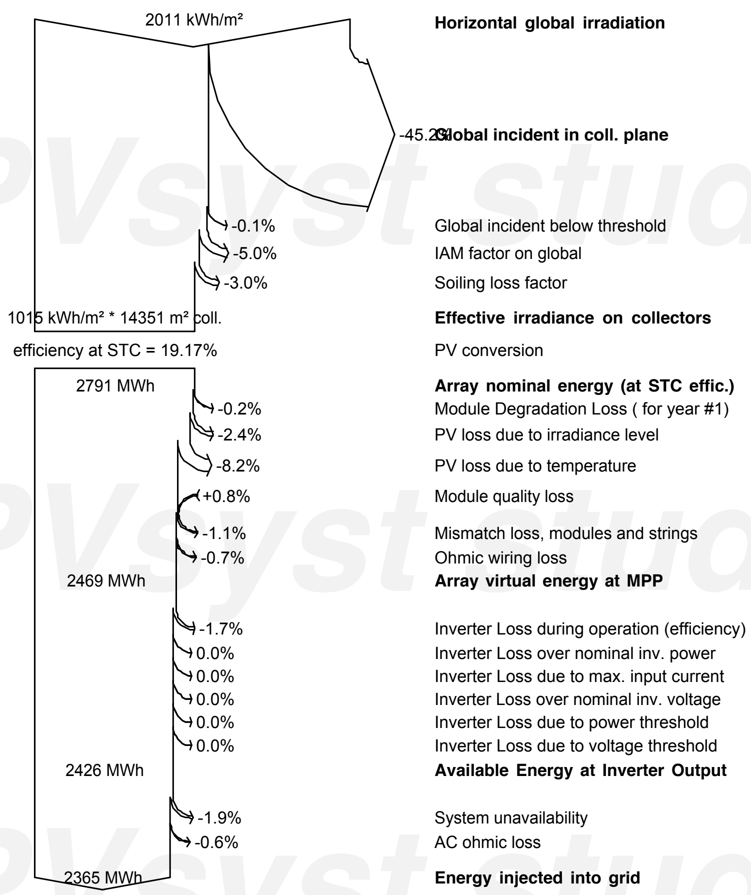
Project : **facadeProject**

Simulation variant : **Mono-simulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/-90°, 90°/90°, 90°/0°		
PV modules	Model	JKM 370M-72	Pnom	370 Wp
PV Array	Nb. of modules	7396	Pnom total	**2737 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	37.0	Pnom total	**2220 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: CO2 Balance

Project : **facadeProject**

Simulation variant : **Mono-simulation variant**

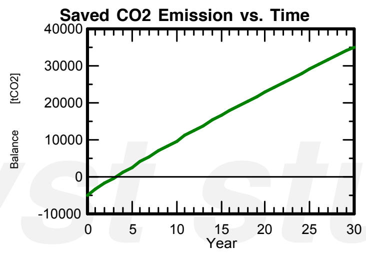
Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/-90°, 90°/90°, 90°/0°		
PV modules	Model	JKM 370M-72	Pnom	370 Wp
PV Array	Nb. of modules	7396	Pnom total	**2737 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	37.0	Pnom total	**2220 kW ac**
User's needs	Unlimited load (grid)			

Produced Emissions	**Total:**	**5009.03 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**46338.9 tCO2**		
	System production:	2365.44 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	653 gCO2/kWh		
	Source:	IEA List	Country:	United Arab Emirates
CO2 Emission Balance	**Total:**	**35197.6 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	1713 kgCO2/kWp	4.36 kgCO2/kg
Quantity	2737 kWp	73960 kg
Subtotal [kgCO2]	4686893	322134



Grid-Connected System: Ageing Tool Results

Project : **facadeProject**

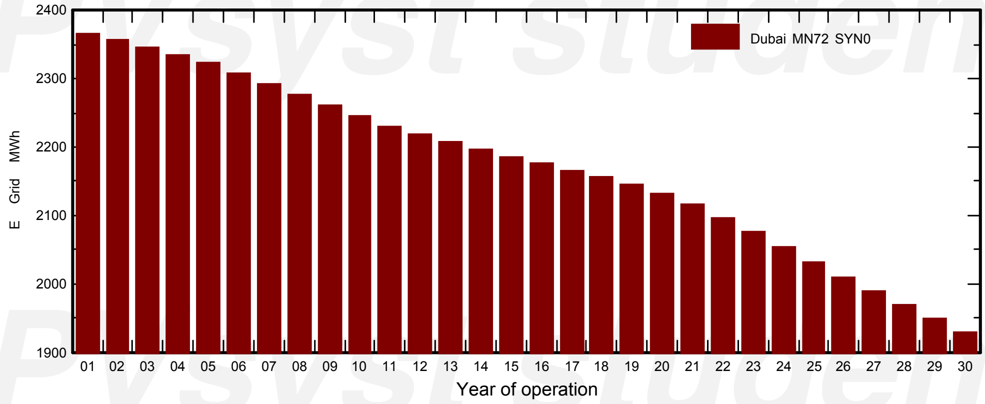
Simulation variant : **Mono-simulation variant**

Simulation for the 1st year of operation

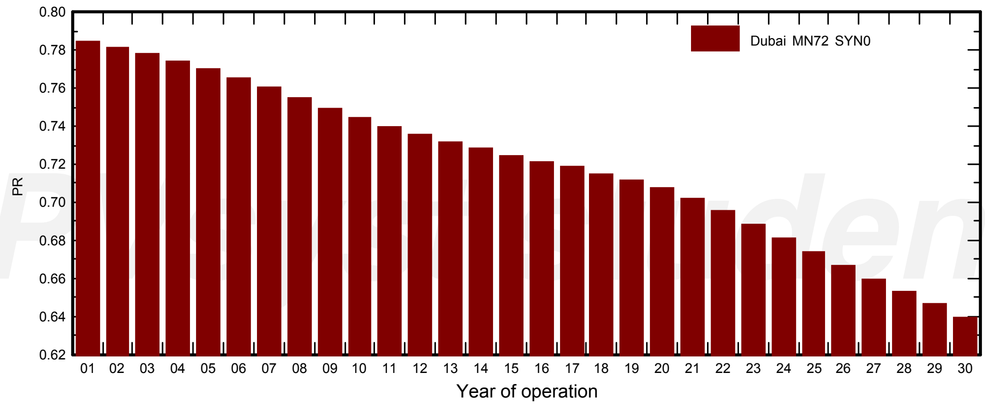
Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/-90°, 90°/90°, 90°/0°		
PV modules	Model	JKM 370M-72	Pnom	370 Wp
PV Array	Nb. of modules	7396	Pnom total	**2737 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	37.0	Pnom total	**2220 kW ac**
User's needs	Unlimited load (grid)			

	Time span of simulation	30 years		
Module average degradation	Loss factor	0.4 %/year		
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year
				Degradation loss after
Meteo used in the simulation	Years from the meteo files	Years simulated		10 years 20 years
Dubai MN72 SYN	0	1-30		5.13 % 9.87 %

Energy injected into grid



Performance Ratio



APPENDIX 4

Grid-Connected System: Simulation parameters

Project :	**facadeProject**			
Geographical Site	**Dubai**		Country	**United Arab Emirates**
Situation	Latitude	25.20° N	Longitude	55.27° E
Time defined as	Legal Time	Time zone UT+4	Altitude	4 m
	Albedo	0.20		
Meteo data:	**Dubai**	Meteonorm 7.2 (1992-2004), Sat=79% - Synthetic		

Simulation variant :	**Poly-simulation variant**			
	Simulation date	13/10/18 19h24		
	Simulation for the	**1st year of operation**		

Simulation parameters	System type	**No 3D scene defined**		
3 orientations	tilts/azimuths	90°/90°, 90°/0°, 90°/-90°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Arrays Characteristics (3 kinds of array defined)

PV module	Si-poly	Model	**JKM 350PP-72-DV**		
Original PVsyst database		Manufacturer	Jinkosolar		
Sub-array "Sub-array #1"		Orientation	#1	Tilt/Azimuth	90°/90°
Number of PV modules		In series	18 modules	In parallel	128 strings
Total number of PV modules		Nb. modules	2304	Unit Nom. Power	350 Wp
Array global power		Nominal (STC)	**806 kWp**	At operating cond.	731 kWp (50°C)
Array operating characteristics (50°C)		U mpp	639 V	I mpp	1144 A
Sub-array "Sub-array #2"		Orientation	#2	Tilt/Azimuth	90°/0°
Number of PV modules		In series	18 modules	In parallel	153 strings
Total number of PV modules		Nb. modules	2754	Unit Nom. Power	350 Wp
Array global power		Nominal (STC)	**964 kWp**	At operating cond.	874 kWp (50°C)
Array operating characteristics (50°C)		U mpp	639 V	I mpp	1367 A
Sub-array "Sub-array #3"		Orientation	#3	Tilt/Azimuth	90°/-90°
Number of PV modules		In series	18 modules	In parallel	128 strings
Total number of PV modules		Nb. modules	2304	Unit Nom. Power	350 Wp
Array global power		Nominal (STC)	**806 kWp**	At operating cond.	731 kWp (50°C)
Array operating characteristics (50°C)		U mpp	639 V	I mpp	1144 A
Total Arrays global power		Nominal (STC)	**2577 kWp**	Total	7362 modules
		Module area	**14373 m²**	Cell area	12900 m²

Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Sub-array "Sub-array #1"	Nb. of inverters	11 units	Total Power	660 kWac
			Pnom ratio	1.22
Sub-array "Sub-array #2"	Nb. of inverters	13 units	Total Power	780 kWac
			Pnom ratio	1.24
Sub-array "Sub-array #3"	Nb. of inverters	11 units	Total Power	660 kWac
			Pnom ratio	1.22
Total	Nb. of inverters	35	Total Power	2100 kWac

PV Array loss factors

Grid-Connected System: Simulation parameters

Array Soiling Losses — Average loss fraction 3.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	9.4 mOhm	Loss Fraction	1.5 % at STC
	Array#2	7.9 mOhm	Loss Fraction	1.5 % at STC
	Array#3	9.4 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	0.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System loss factors

	Wires: 3x3000.0 mm²	200 m	Loss Fraction	2.0 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction	2.0 %

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

Project : **facadeProject**

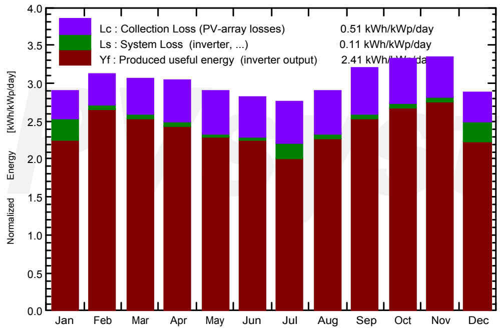
Simulation variant : **Poly-simulation variant**

Simulation for the 1st year of operation

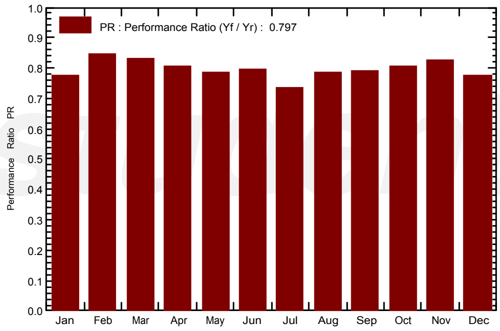
Main system parameters	System type	**No 3D scene defined**			
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°			
PV modules	Model	JKM 350PP-72-DV		Pnom	350 Wp
PV Array	Nb. of modules	7362		Pnom total	**2577 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	35.0		Pnom total	**2100 kW ac**
User's needs	Unlimited load (grid)				

Main simulation results				
System Production	**Produced Energy**	**2264 MWh/year**	Specific prod.	879 kWh/kWp/year
	Performance Ratio PR	79.72 %		

Normalized productions (per installed kWp): Nominal power 2577 kWp



Performance Ratio PR



Poly-simulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	117.8	47.70	18.46	89.9	83.53	202.2	179.5	0.774
February	126.6	55.10	20.30	87.7	81.27	196.2	191.5	0.848
March	163.0	75.30	23.93	94.6	87.08	207.3	202.6	0.831
April	190.4	75.60	28.03	91.1	82.94	193.0	188.7	0.804
May	220.1	83.20	32.96	89.9	82.06	186.4	182.4	0.787
June	212.4	89.20	33.95	84.8	78.29	177.8	174.1	0.796
July	204.9	94.80	35.98	85.2	78.39	176.7	161.0	0.734
August	200.1	91.00	35.85	90.2	82.25	185.9	182.0	0.783
September	178.5	70.60	32.47	96.2	87.88	200.6	196.2	0.792
October	159.3	57.80	29.74	103.2	95.09	219.0	214.0	0.805
November	128.3	46.00	24.95	100.1	92.98	218.5	213.4	0.827
December	109.4	48.70	20.84	89.2	82.97	199.3	178.5	0.776
Year	2010.8	835.00	28.17	1102.1	1014.72	2363.0	2263.8	0.797

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

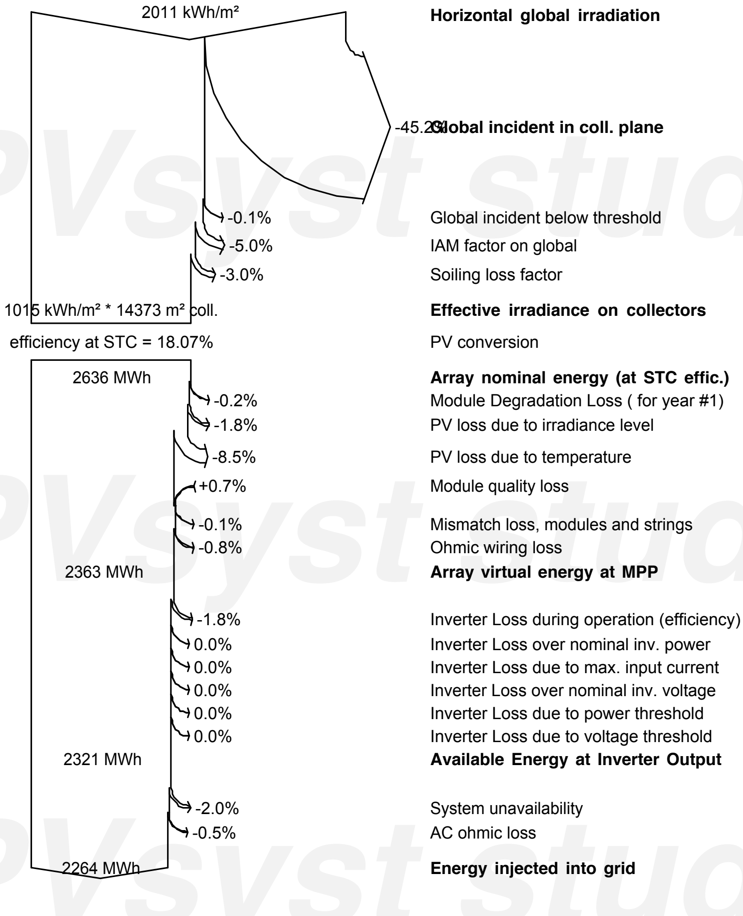
Project : **facadeProject**

Simulation variant : **Poly-simulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	JKM 350PP-72-DV	Pnom	350 Wp
PV Array	Nb. of modules	7362	Pnom total	**2577 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	35.0	Pnom total	**2100 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: CO2 Balance

Project : **facadeProject**

Simulation variant : **Poly-simulation variant**

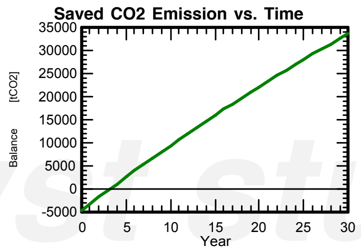
Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	JKM 350PP-72-DV	Pnom	350 Wp
PV Array	Nb. of modules	7362	Pnom total	**2577 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	35.0	Pnom total	**2100 kW ac**
User's needs	Unlimited load (grid)			

Produced Emissions	**Total:**	**4733.82 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**44347.3 tCO2**		
	System production:	2263.77 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	653 gCO2/kWh		
	Source:	IEA List	Country:	United Arab Emirates
CO2 Emission Balance	**Total:**	**33744.8 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	1713 kgCO2/kWp	4.36 kgCO2/kg
Quantity	2577 kWp	73620 kg
Subtotal [kgCO2]	4413166	320653



Grid-Connected System: Ageing Tool Results

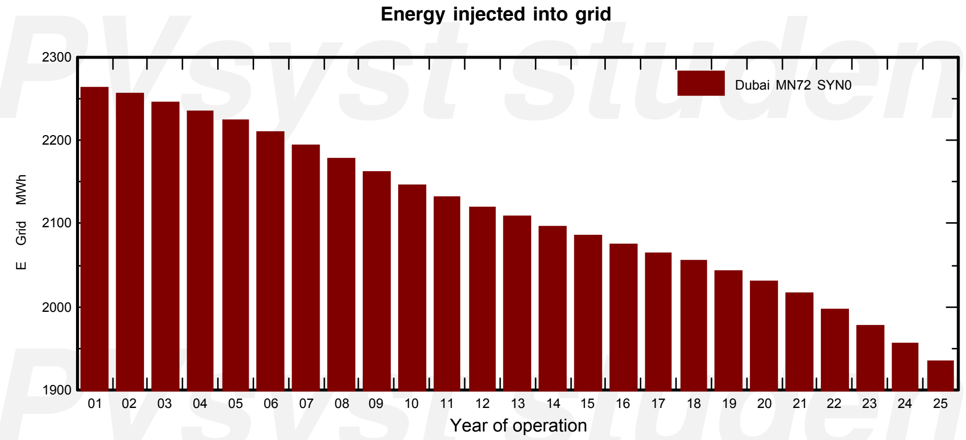
Project : **facadeProject**

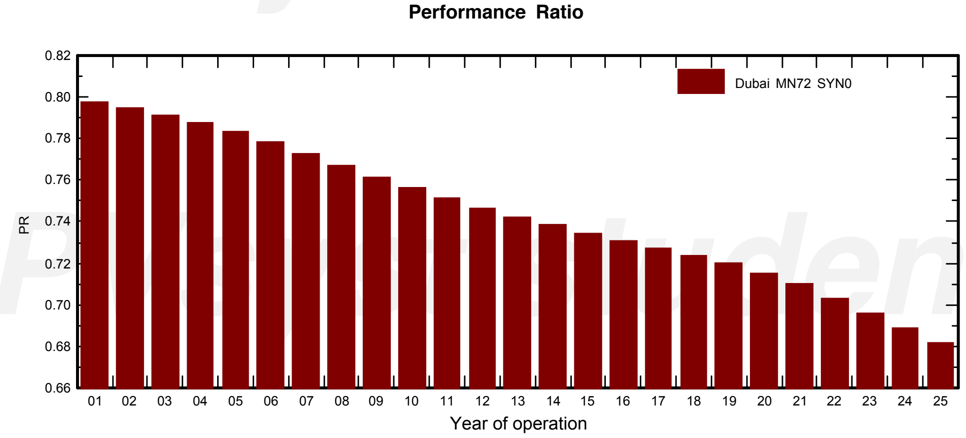
Simulation variant : **Poly-simulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	JKM 350PP-72-DV	Pnom	350 Wp
PV Array	Nb. of modules	7362	Pnom total	**2577 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	35.0	Pnom total	**2100 kW ac**
User's needs	Unlimited load (grid)			

	Time span of simulation	25 years			
Module average degradation	Loss factor	0.4 %/year			
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year	
				Degradation loss after	
Meteo used in the simulation	Years from the meteo files	Years simulated		10 years	20 years
Dubai MN72 SYN	0	1-25		5.2 %	10.31 %





APPENDIX 5

Grid-Connected System: Simulation parameters

Project :	**facadeProject**			
Geographical Site	**Dubai**		Country	**United Arab Emirates**
Situation	Latitude	25.20° N	Longitude	55.27° E
Time defined as	Legal Time	Time zone UT+4	Altitude	4 m
	Albedo	0.20		
Meteo data:	**Dubai**	Meteonorm 7.2 (1992-2004), Sat=79% - Synthetic		

Simulation variant :	**thin-filmsimulation variant**	
	Simulation date	13/10/18 19h49
	Simulation for the	**1st year of operation**

Simulation parameters	System type	**No 3D scene defined**		
3 orientations	tilts/azimuths	90°/90°, 90°/0°, 90°/-90°		
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Arrays Characteristics (3 kinds of array defined)

PV module a-Si:H single	Model	**MPV105-S**		
Original PVsyst database	Manufacturer	Masdar PV GmbH		
Sub-array "Sub-array #1"	Orientation	#1	Tilt/Azimuth	90°/90°
Number of PV modules	In series	9 modules	In parallel	349 strings
Total number of PV modules	Nb. modules	3141	Unit Nom. Power	105 Wp
Array global power	Nominal (STC)	**330 kWp**	At operating cond.	315 kWp (50°C)
Array operating characteristics (50°C)	U mpp	639 V	I mpp	492 A
Sub-array "Sub-array #2"	Orientation	#2	Tilt/Azimuth	90°/0°
Number of PV modules	In series	9 modules	In parallel	419 strings
Total number of PV modules	Nb. modules	3771	Unit Nom. Power	105 Wp
Array global power	Nominal (STC)	**396 kWp**	At operating cond.	378 kWp (50°C)
Array operating characteristics (50°C)	U mpp	639 V	I mpp	591 A
Sub-array "Sub-array #3"	Orientation	#3	Tilt/Azimuth	90°/-90°
Number of PV modules	In series	9 modules	In parallel	349 strings
Total number of PV modules	Nb. modules	3141	Unit Nom. Power	105 Wp
Array global power	Nominal (STC)	**330 kWp**	At operating cond.	315 kWp (50°C)
Array operating characteristics (50°C)	U mpp	639 V	I mpp	492 A
Total Arrays global power	Nominal (STC)	**1056 kWp**	Total	10053 modules
	Module area	**14376 m²**		

Sub-array "Sub-array #1" : Inverter	Model	**Sunny Tripower 60-10**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	5 units	Total Power	300 kWac
			Pnom ratio	1.10
Sub-array "Sub-array #2" : Inverter	Model	**Sunny Tripower 60-10**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	1.10

Grid-Connected System: Simulation parameters

Sub-array "Sub-array #3" : Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	5 units	Total Power	300 kWac
			Pnom ratio	1.10
Total	Nb. of inverters	16	Total Power	960 kWac

PV Array loss factors

Array Soiling Losses — Average loss fraction 3.0 %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	22 mOhm	Loss Fraction	1.5 % at STC
	Array#2	18 mOhm	Loss Fraction	1.5 % at STC
	Array#3	22 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	0.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Module average degradation	Year no	1	Loss factor	0.4 %/year
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

System loss factors

	Wires: 3x1000.0 mm²	200 m	Loss Fraction	2.4 % at STC
Unavailability of the system	7.3 days, 3 periods		Time fraction	2.0 %

User's needs : Unlimited load (grid)

Grid-Connected System: Main results

Project : **facadeProject**

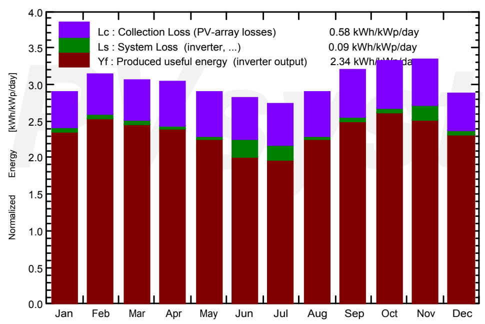
Simulation variant : **thin-filmsimulation variant**

Simulation for the 1st year of operation

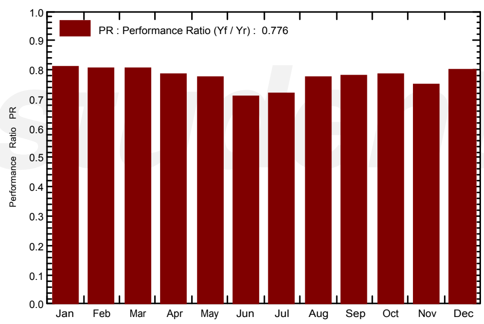
Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	MPV105-S	Pnom	105 Wp
PV Array	Nb. of modules	10053	Pnom total	**1056 kWp**
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	16.0	Pnom total	**960 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**903.3 MWh/year**	Specific prod.	856 kWh/kWp/year
	Performance Ratio PR	77.65 %		

Normalized productions (per installed kWp): Nominal power 1056 kWp



Performance Ratio PR



thin-filmsimulation variant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	117.8	47.70	18.46	90.0	83.59	79.11	77.20	0.813
February	126.6	55.10	20.30	87.7	81.31	76.52	74.71	0.807
March	163.0	75.30	23.93	94.7	87.09	82.34	80.48	0.806
April	190.4	75.60	28.03	91.0	82.91	77.40	75.68	0.788
May	220.1	83.20	32.96	89.8	82.00	75.07	73.46	0.775
June	212.4	89.20	33.95	84.8	78.23	71.17	63.67	0.712
July	204.9	94.80	35.98	85.1	78.34	71.01	64.71	0.720
August	200.1	91.00	35.85	90.1	82.21	75.13	73.56	0.773
September	178.5	70.60	32.47	96.2	87.88	80.88	79.10	0.779
October	159.3	57.80	29.74	103.2	95.14	87.79	85.81	0.788
November	128.3	46.00	24.95	100.2	93.05	85.76	79.39	0.751
December	109.4	48.70	20.84	89.3	83.04	77.37	75.54	0.801
Year	2010.8	835.00	28.17	1102.2	1014.79	939.57	903.33	0.776

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Grid-Connected System: Loss diagram

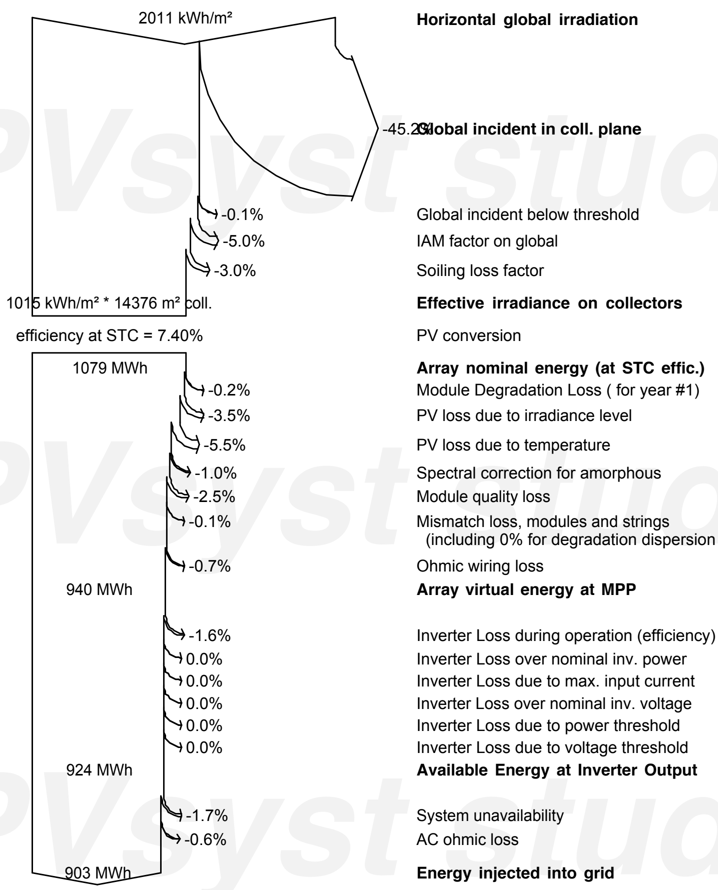
Project : **facadeProject**

Simulation variant : **thin-filmsimulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	MPV105-S	Pnom	105 Wp
PV Array	Nb. of modules	10053	Pnom total	**1056 kWp**
Inverter		Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	16.0	Pnom total	**960 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: CO2 Balance

Project : **facadeProject**

Simulation variant : **thin-filmsimulation variant**

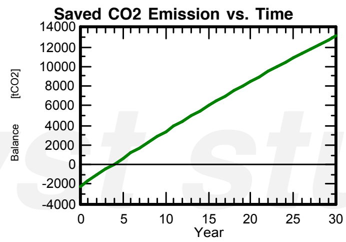
Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	MPV105-S	Pnom	105 Wp
PV Array	Nb. of modules	10053	Pnom total	**1056 kWp**
Inverter		Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	16.0	Pnom total	**960 kW ac**
User's needs	Unlimited load (grid)			

Produced Emissions	**Total:**	**2245.75 tCO2**		
	Source:	Detailed calculation from table below		
Replaced Emissions	**Total:**	**17696.1 tCO2**		
	System production:	903.33 MWh/yr	Lifetime:	30 years
			Annual Degradation:	1.0 %
	Grid Lifecycle Emissions:	653 gCO2/kWh		
	Source:	IEA List	Country:	United Arab Emirates
CO2 Emission Balance	**Total:**	**13108.6 tCO2**		

System Lifecycle Emissions Details:

Item	Modules	Supports
LCE	1713 kgCO2/kWp	4.36 kgCO2/kg
Quantity	1056 kWp	100530 kg
Subtotal [kgCO2]	1807887	437859



Grid-Connected System: Ageing Tool Results

Project : **facadeProject**

Simulation variant : **thin-filmsimulation variant**

Simulation for the 1st year of operation

Main system parameters	System type	**No 3D scene defined**		
PV Field Orientation	3 orientations	Tilt/Azimuth = 90°/90°, 90°/0°, 90°/-90°		
PV modules	Model	MPV105-S	Pnom	105 Wp
PV Array	Nb. of modules	10053	Pnom total	**1056 kWp**
Inverter		Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	16.0	Pnom total	**960 kW ac**
User's needs	Unlimited load (grid)			

	Time span of simulation	25 years			
Module average degradation	Loss factor	0.4 %/year			
Mismatch due to degradation	Imp RMS dispersion	0.4 %/year	Vmp RMS dispersion	0.4 %/year	
				Degradation loss after	
Meteo used in the simulation	Years from the meteo files	Years simulated		10 years	20 years
Dubai MN72 SYN	0	1-25		3.61 %	7.65 %